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Rich Waters

Jordbruksverket

Havs och Vatten myndigheten

Combining high-resolution spatially distributed models with export coefficients produced by field-scale process-oriented model

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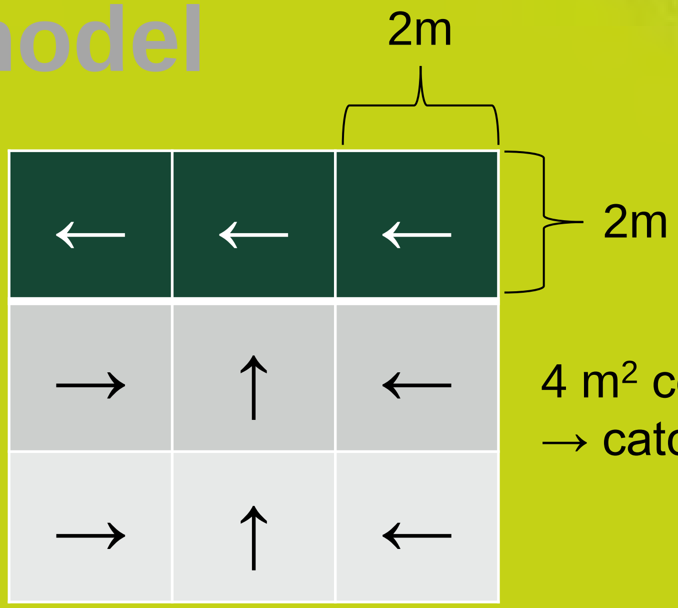
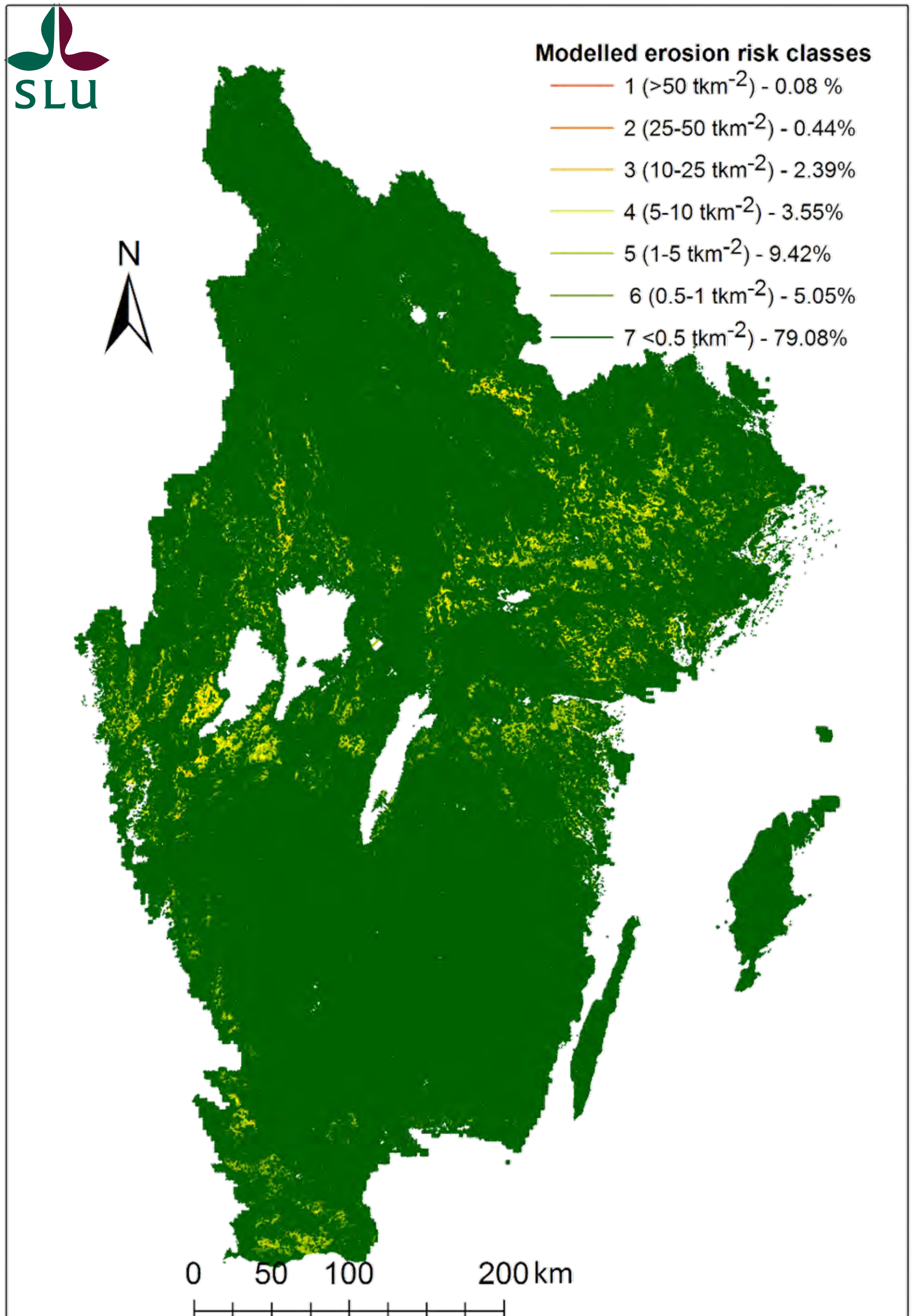


