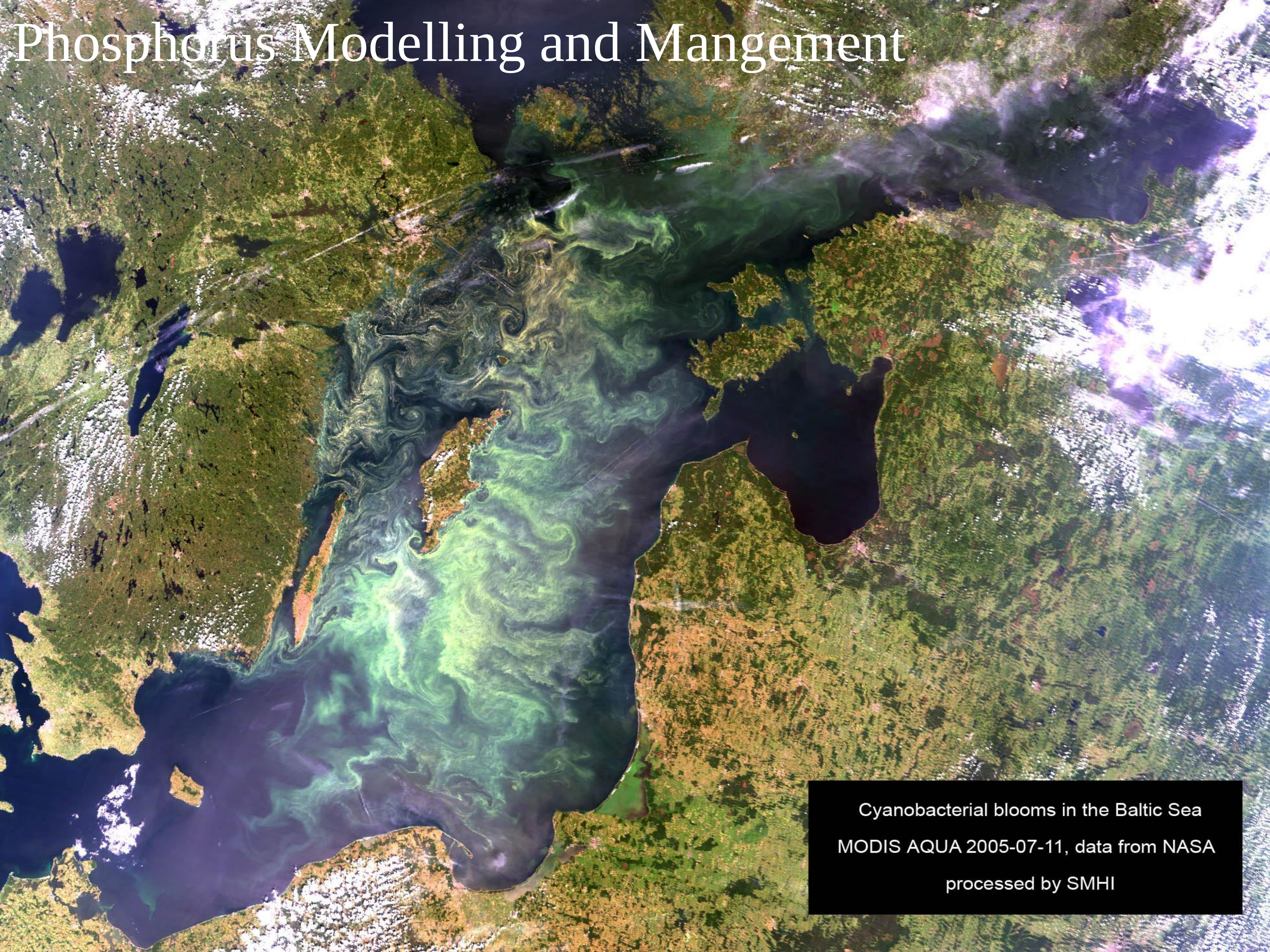
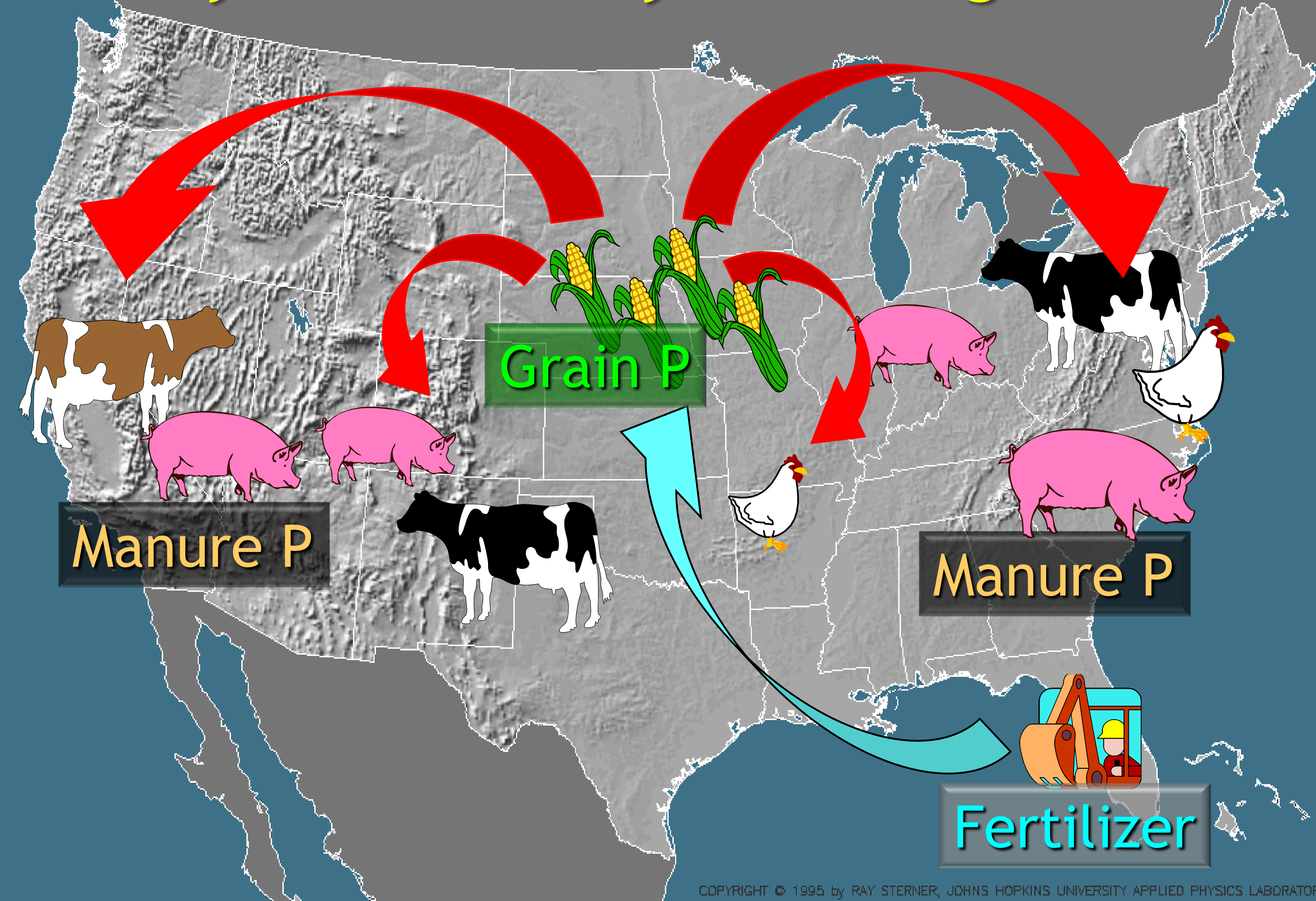
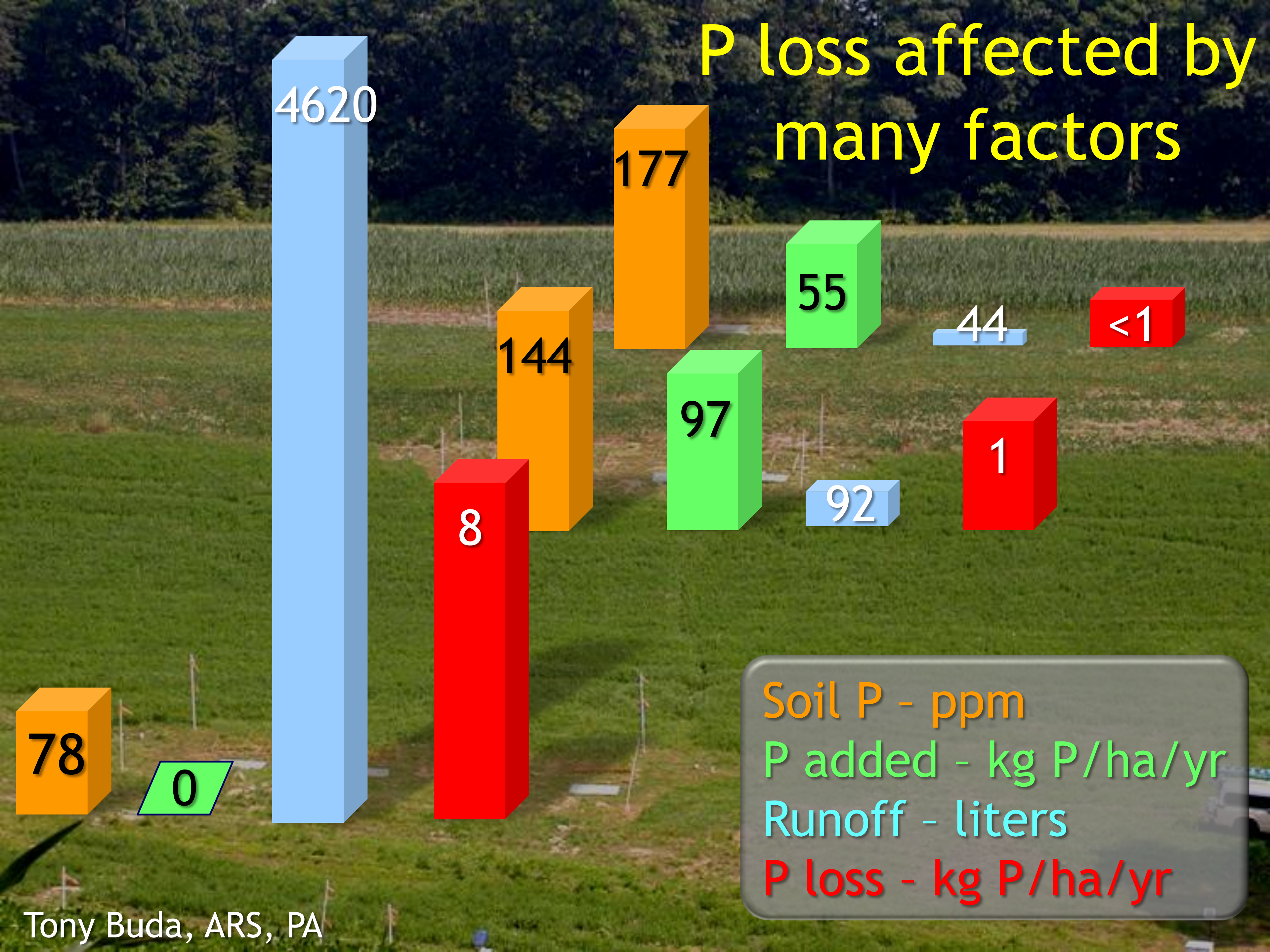
Phosphorus Modelling and Mangement

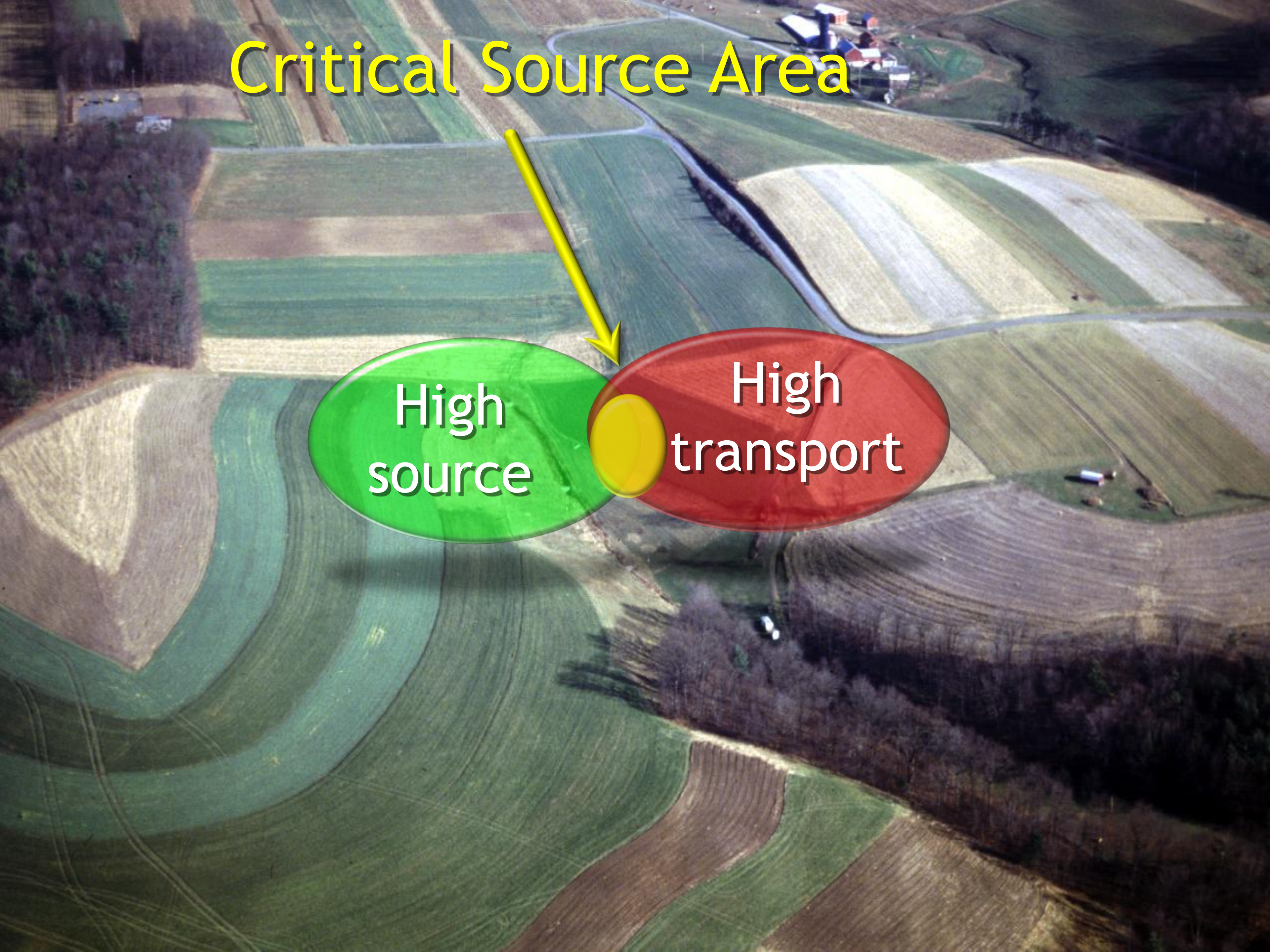


Cyanobacterial blooms in the Baltic Sea
MODIS AQUA 2005-07-11, data from NASA
processed by SMHI

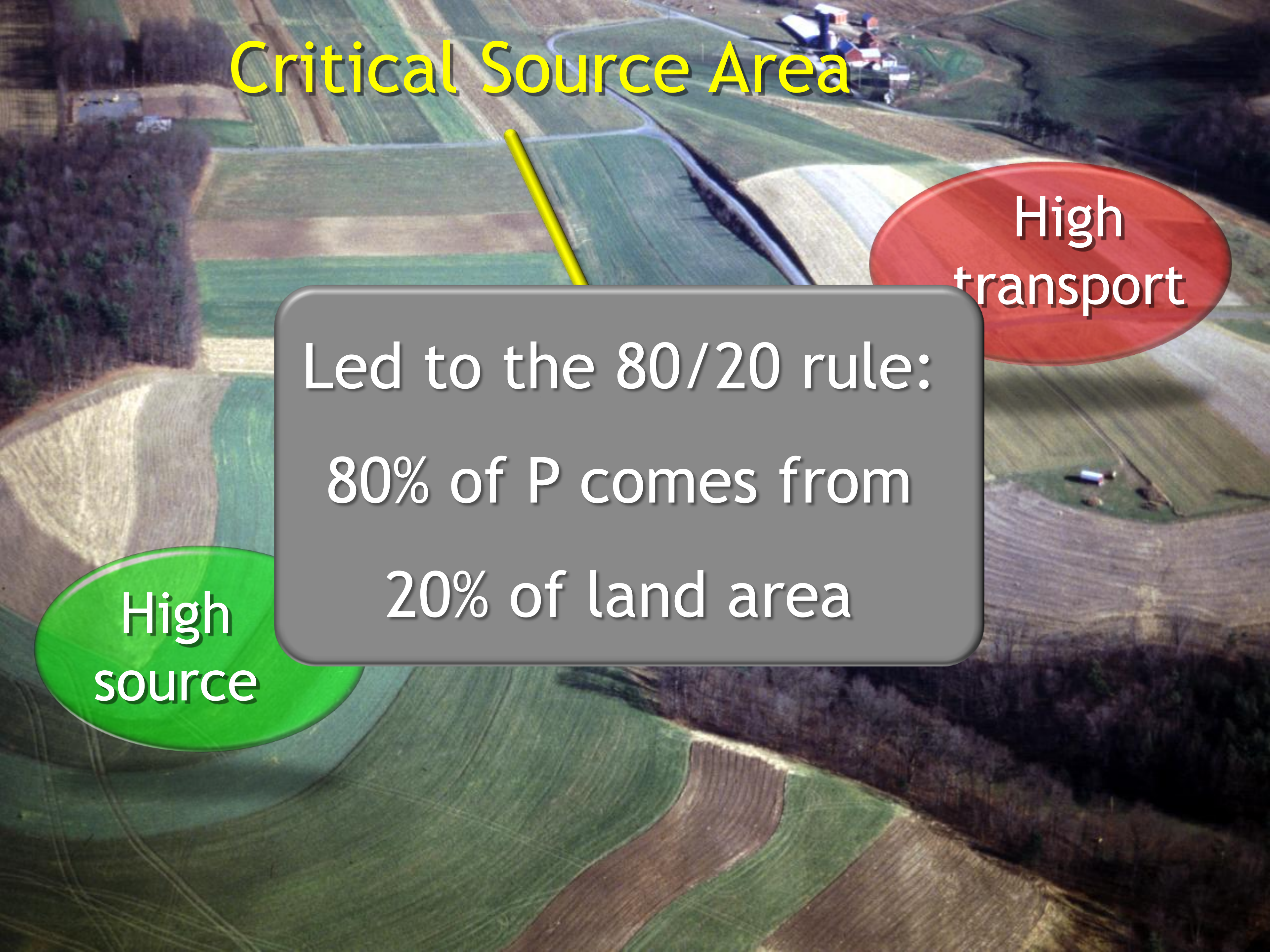
Today's nutrient cycle is fragmented




P loss affected by many factors
4620
177
144
55
97
44
<1
1
92
8
78
0
Soil P – ppm
P added – kg P/ha/yr
Runoff – liters
P loss – kg P/ha/yr
Tony Buda, ARS, PA


Critical Source Area
High source
High transport

Critical Source Area



Led to the 80/20 rule:

80% of P comes from

20% of land area

Use of models

- Models inform decisions & targeting
  - Best way to prioritize finite resource allocation; e.g., NRCS Mississippi River Basin Initiative
- Models are a representation of reality

Input discrepancies

	EPA	USDA	Diff.
	million acres		%
Land area	41.1	42.5	3
Agricultural land	9.0	12.1	35
Cropped	3.3	4.4	33
Conventional till	1.7	0.4	-74
Conservation till	1.7	3.9	133

LimnoTech 2011

Input discrepancies

- Models have uncertainty, due to
  - Routines used; especially for hydrology
  - Input data availability
  - BMP N & P reduction efficiencies
  - Accounting for the legacy of past mgt.