4 m^2 cell → flow pathways → fields → sub-catchments → → catchments → river basins



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RESEARCH ARTICLE

From single fields to river basins: Identification of critical source areas for erosion and phosphorus losses at high resolution

Faruk Djodjic, Hampus Markensten

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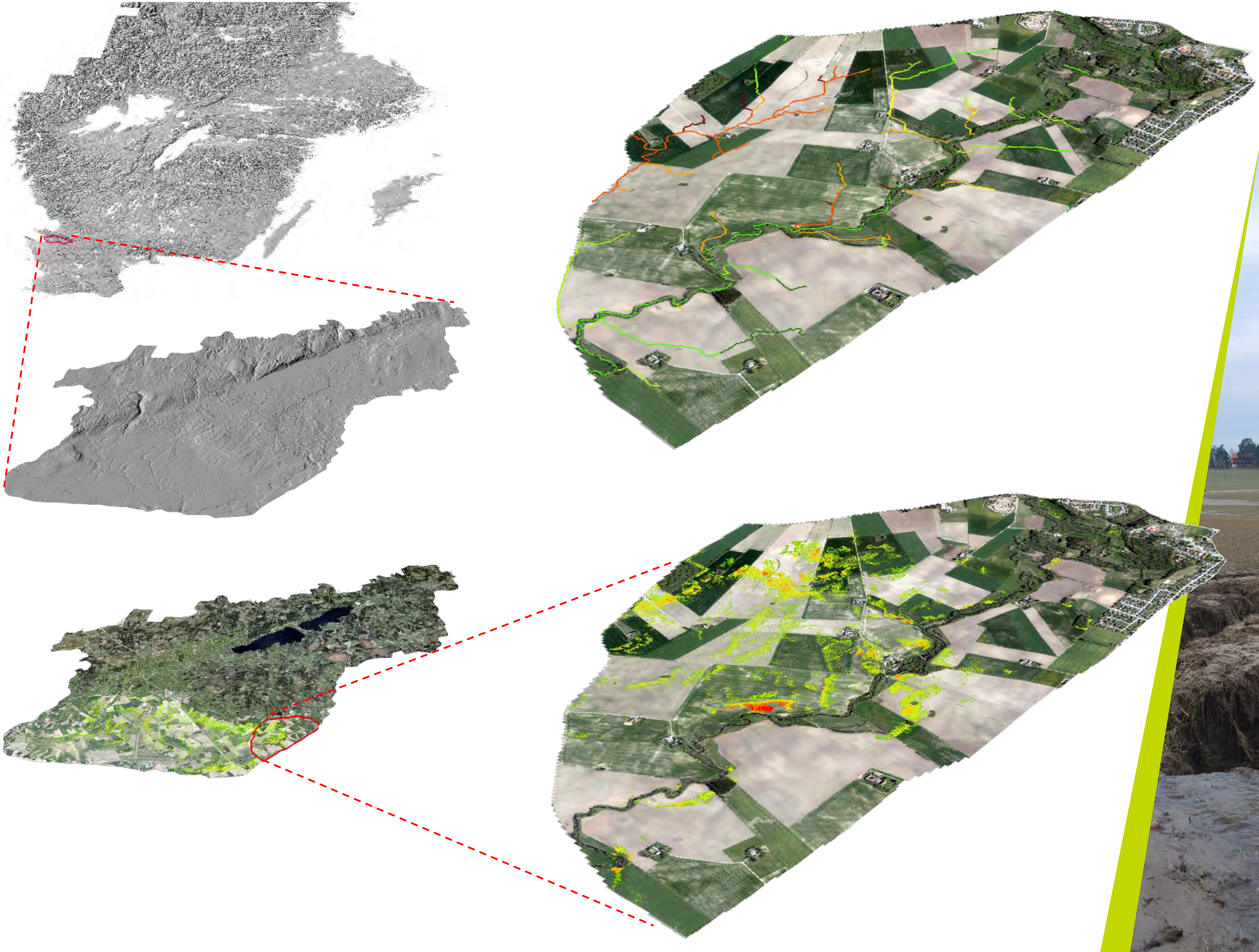
Abstract Concentrations of phosphorus (P), the main limiting nutrient in freshwater ecosystems, need to be reduced, but this is difficult due to high spatial and temporal variations and limited resources. Reliable targeting of critical source areas, such as erosion-prone fields and parts of fields, is necessary to improve the cost efficiency of mitigation measures. We used high-resolution (2 m × 2 m) distributed modelling to calculate erosion risk for a large area (202 279 km^2) covering > 90% of Swedish arable land. Comparison of model results with independent farmers' observations in a pilot catchment showed high spatial agreement. The modelled worst case scenario produced reasonable quantitative results comparable to measured 90th percentile values of suspended sediment (SS) loads at both field and small catchment scale ($R^2 = 0.81$, $p < 0.001$). Overall, loads of SS, especially during extreme episodes, strongly governed losses of unreactive P and total P at both field and catchment scale.

Keywords Critical source areas · Distributed modelling · Erosion · High-resolution · Phosphorus

INTRODUCTION

Loads of phosphorus (P), the main limiting nutrient in freshwater ecosystems, cause intense algal blooms and impair water quality (Schindler 1974). Identification and limitation of point-source inputs of P to surface waters have been rather successful, whereas nonpoint sources, mainly within agriculture, remain elusive and more difficult to identify, quantify, target and remediate (Sharpley 2016). For instance, in Sweden, emissions of P from wastewater treatment plants have been reduced from 1050 ton in 1987 to 237 ton in 2016, reaching an average treatment efficiency of 96% (Statistics Sweden 2018). Recent estimates of the nutrient loads from Sweden to the Baltic Sea have identified diffuse losses from agriculture as the largest anthropogenic source of P (Ejhed et al. 2016). However, the effects of mitigation programmes focusing on agricultural sources remain difficult to quantify. For most abatement programmes, the key metric of success is the extent to which a practice is implemented, rather than the effectiveness of its implementation in mitigating water quality degradation (Kleinman et al. 2015).