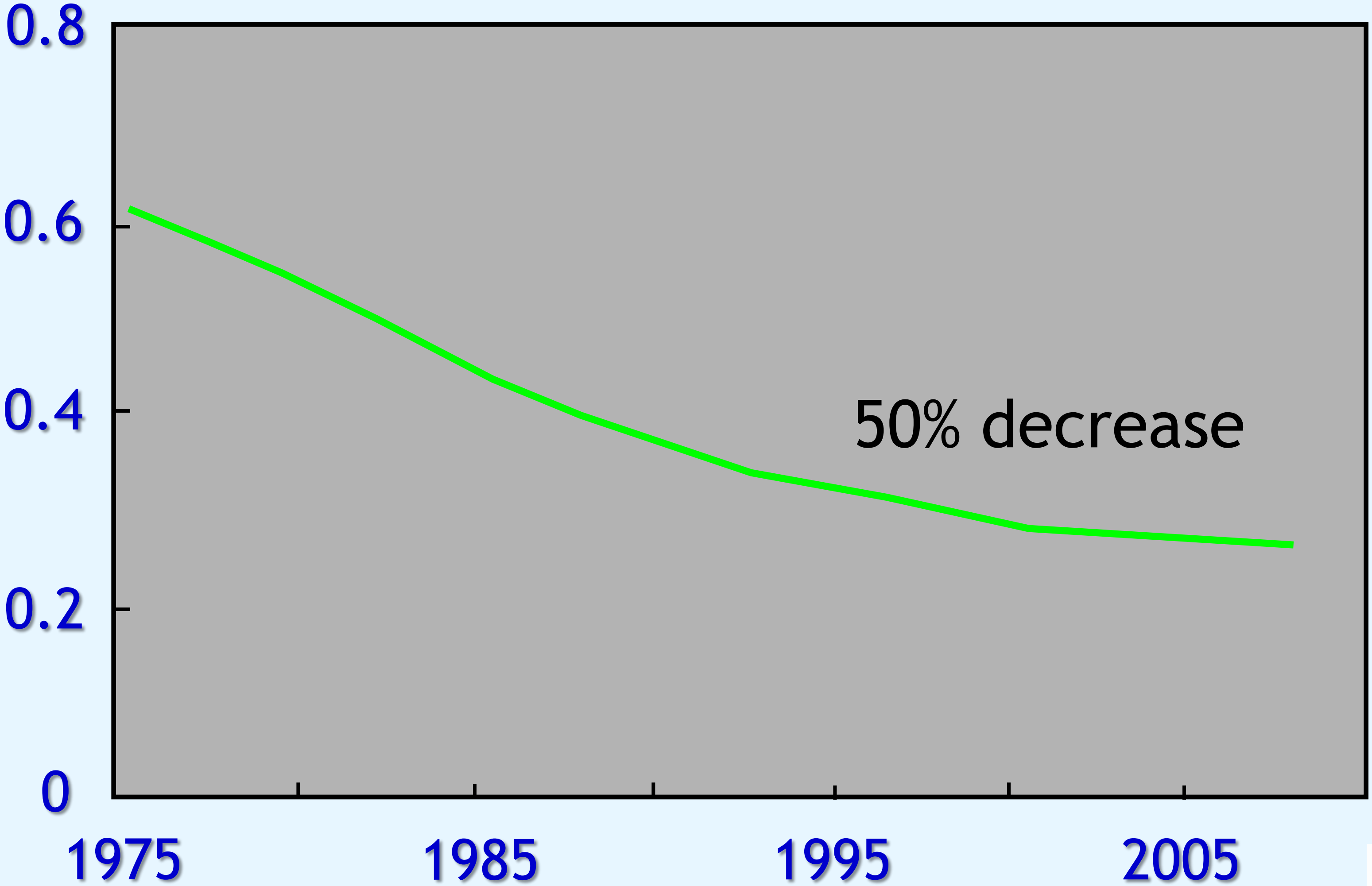
Lar
Ag
C
Limno

Conservation tillage

Lesson from Lake Erie Basin

Trends in P - Maumee River

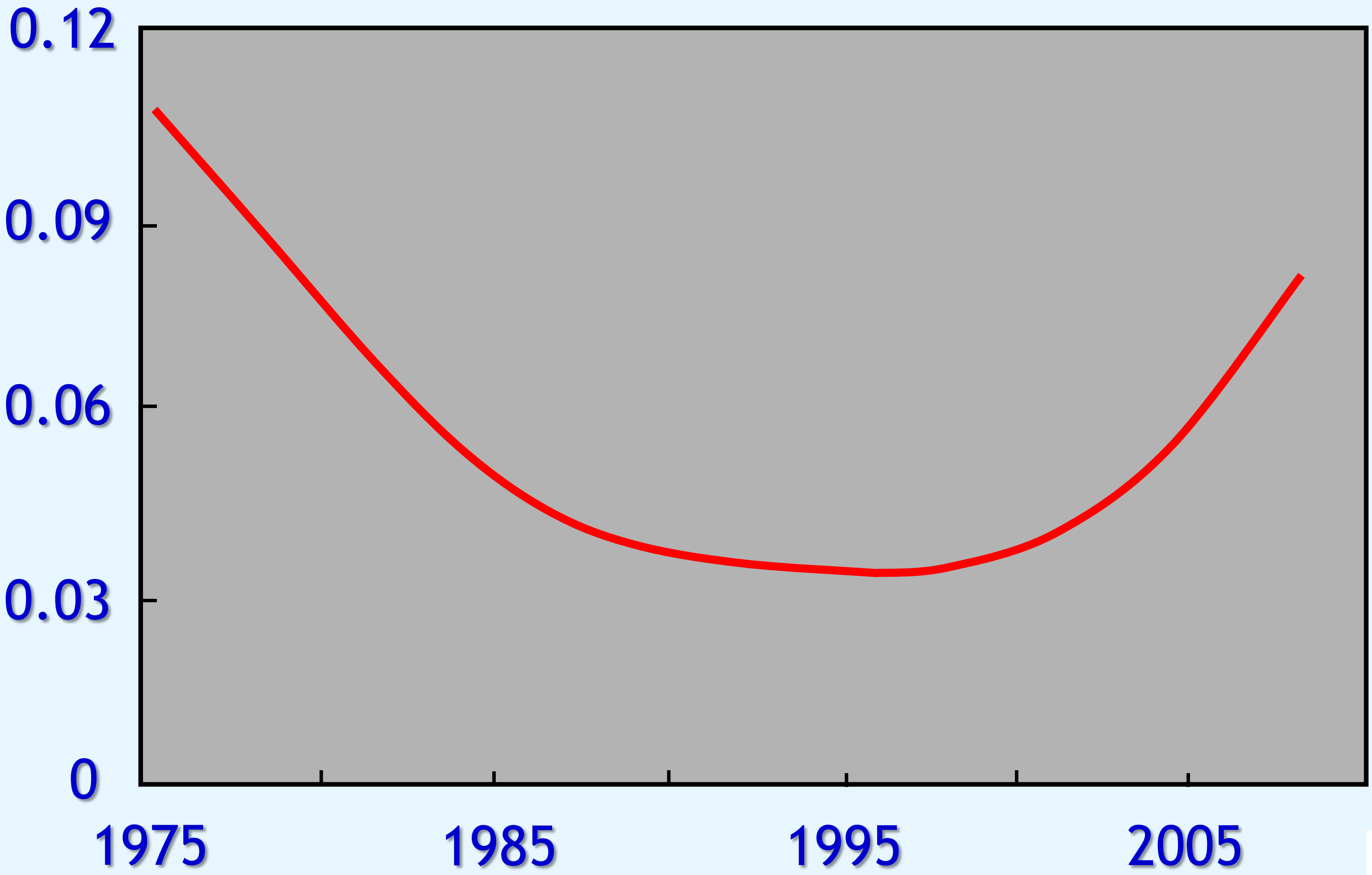
Annual flow-weighted total P, ppm



Dave Baker & Peter Richards, OH

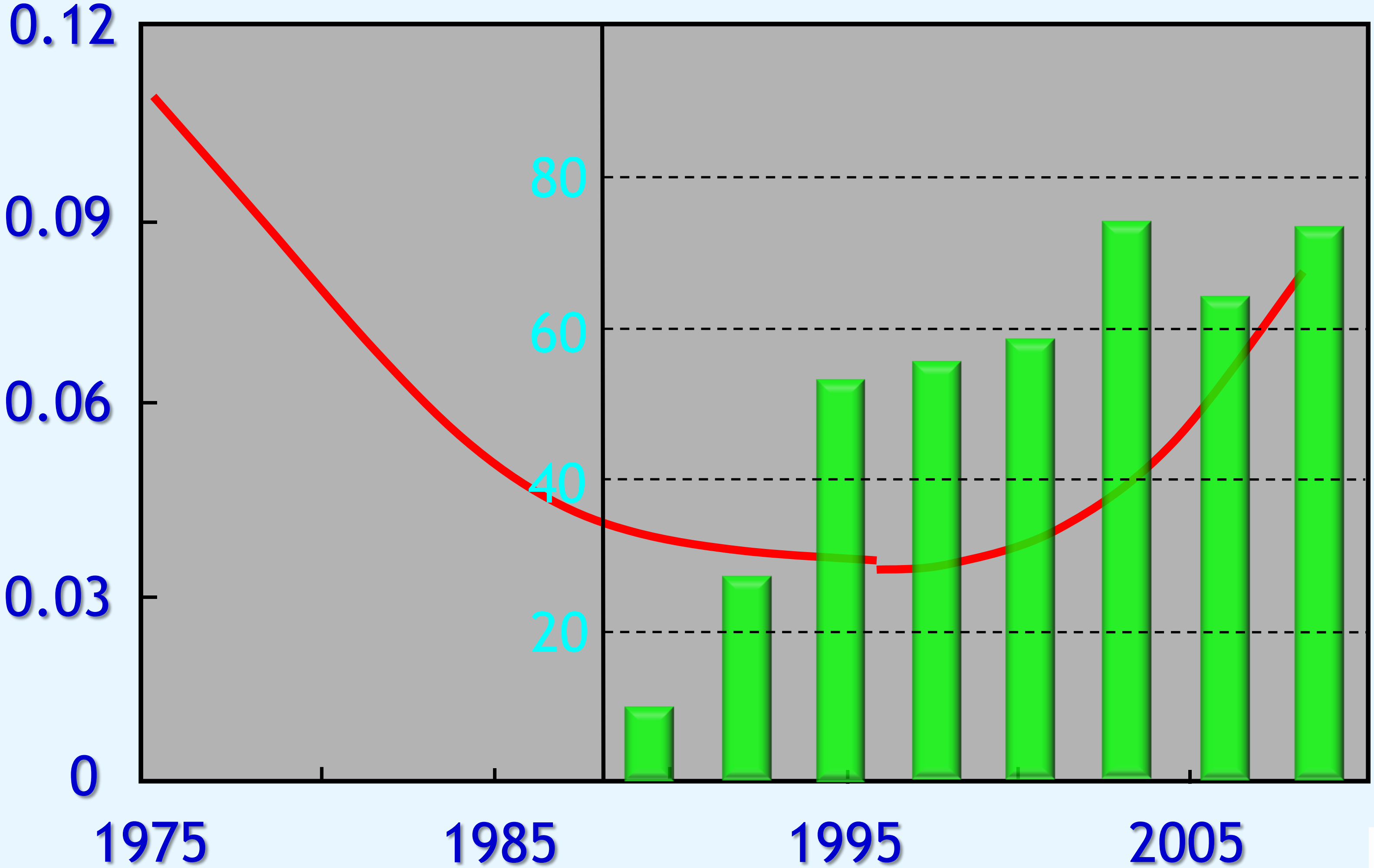
Trends in P - Maumee River

Annual flow-weighted dissolved P, ppm

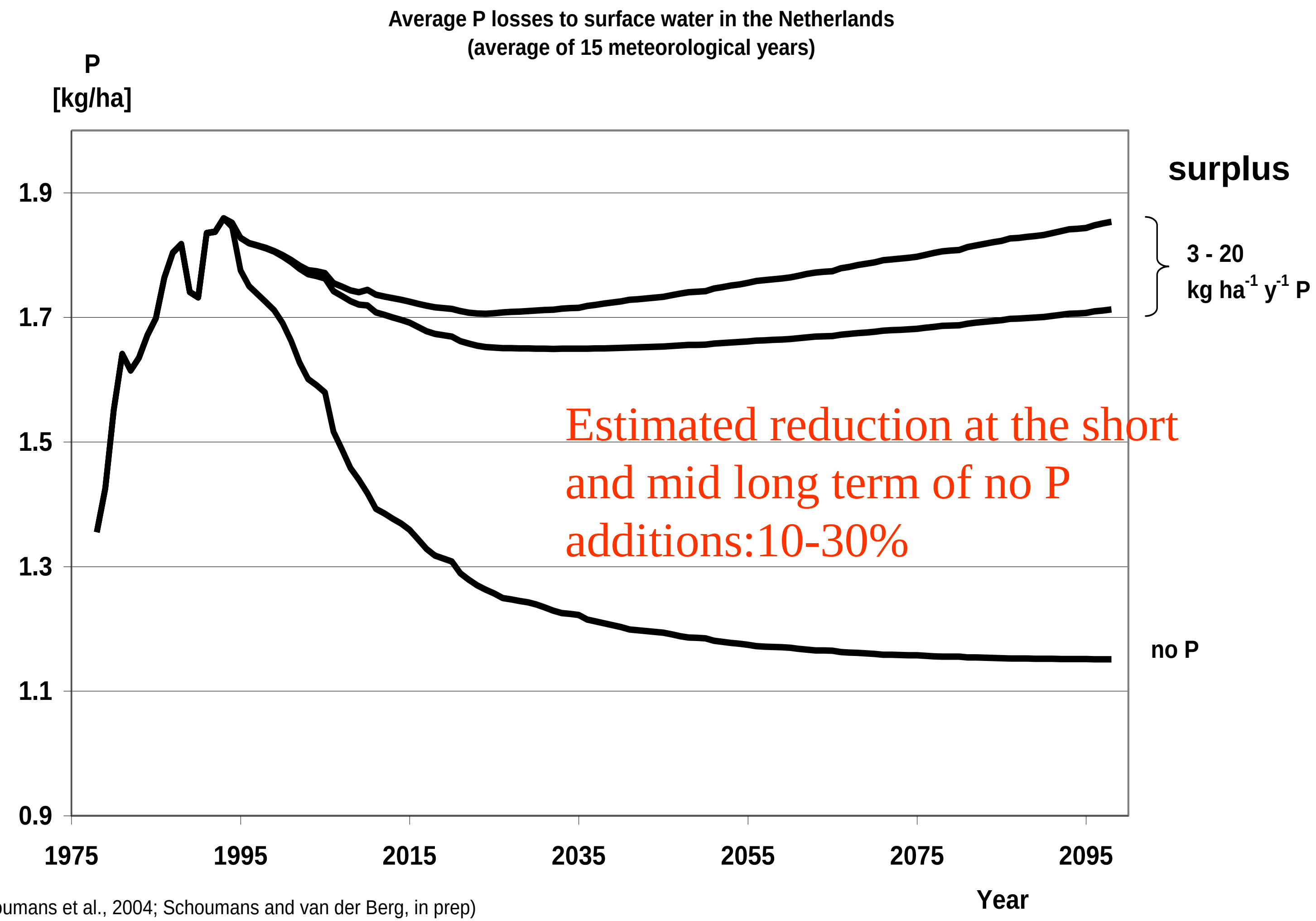


Trends in P - Maumee River

Adoption of mulch and no-till soybeans, %



Modelled effects of P-application in Dutch agriculture (STONE model)



(Schoumans et al., 2004; Schoumans and van der Berg, in prep)

Phosphorus model – losses from diffuse sources

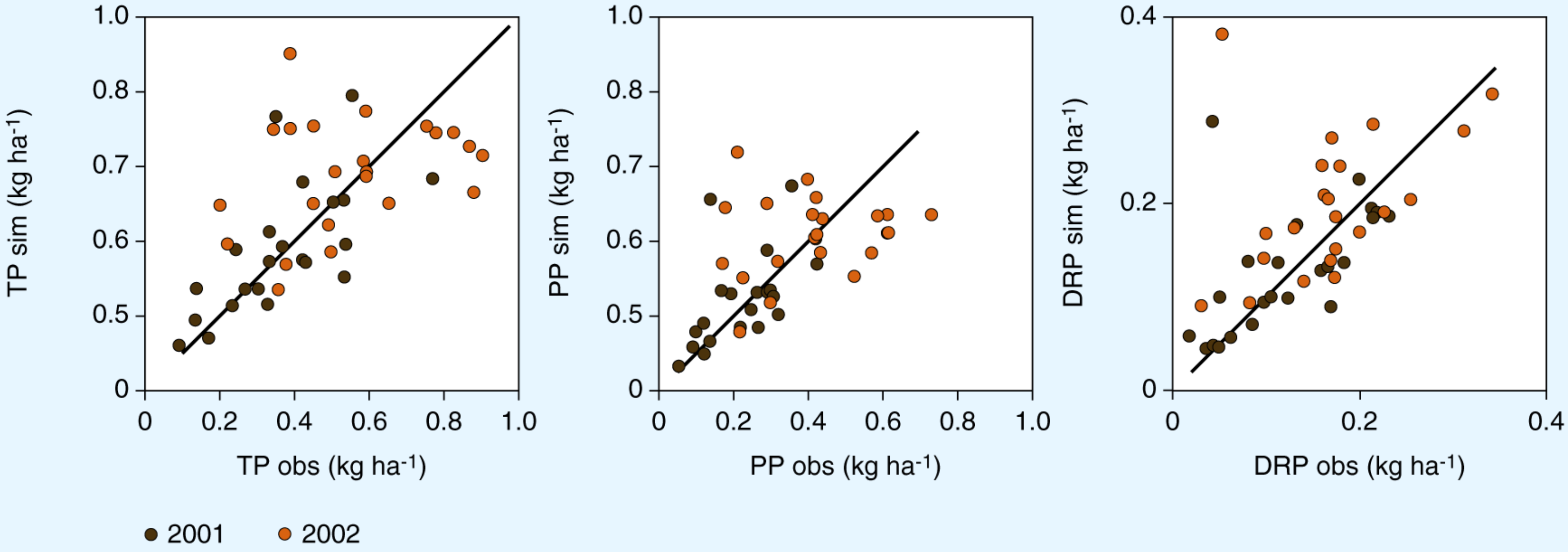
Model has an R^2 = 0,80 (p<0.0001).

$$TP_{ij} = 1{,}06 \cdot \exp\left(-6{,}533 + 0{,}865 \cdot \ln\left(R - Flom_{ij}\right) + 0{,}0187 \cdot A_j + 0{,}00629 \cdot S_j + 0{,}0141 \cdot SL_j - 0{,}0383 \cdot BU_j\right).$$

Where
TP_{ij} is annual (i) diffuse loss of total P in kg P/ha from catchment (j)
R-flom = overland and drainage flow from catchment in mm per year.
S_j e= proportion of sandy soils in catchment.
A_j = proportion of agricultural land in catchment.
SL_j = slope of stream in per mille
BU_j = proportion of lowlying rapirian soils (wetlands, meadows) in catchment.

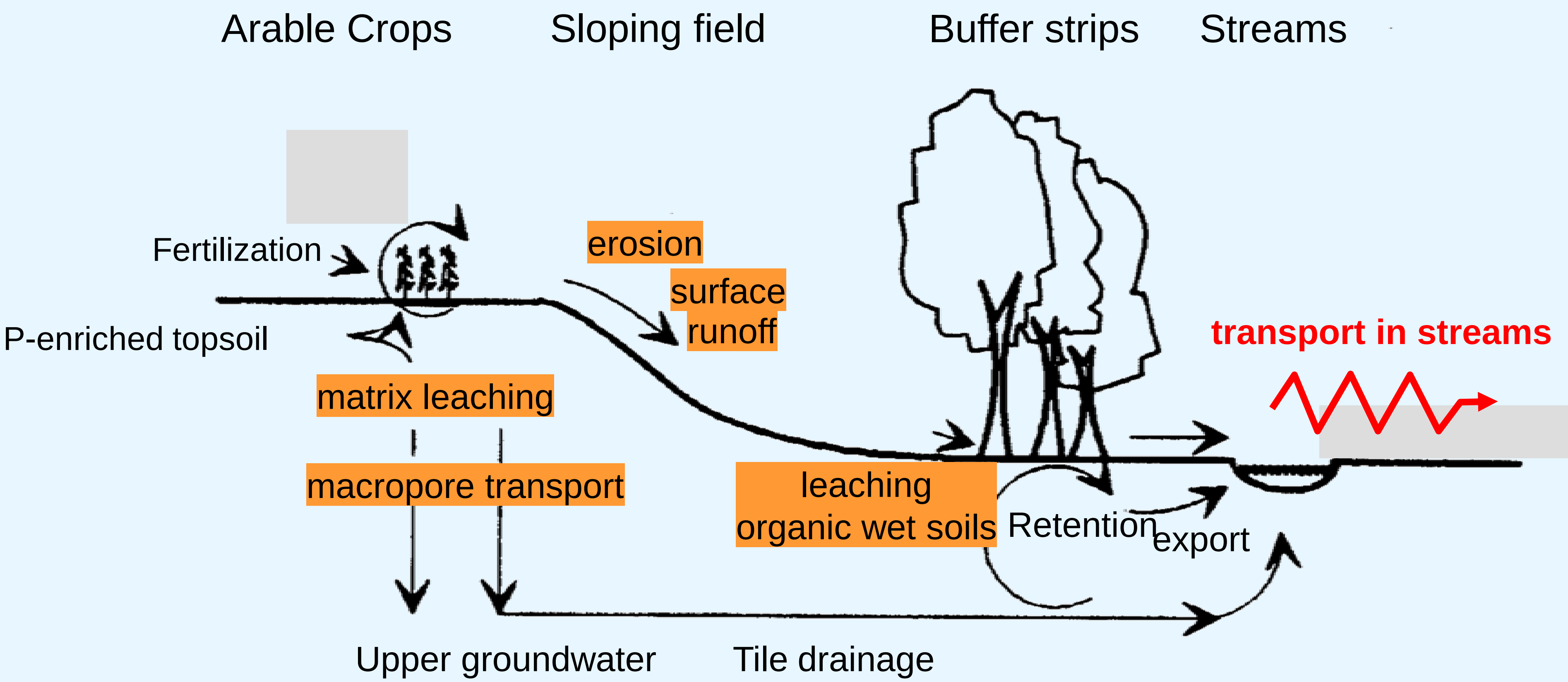
Andersen, H.E., Kronvang, B. & Larsen, S.E. 2005: Development, validation and application of Danish empirical phosphorus models. - Journal of Hydrology 304: 355-365.

Validation of models for diffuse P loss



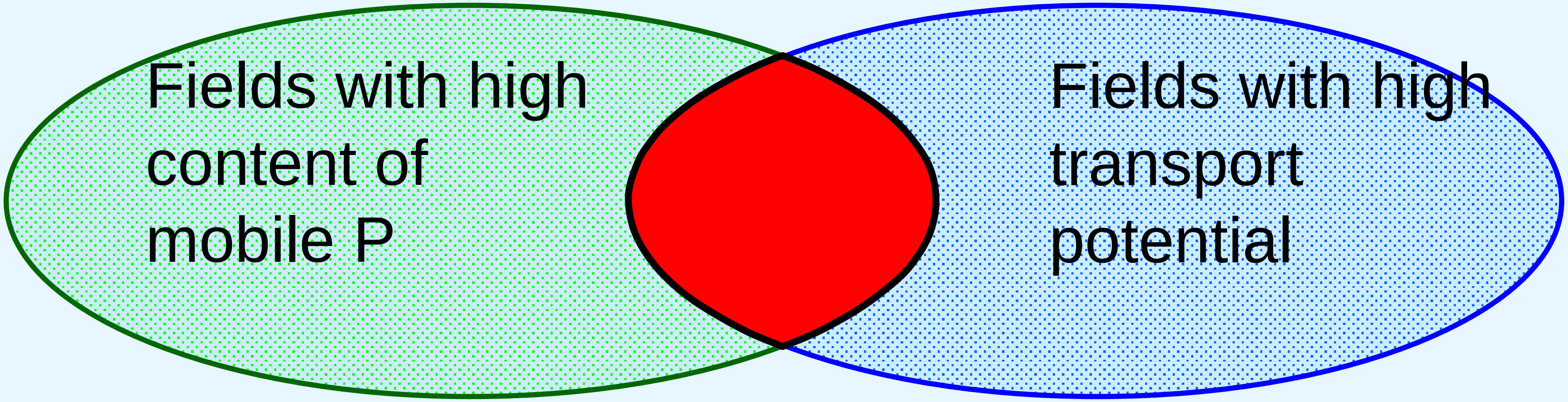
Time for a break?

P losses is a result of many complex processes and pathways



Source factors

Transport factors



Critical source areas = risk areas

High risk for P-loss

Concept of the new P index

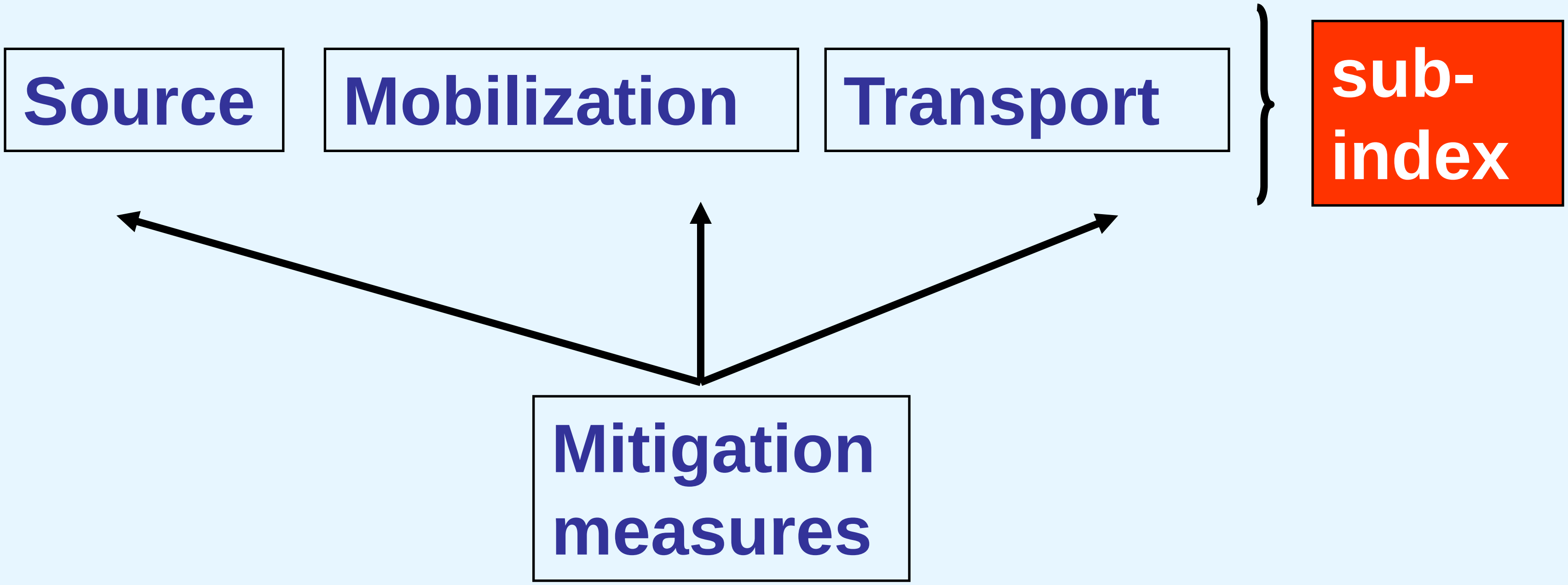
For each P loss pathway individually we evaluate the factors:

Source	Mobilization	Transport	} sub-index

Each factor is characterized by variables which correlate to P loss and are easily available. Sub-index standardized to values between 0 and 100

Advantages of the sub-index concept

- Differentiated combination of source and transport factors
- Easy to incorporate new knowledge
- Directly shows the relative risk for each process
- Effect of mitigation measures easily incorporated



Structure

	Source	Mobilization	Transport	Index value
Erosion				0 - 100
Surface runoff				0 – 100
Leaching via matrix				0 – 100
Leaching via macro pores				0 – 100

Architecture in Danish P Index

P transfer continuum

Data | Source | Mobilization | Transport

Sub-index transport process

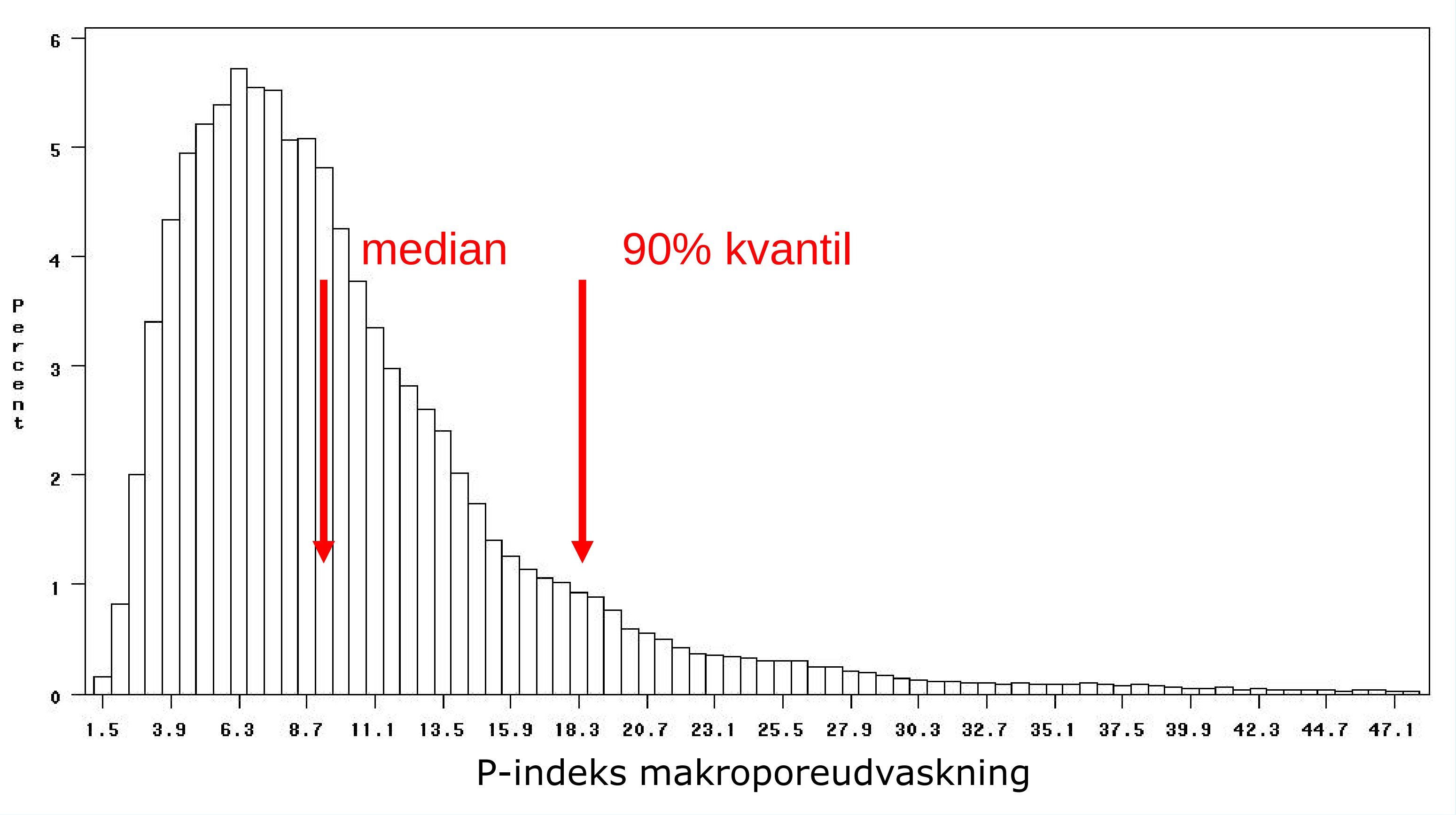
- Erosion
- Surface runoff
- Matric leaching
- Macropore transport

Relative expression of P loss (0 - 100)

	Source	Mobilization	Transport
Erosion	**P**-status **P**-input	**E**rosion potential	**D**istance to recipient
Surface Runoff	**P**-status **P**-input	**R**unoff area **W**inter precipitation	**D**istance to recipient
Matrix leaching	**P**-status **P**-input	**P**-sorption capacity (subsoil)	**N**et precipitation; **D**rainage/ **D**istance tol recipient
Macropore Loss	**P**-status **P**-input		Likelihood of macropore transport; **D**rainage

	Source	Mobilization	Transport
Erosion	**TP + P input**	**Modelled soil erosion,** **tile drainage**	**Flow distance to surface waters**
Surface runoff	**DP, PP + P input**	**Runoff volume = topographically derived discharge area, winter precipitation**	**Flow distance to surface waters**
Matrix flow	**DP + P input**	**<u>Subsoil PSC: (Alox + Feox)</u>** **Low: < 60 mmol/kg** **Medium: 60 - 100 mmol/kg** **High: >100 mmol/kg**	**HER, tile drainage or distance to surface waters**
Macropore	**DP, PP + P input**	**Contact volume in topsoil = f [porosity]**	**Subsoil macropores, Likelihood of macropore flow**

Subdivision in index classes based on frequency distribution



K%-kvantilen er den værdi, som er større end k% af alle værdier i populationen.

Calculating erosion sub-P Index

DEM

Soil map

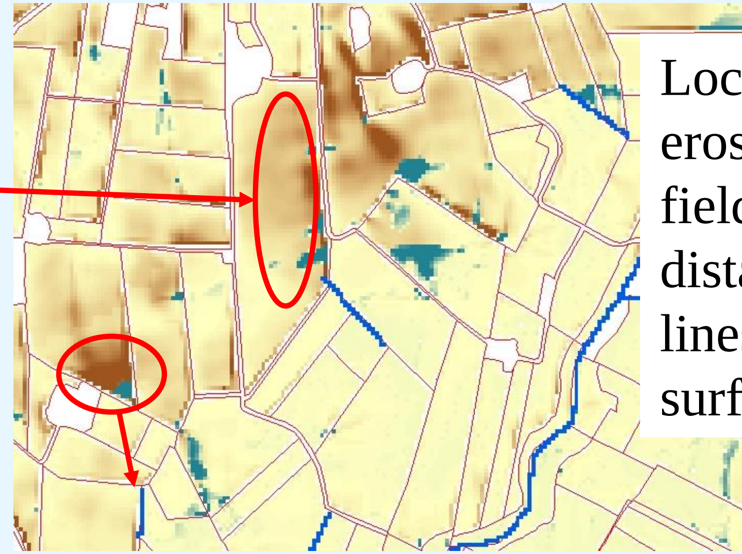
Climate data

Landuse

Source factor

Ca sub-P

Calculate soil erosion rate at slope unit scale by WaTEM



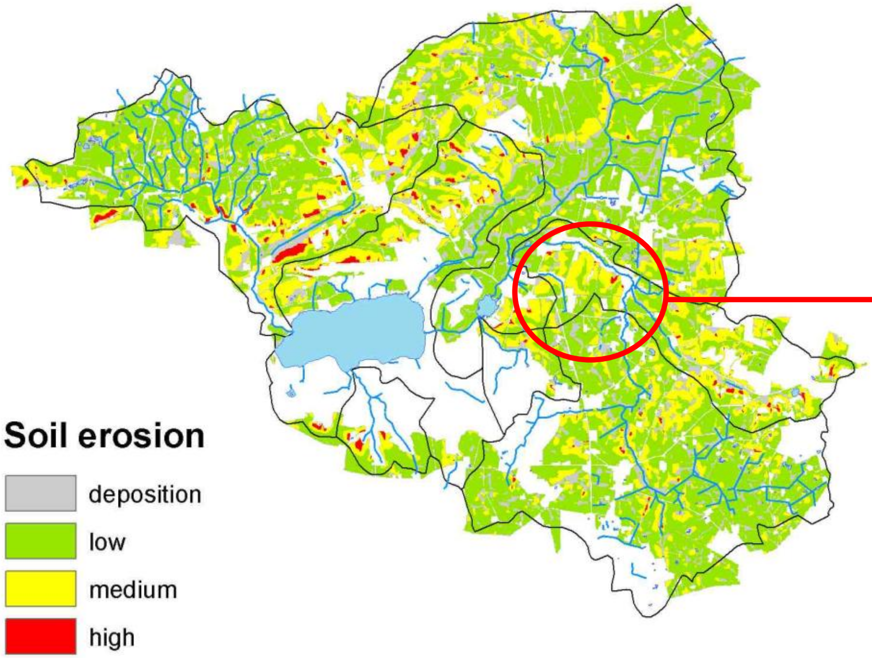
Localisation of erosion areas within fields -> calculate distance along flow lines to nearest surface waters