The majority (~ 80%) of diffuse P losses originate from a small proportion of catchment areas (~ 20%), a situation known as the 80:20 rule (Sharpley et al. 2009). These so-called critical source areas (CSAs) coincide with hydrologically active, interconnected areas where overland and/or shallow subsurface flow mobilise and transfer P from terrestrial to aquatic ecosystems. In humid hill-land watersheds, relatively small and well-defined areas typically contribute much of the nonpoint source water, sediment, P and N exported in watershed outflow (Pionke et al. 2000). McClain et al. (2003) coined the term biogeochemical ''hot spots'' to describe "areas (or patches) that show disproportionately high reaction rates relative to the surrounding area (or matrix)." According to Pionke et al. (2000), it is important to develop concepts, modelling tools and sampling protocols to identify and assess the impact of these CSAs. Identification, quantification and targeting of these CSAs still remain a challenge for the research community and for policy makers. Therefore, despite the extensive body of scientific evidence suggesting that P losses are episodic and spatially variable, current environment protection programmes are not designed to target the most vulnerable parts of the landscape, but applied in a rather general way. Soil erosion is linked to the detachment of soil particles and associated P and provides physical

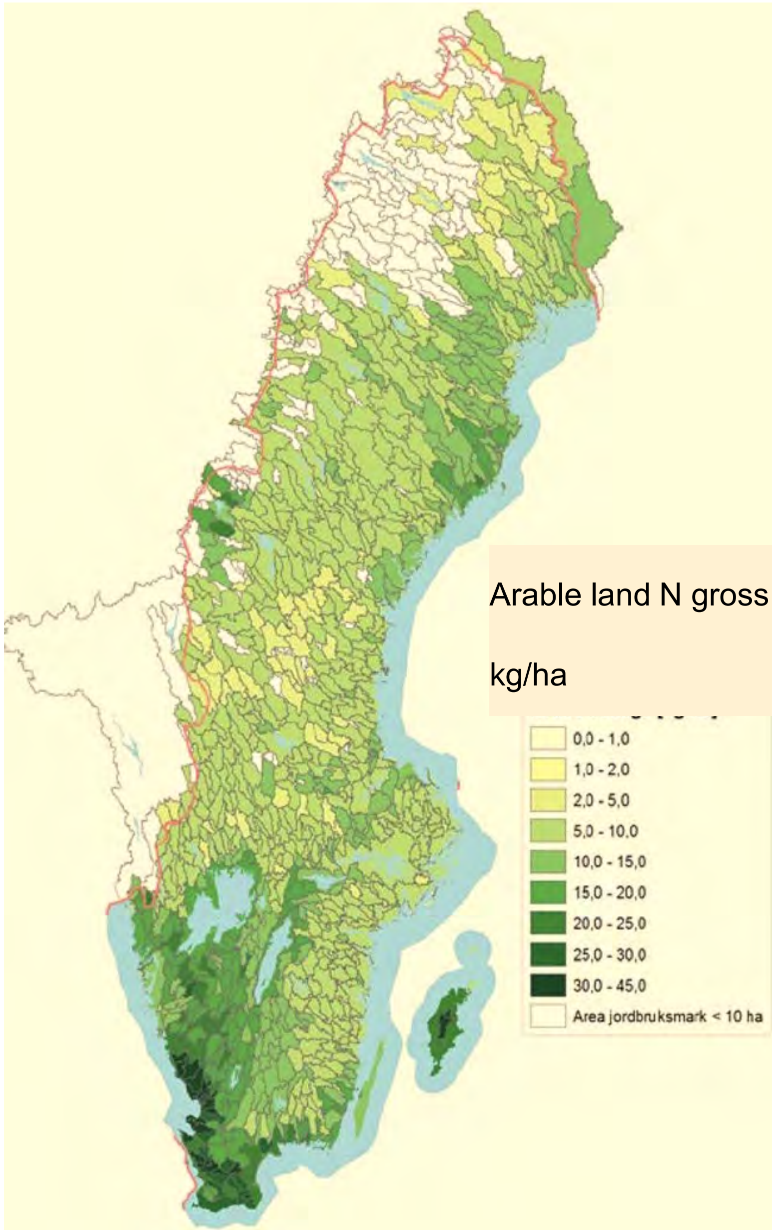


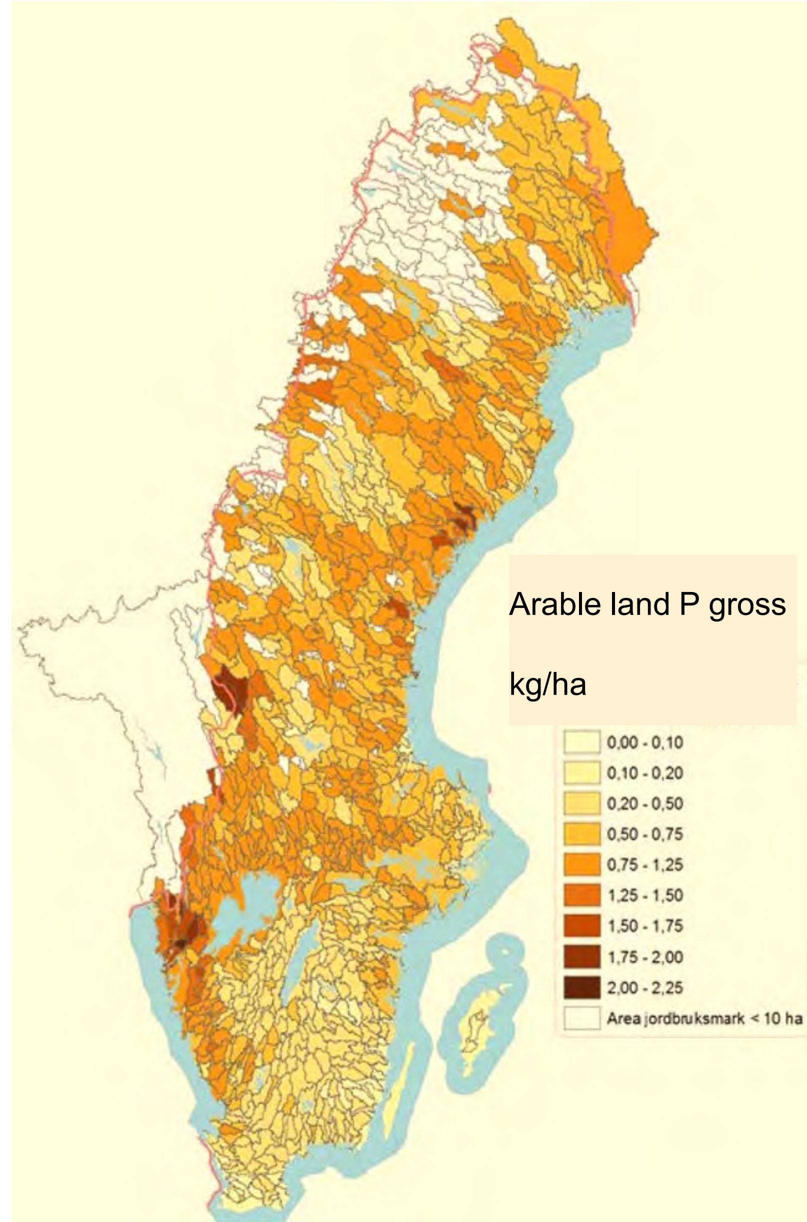
Combining high-resolution spatially distributed models with export coefficients produced by field-scale process-oriented model

0.05	**0.06**	**0.03**
0.08	0.08	0.10
0.12	0.10	0.15

Export coefficient = f(crop, soil properties, climate, management options, yields)