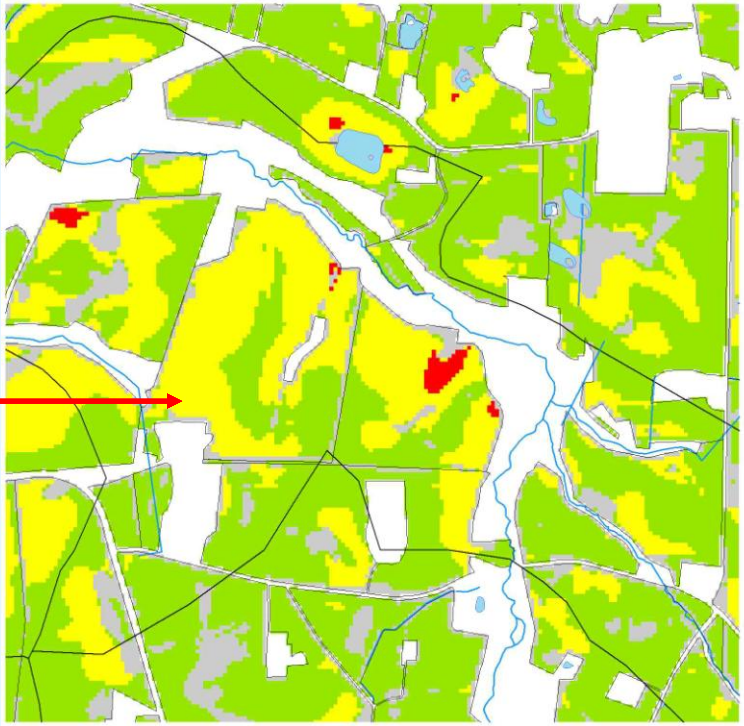
Source factor

Mobilisation factor

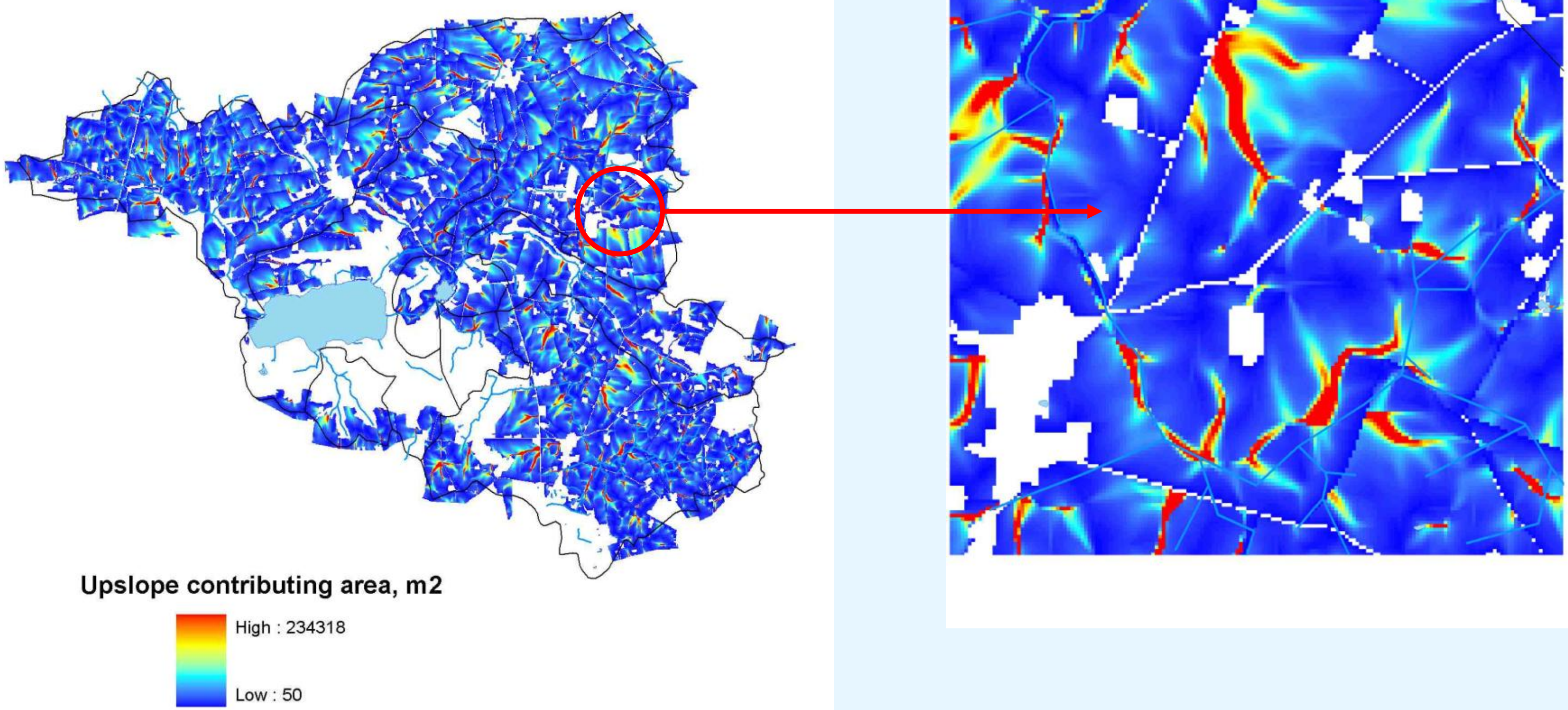
Transport factor

Soil erosion

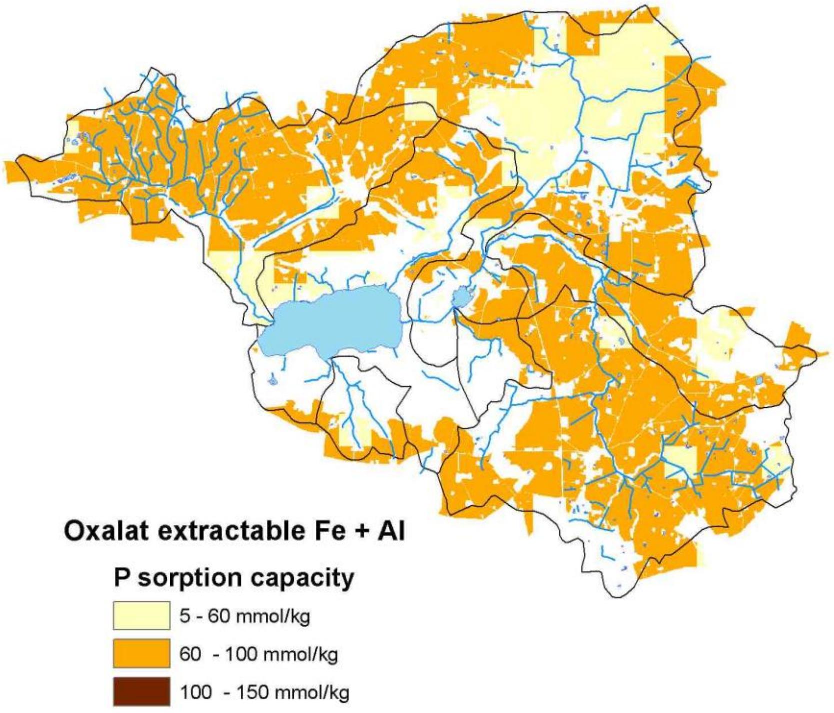




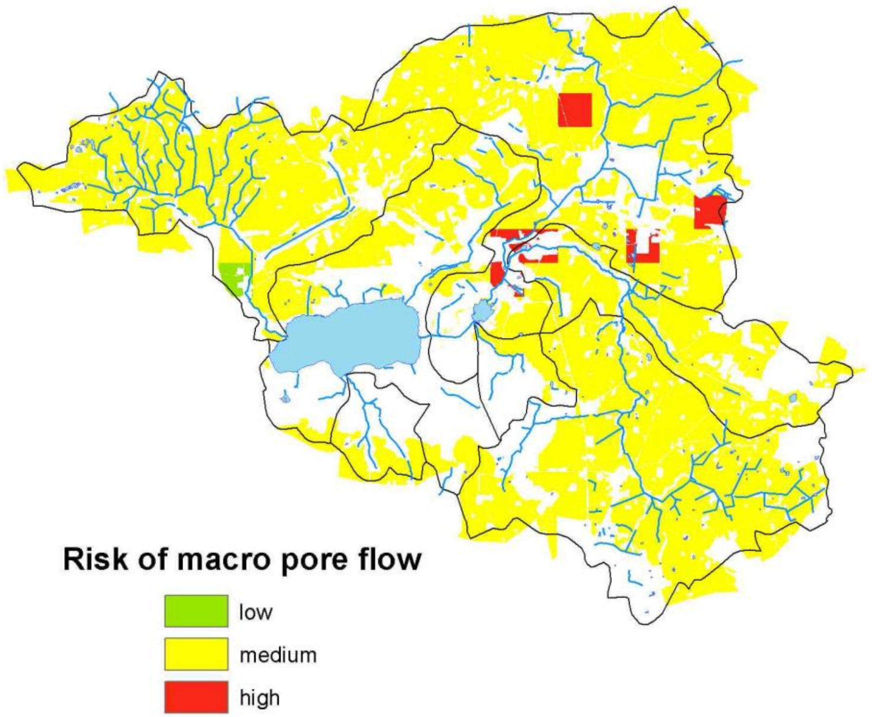
Areas where surface runoff is likely to occur



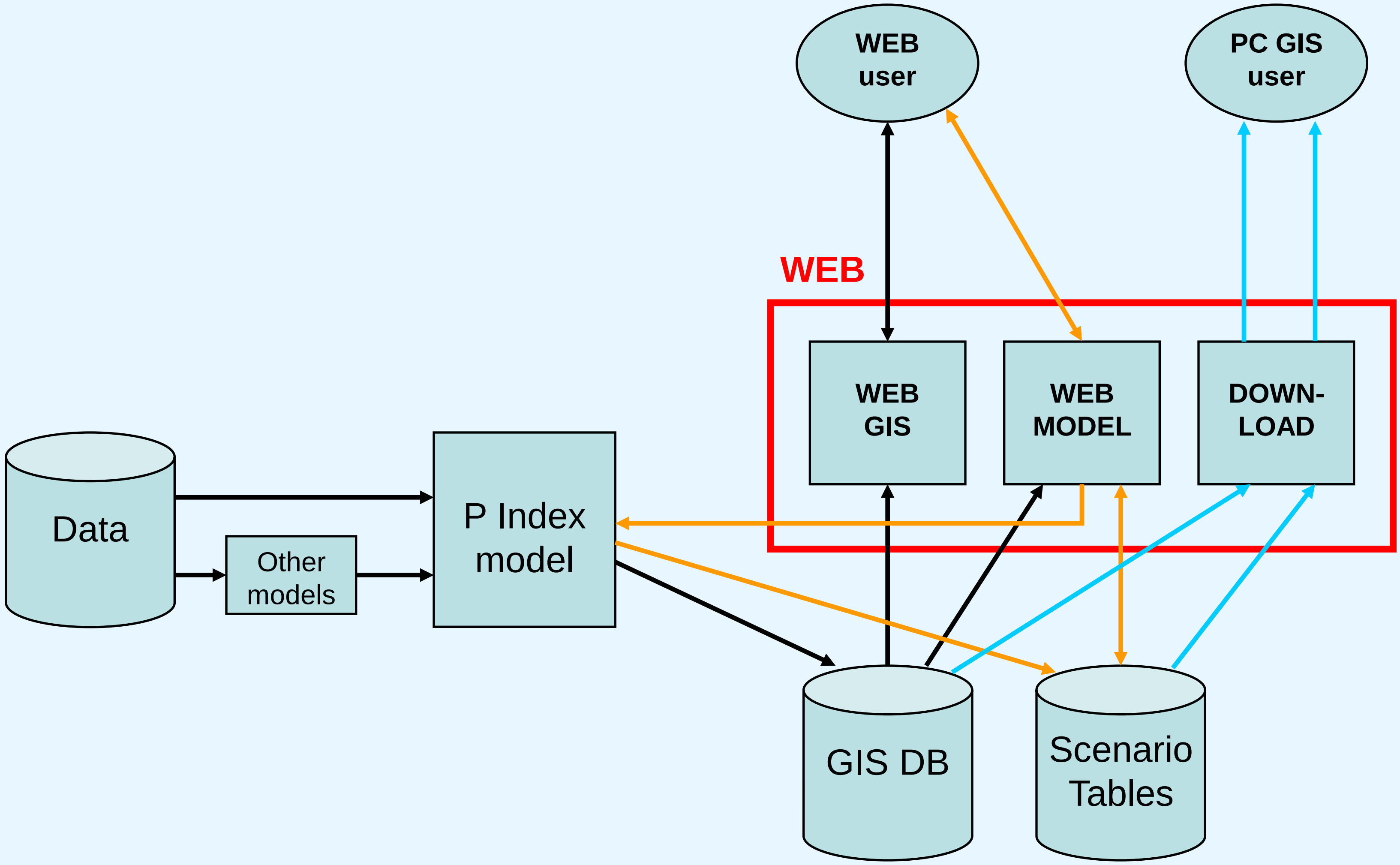
P sorption capacity in subsoil



Existence of macro pores + the likelihood that macro pores are active



WEB based P Index Tool



Mitigation options

- **Where can mitigation options be applied?**
- **Effect on P losses**
- **Costs**
  - **- establishing e.g. buffer strips, wetlands**
  - **- costs for management**
  - **- farmer loss in yield**
  - **- farmer budget and wellfare economy**

A. Mitigation of farming practices	
A1	Reduced tillage of soil
A2	Permanent grass
A3	Aviod or treat wheel tracks in field
A4	Manure should be incorporated in soil after spreading between harvest and 1st April
A5	Fertilization and soil tillage not allowed between harvest and 1. Aprill
A6	Low P fertilization (negative P surplus)

B. Changes in land uses in risk areas	
B1	Set aside
B2	Afforestation
B3	Buffer strips
B4	Reetablishing lakes
B5	Extensivation of farming and temporary inundations of meadows
B6	Restoration of wetlands
B7	Stop for pumping of water from lowlying areas

C. Mititation options in risk areas based on environmental options	
C1	Irrigation of meadows with tile drainage water
C2	Constructed wetlands – on fields

Links between P index value and mitigation options: Definition of P loss potentials for different P-pathways based on experimental data

Loss potential	Erosion	Surface Runoff	Matrix leaching	Macropore transport
	kg P ha^{-1} yr^{-1}			
High risk	2	1	0,5	1
Moderate risk	0,1	0,1	0,1	0,1
Low risk	0	0	0	0

Pilot study on lake Haderslev Dam

272 ha lake , 104 km^2 catchment

Agriculture: 70 %

High recreational value

Source apportionment of P contributions to lake Haderslev Dam (2000 – 2005)

Scattered dwellings	Point sources	Background losses	Agricultural losses
288 kg 7%	**406 kg** 9%	**1862 kg** 42%	**1872 kg** 42%

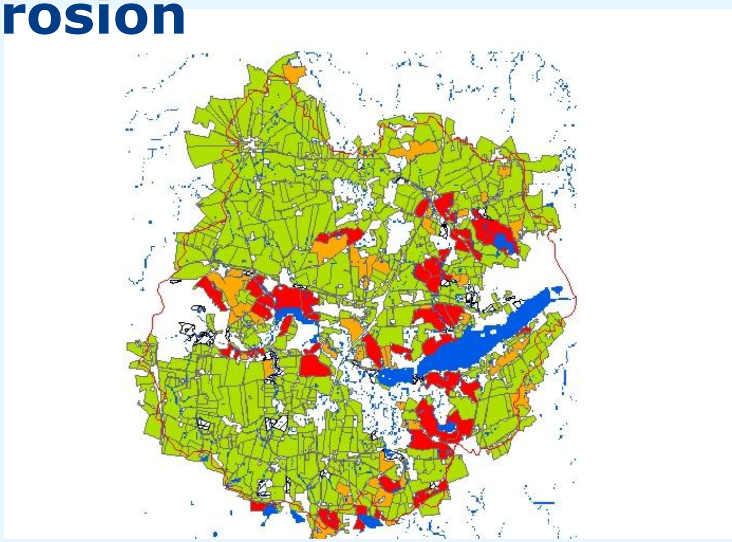
How can the problem be solved? – i.e. how can we reduce diffuse, agricultural losses to the lake?

We need to identify those areas/fields which contribute the most of diffuse P losses in order to target mitigation measures

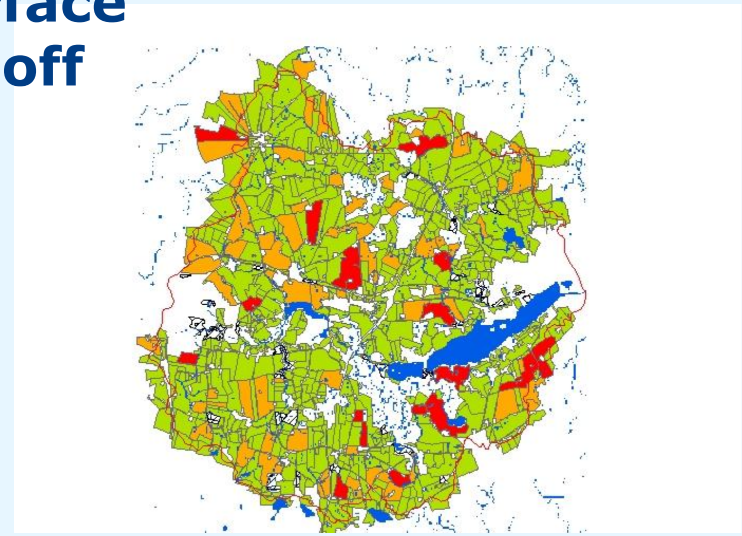
The P index is a robust method for identifying risk areas for diffuse P losses in the landscape

…Areas with high risk of P losses

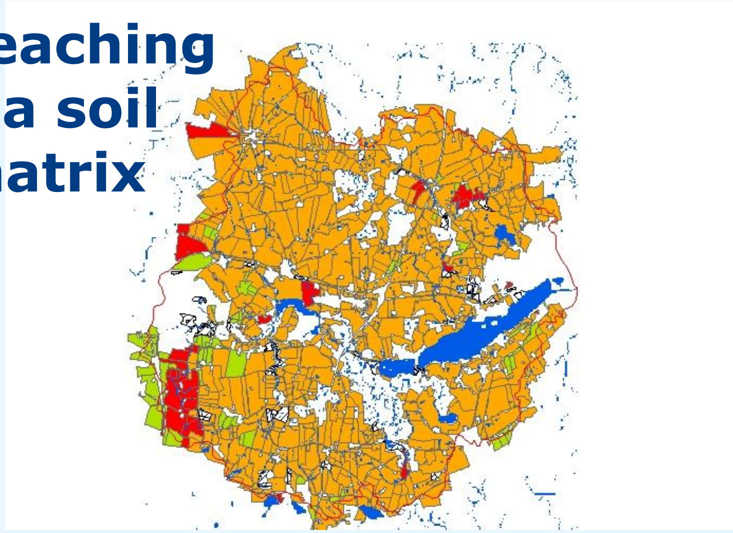
Erosion



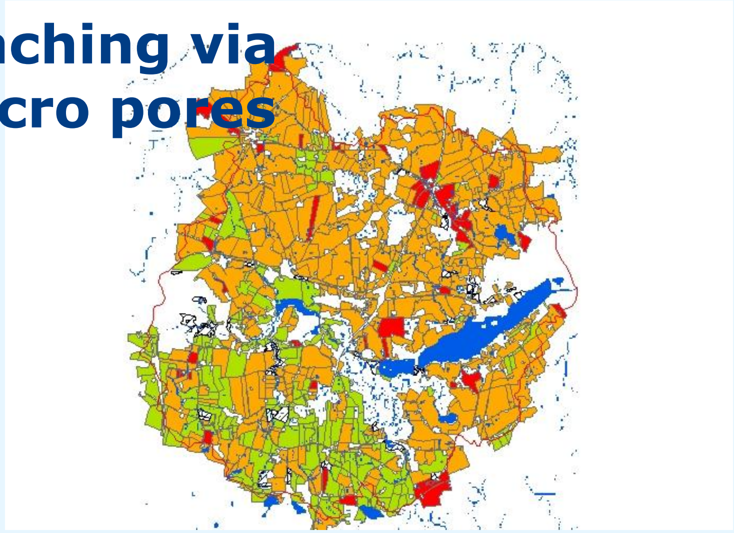
Surface runoff



Leaching via soil matrix



Leaching via macro pores



Risk areas for diffuse P losses in the lake Haderslev Dam catchment

Pathway	Area in high risk
Erosion	**271 ha (3.2%)**
Surface runoff	**109 ha (1.3%)**
Leaching via soil matrix	**403 ha (4.8%)**
Leaching via macro pores	**482 ha (5.7%)**

P loss pathway = erosion

Risk class	P loss potential *kg P ha^{-1} yr^{-1}*	Measure	Effect on P loss *%*	Cost *€ ha^{-1} yr^{-1}*
High	3	Permanent grass (A2)	100	670
Medium	0.1	Incorporation of fertilizer/manure between harvest and 1 April (A4)	10	20
Low	0	P mining (A6)	5	6
		Buffer zones (B3) 2 m 10 m	 25 50	620
		Set aside (B1)	100	620
		Afforestation (B2)	100	570
		Conservation tillage (A1)	70	?
		Avoid or treat wheel tracks in fields (A3)	20	?

P loss pathway = erosion

Risk class	P loss potential *kg P ha^{-1} yr^{-1}*	Measure	Effect on P loss *%*	Cost *€ ha^{-1} yr^{-1}*
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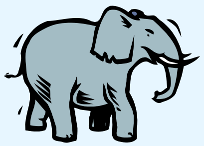
		Buffer zones (B3) 2 m 10 m	 25 50	620
		Set aside (B1)	100	620
		Afforestation (B2)	100	570
		Conservation tillage (A1)	70	?
		Avoid or treat wheel tracks in fields (A3)	20	?

Effect on P loss and cost effectiveness of selected mitigation measures applied in risk areas

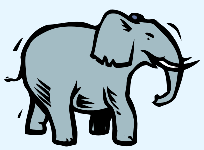
Measure	Area in high risk *ha*	Effect *kg P yr^{-1}*	Cost effectiveness *€ (kg P)$^{-1}$*
Erosion			
Permanent grass	271	813	223
10 m buffer zone	271	407	33
Surface runoff			
10 m buffer zone	109	11	600
Matrix leaching			
Negative P balance	403	10	240
Macro pore leaching			
Irrigation with drain water	357	179	691

By applying the most effective measure for each high risk area diffuse agricultural losses can be reduced by 1,100 kg P (25 % of total input) at an annual cost of € 314,000

The elephants



Public expects blue waters and green pastures



With predicted population growth, 50 -100% increase in crops yields on same acreage

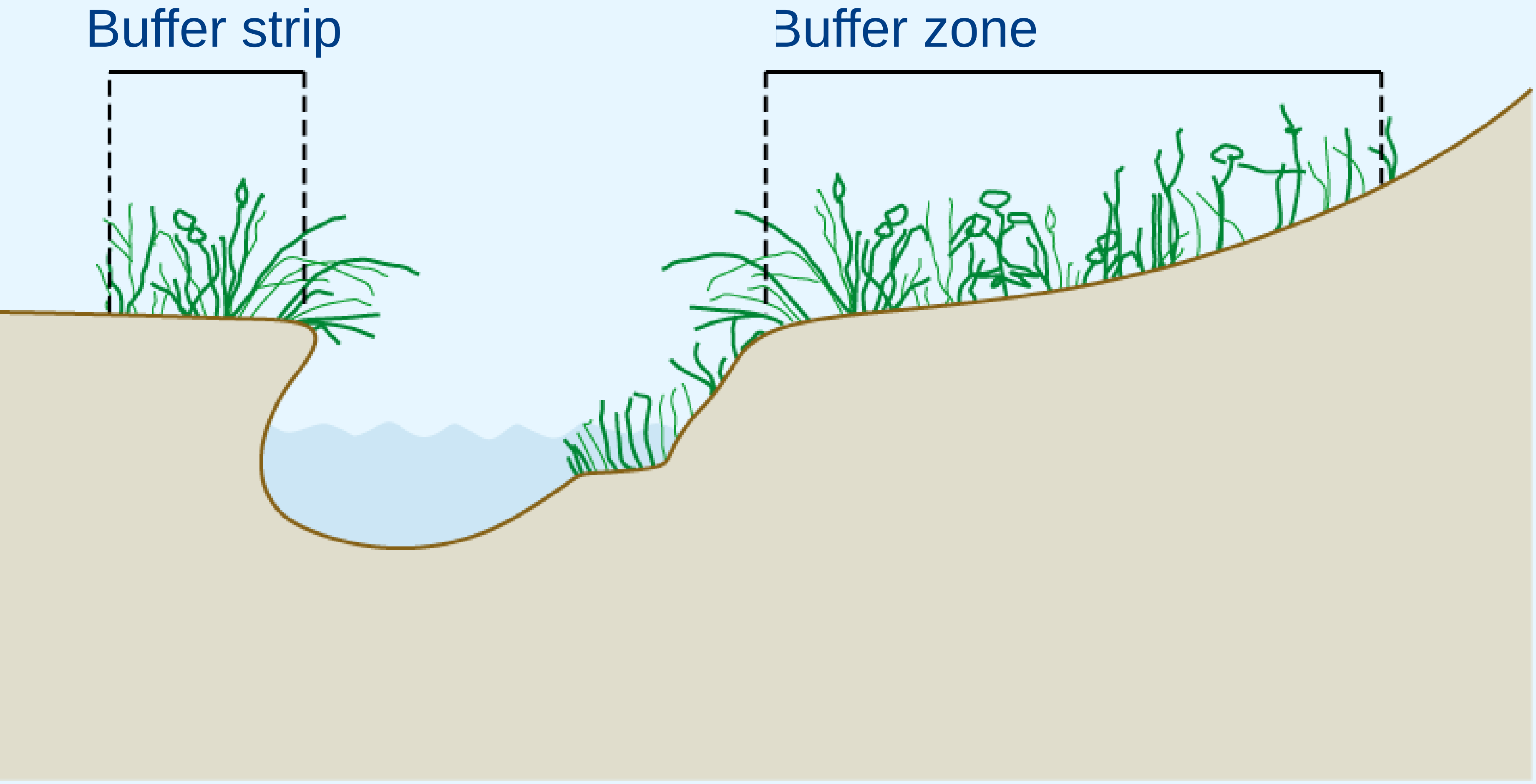
- Will create pressures to intensify
- Pressures to maximize yields
- Likely on less suitable lands
- Economics remains a major driver

The bottom line

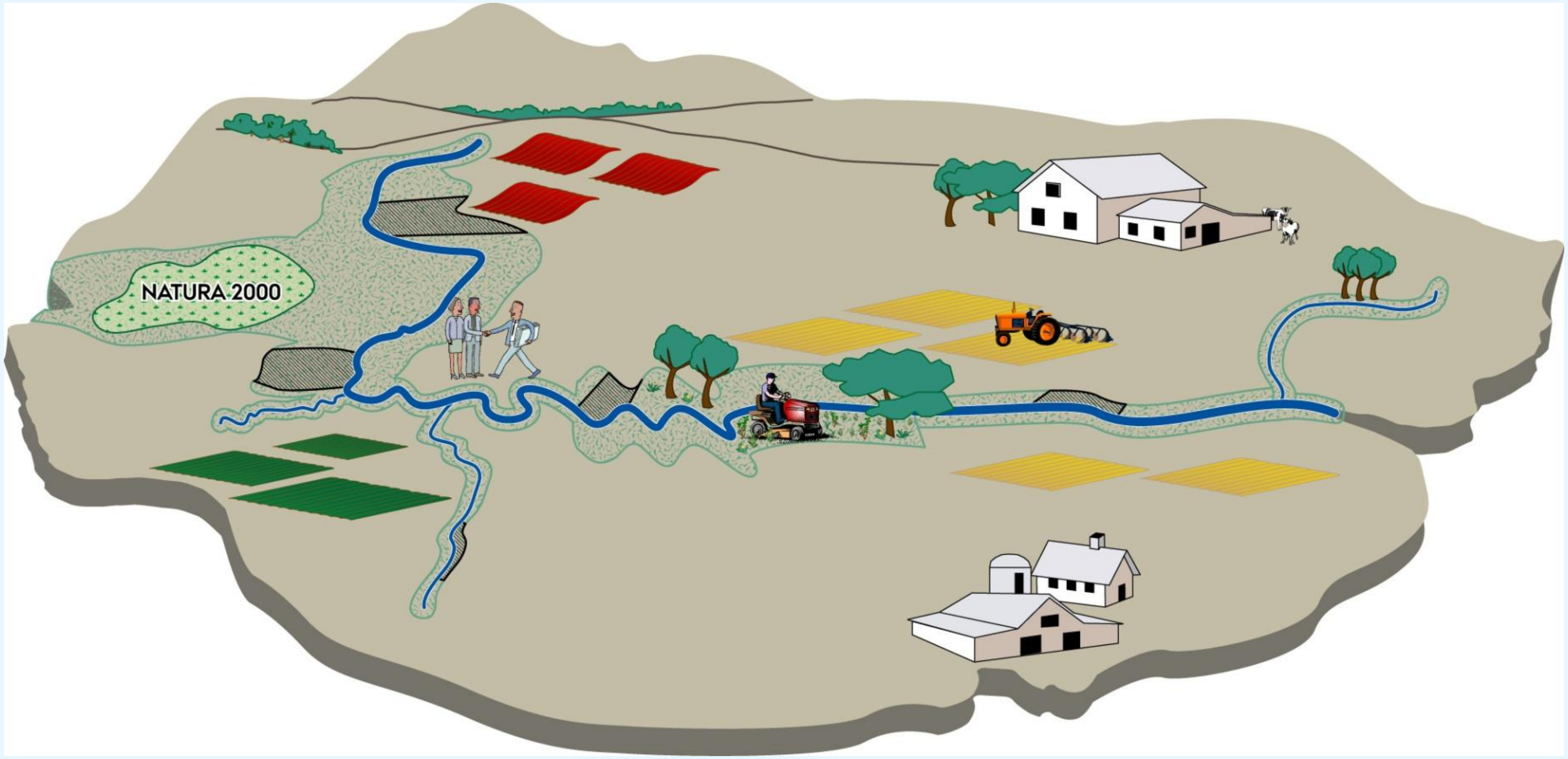
- Complex site hydrology turns everything on it's head
- Robust monitoring to document change
- Accounting for the legacy of past mgt.
- Explaining legacy effects
  - Reduce public disillusionment and impatience

Herding elephants

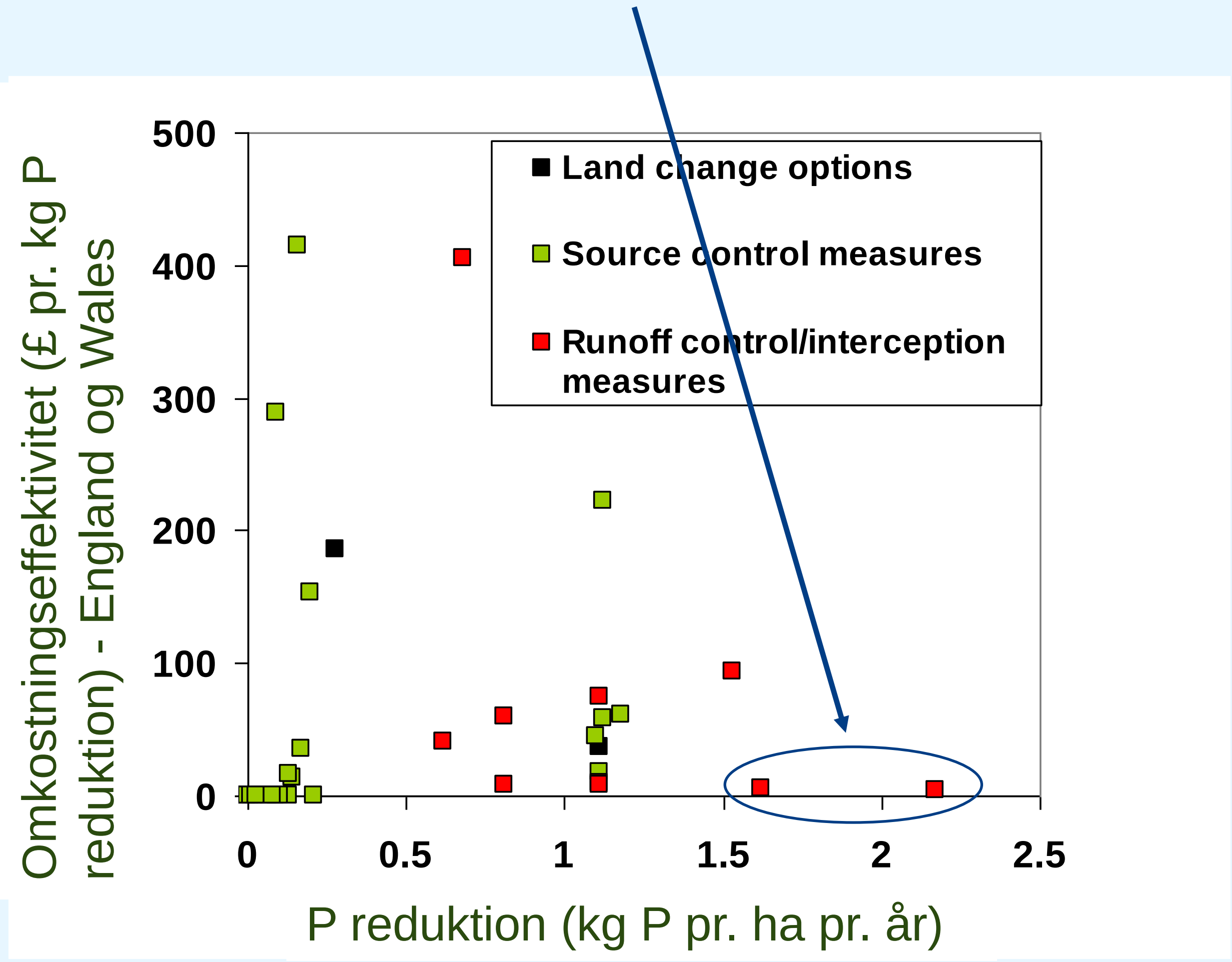
- Policy requires black & white guidelines
- Science tries to account for all variables and situations
- Realistic goal setting
- Targeted management in an equitable manner

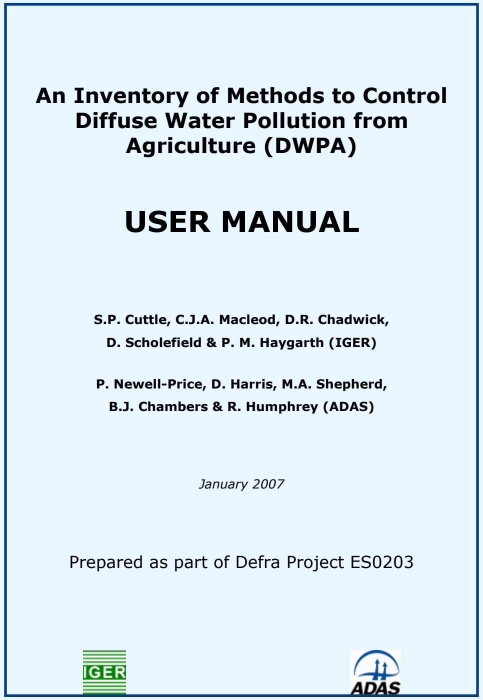

Buffer strip
Buffer zone

Buffer strips should be implemented after analyzing the local conditions (soil type, slope, erosion signs, biodiversity, cattle grazing in streams, etc.



A very cost-effective mitigation option





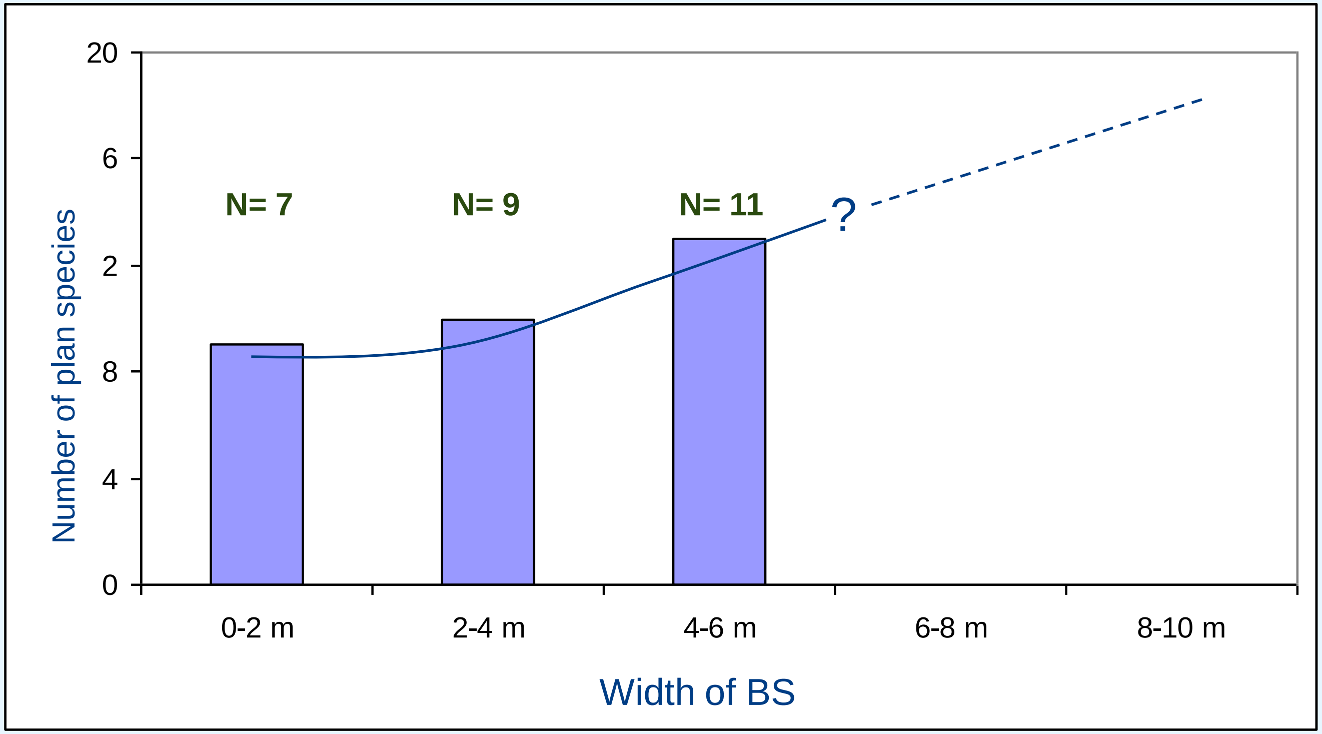
Data fra Haygarth et al. 2009; J. Environ. Qual.

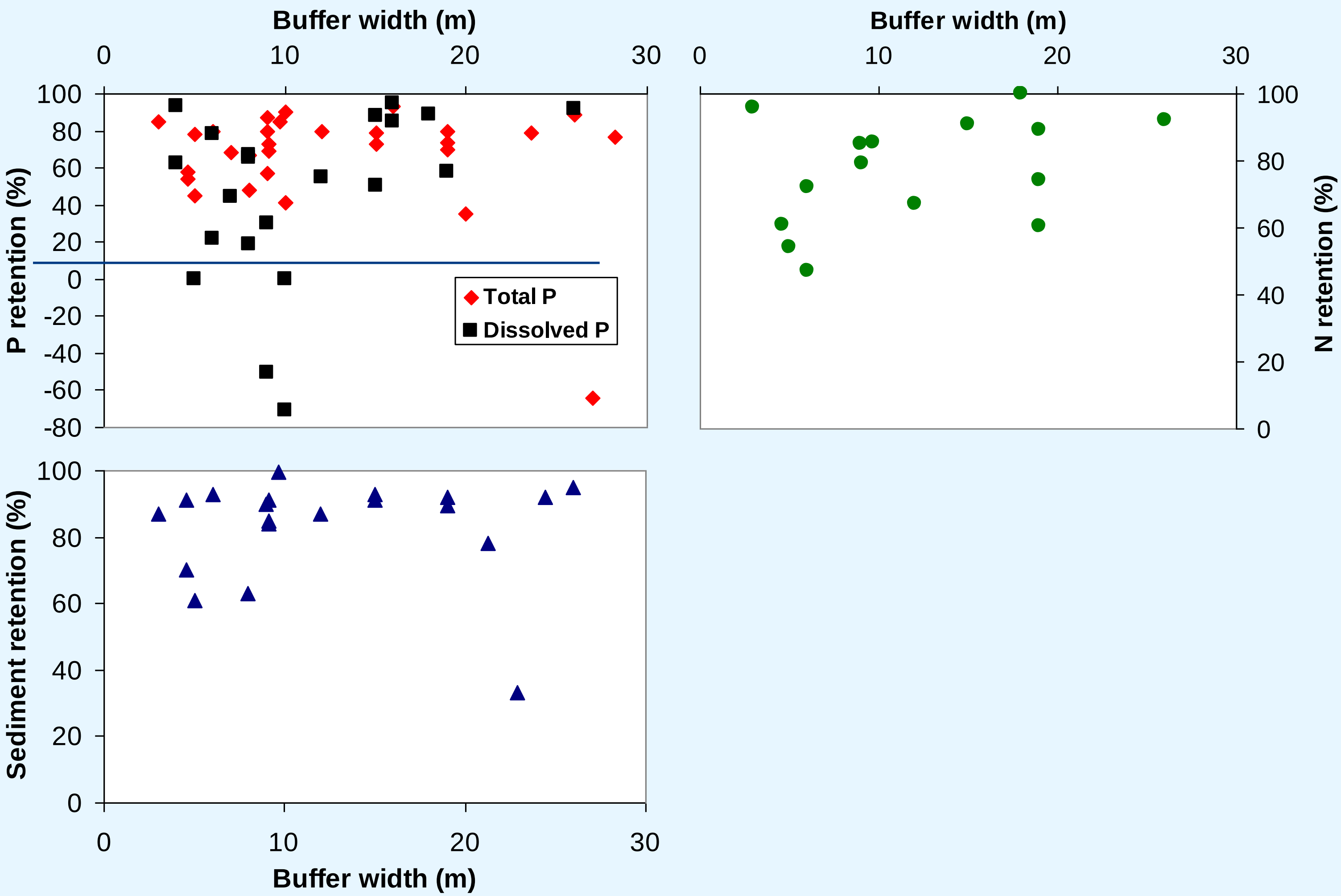
Estimated effect of having 10 m wide buffer strips along all danish streams

Reduktion i P-tab til overfladevand	VMPIII	New estimates
Surface Runoff from fields	4-30 tons P/yr	4-30 tons P/yr
Bank erosion (longer term)	55-129 tons P/yr	0 tons P/yr*
P leaching from organic soils	11-80 tons P/yr	0 tons P/yr
Fytoremediation of P (harvesting plants from BS (longer term)	0	2-8 tons P/yr

*Natural trees in 10% of BS’s can reduce P-loss from bank erosion with11-83 tons P/yr

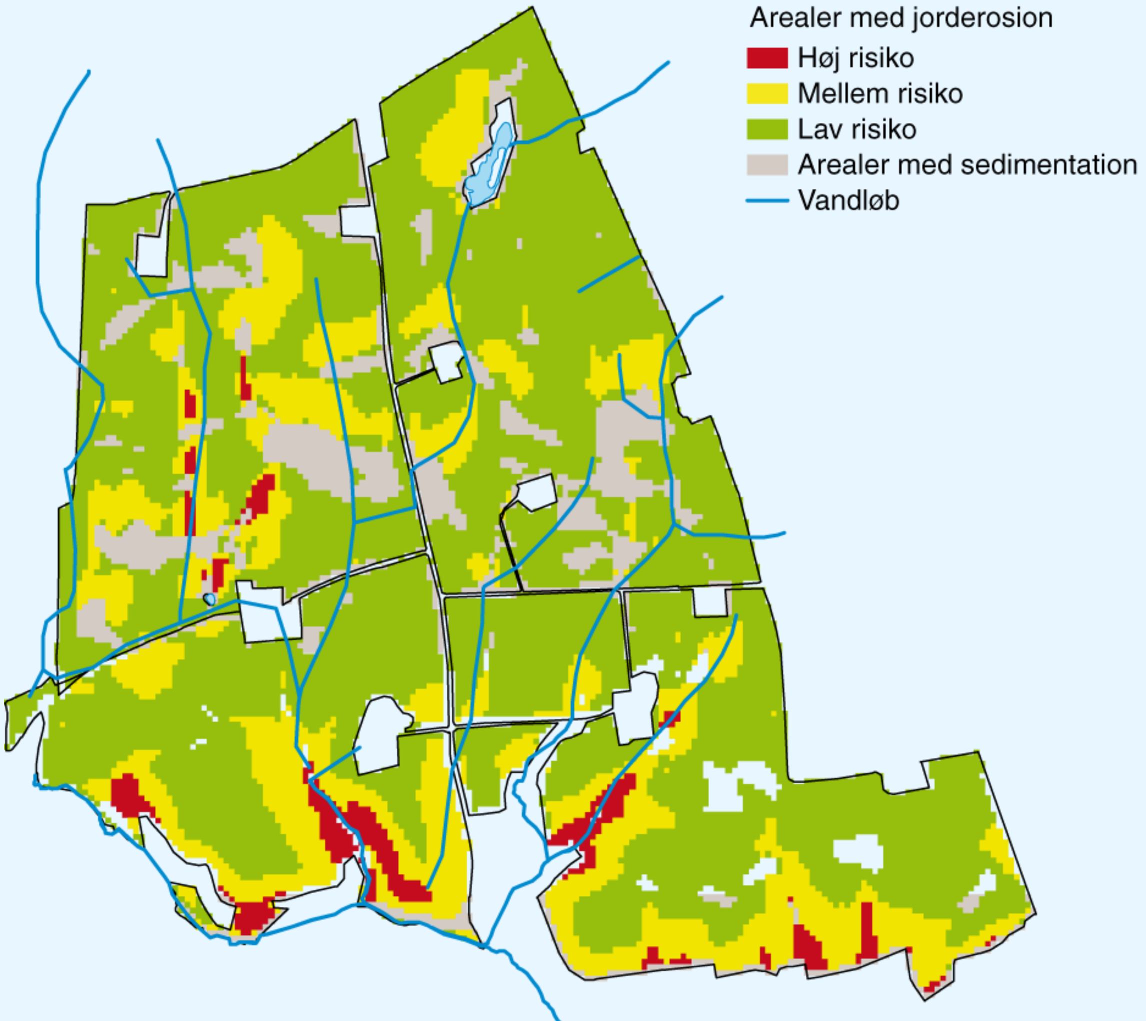
Biodiversity needs room – it will increase with the width of a BS




Buffer width (m)
P retention (%)
Total P
Dissolved P
Buffer width (m)
N retention (%)
Sediment retention (%)
Buffer width (m)

BS's can reduce the amount of sediment bound P derived from soil erosion - but for how long?

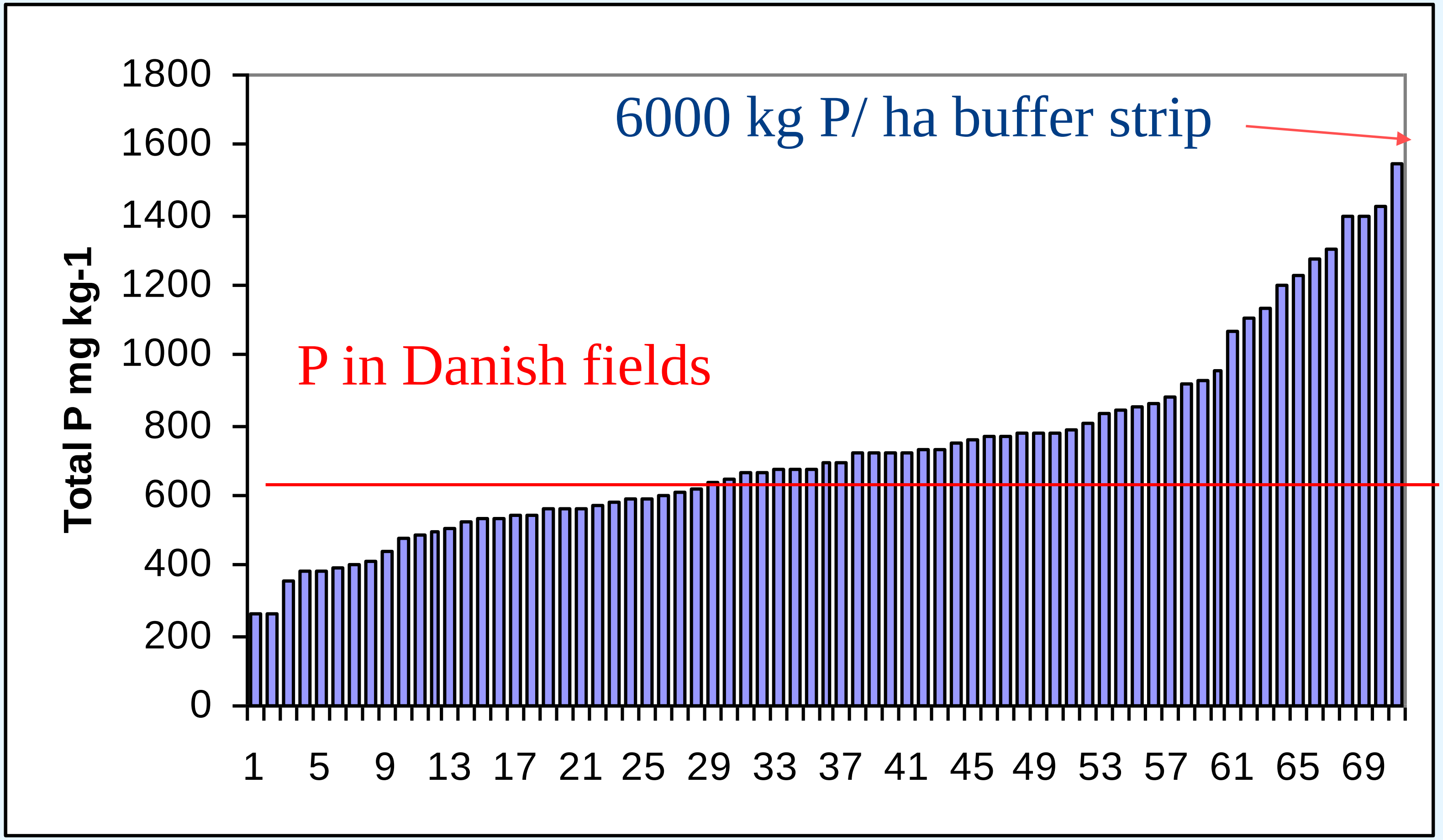
BS's should be established with a width planned after a local analysis



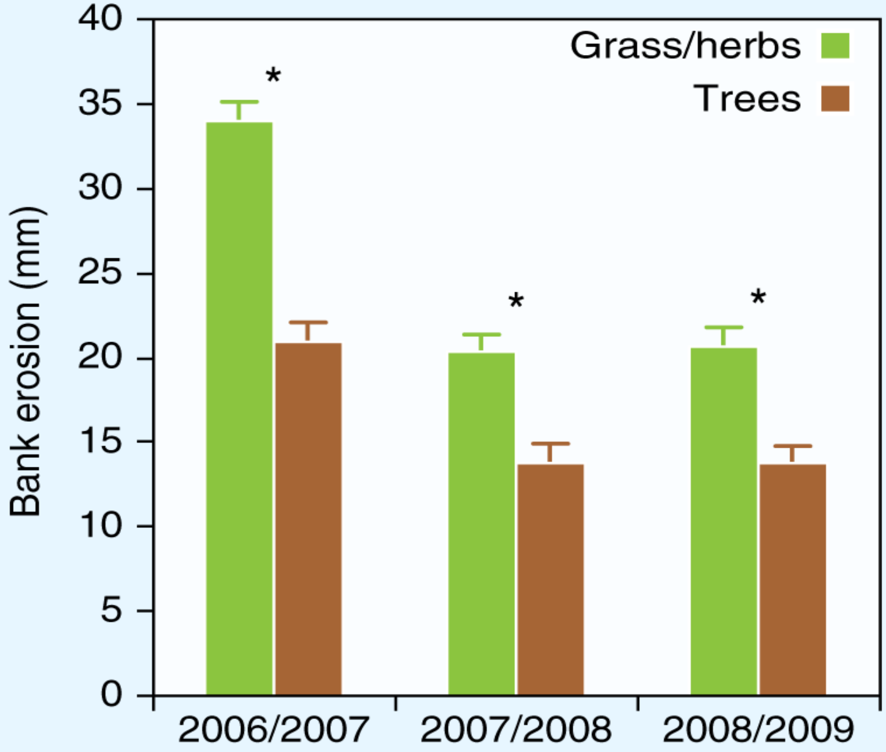
P-risk model

from Aarhus Universitet

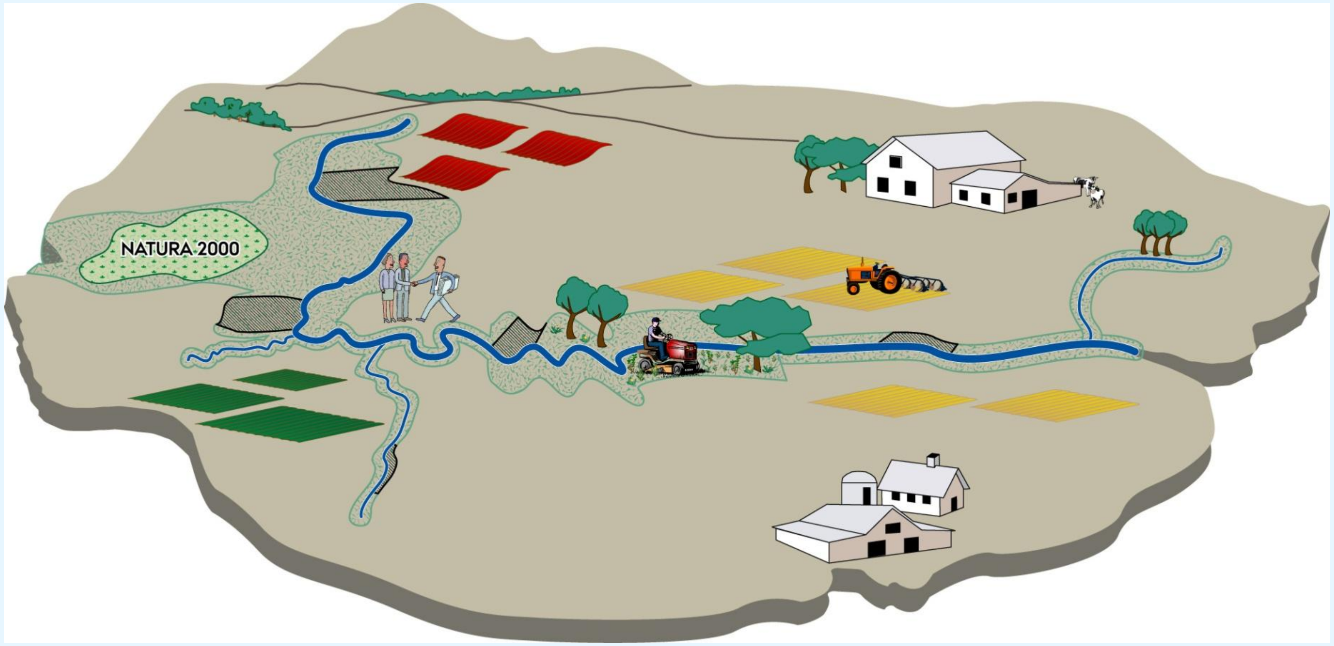
Phosphorus content in bufferstrip soils (1 m from stream edge) along 36 reaches in River Odense Å



Trees in BS's a powerfull mean to reduce bank erosion – 3 year results from a research study in Odense river, Denmark (bank erosion is significantly reduced with 25-40% with trees as compared to grazz or herb vegetation (Kronvang et al., 2012 J. Environmental Quality)



BS's is a powerful management tool – BUT – *there are unanswered questions to address:*

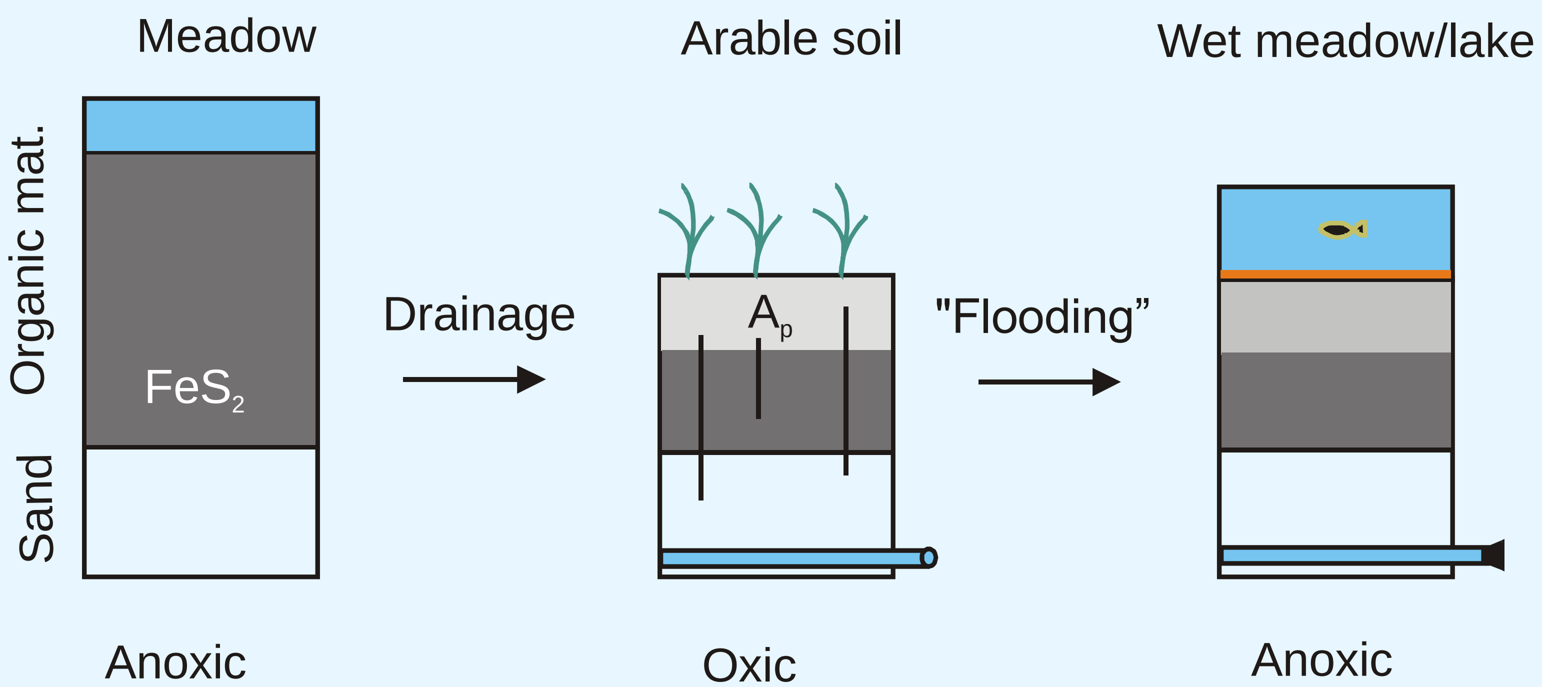


<u>??? Some questions:</u>

- **Width of BS – how?**
- **Biodiversity – how?**
- **Effect on stream ecology?**
- **Risk of Pollution swapping?**
- **Life time?**
- **Management of BS?**
- **Links to agricultural production**
- **Effects of energy crops**
- **Carbon sequestration?**

Iron(III)oxide reduction and phosphate release

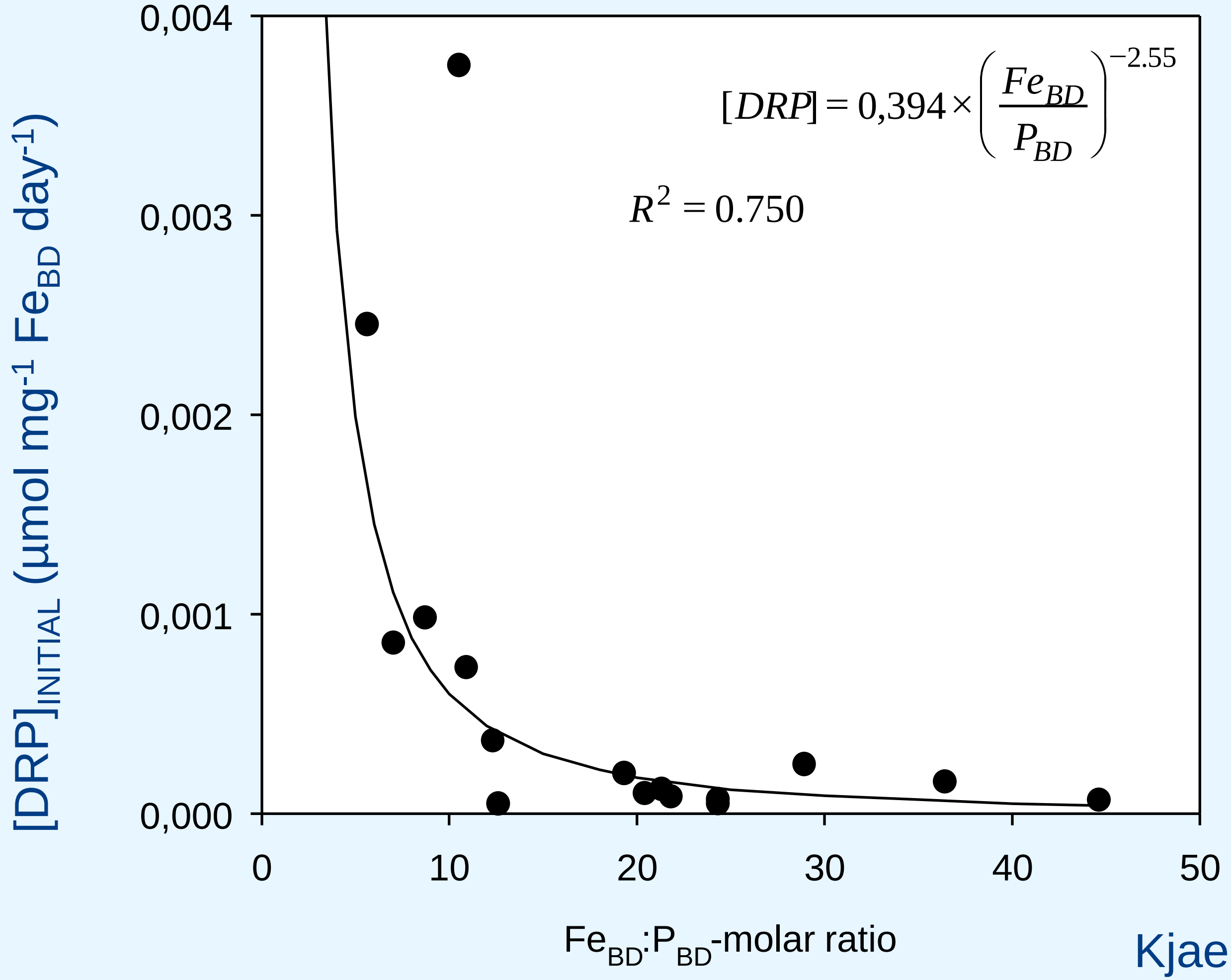
Processes in reestablished meadows?



Mineralisation => settling
Pyrite oxidation => ochreous precip.
+P, +N, +$CaCO_3$
+Heavy metals

Nitrate reduction
+ Ochreous precip.?
+ Phosphate?
+ Heavy metals?
+ Methane, nitrous oxide

Phosphorus release kinetics



Kjaergaard et al., 2007

Phosphorus retention in restored wetlands

Results from the monitoring programme

	P-retention Kg P ha^{-1} yr^{-1}	%
Wetlands		
Ulleruplund	-0.43	-88
Egebjerg Enge	0.13	6
Karlsmosen	8.1 – 9.0	53-60
Snaremose	0.4	4
Shallow lakes		
Årslev Engsø	-1.3	-4
Ødis Sø	-2.3	-192
Wedellsborg	16	?

Restoring River Lyngbygaard – large scale reestablishing of a wetland on former arable fields being artificially pumped for drainage

Main results
NO_3 removal and net TP release – mostly particulate from erosion