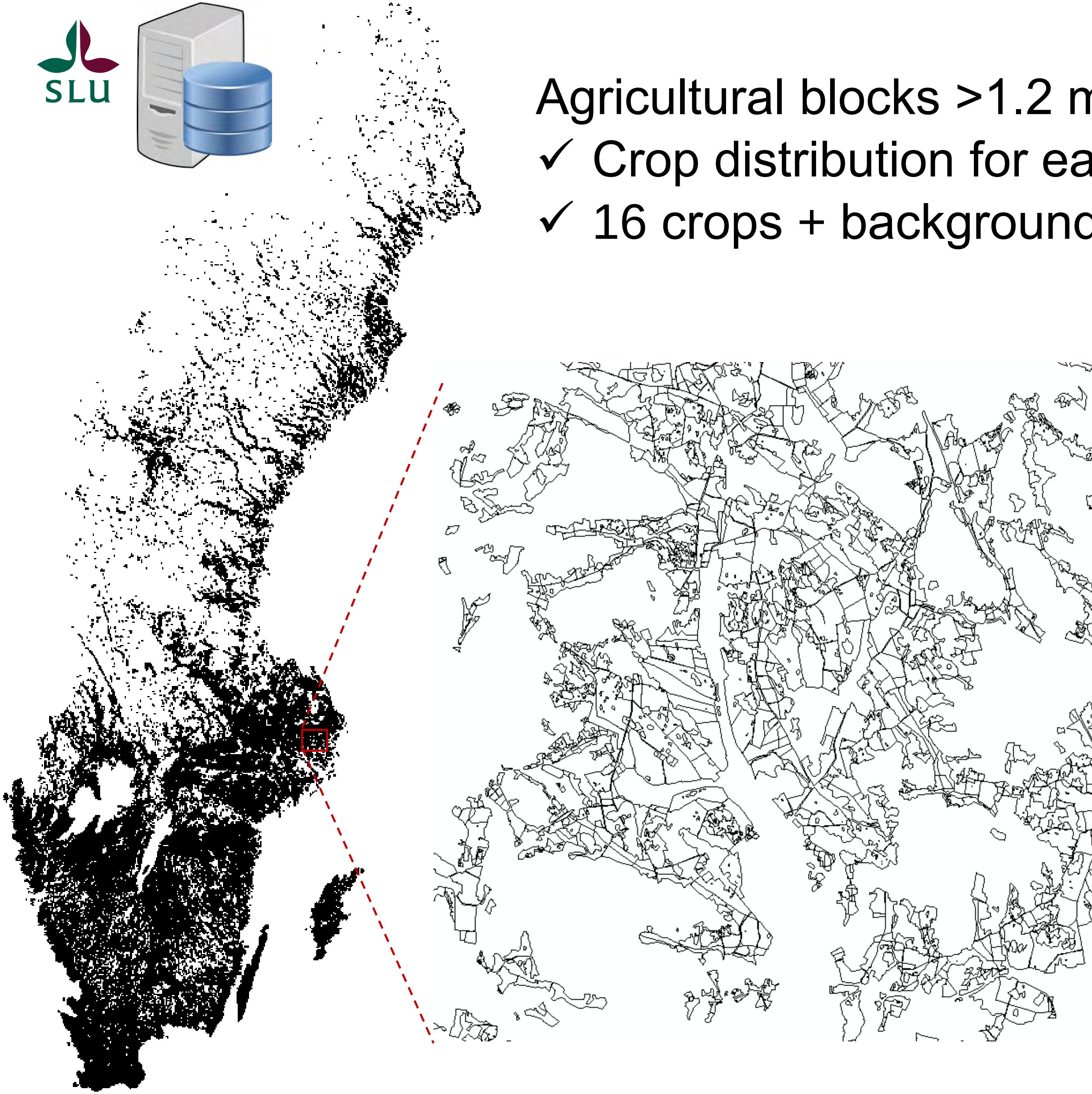
NLeCCS (Nutrient Leaching Coefficient Calculation System) Pollution Load Compilation - HELCOM





Agricultural blocks >1.2 million

- ✓ Crop distribution for each block
- ✓ 16 crops + background



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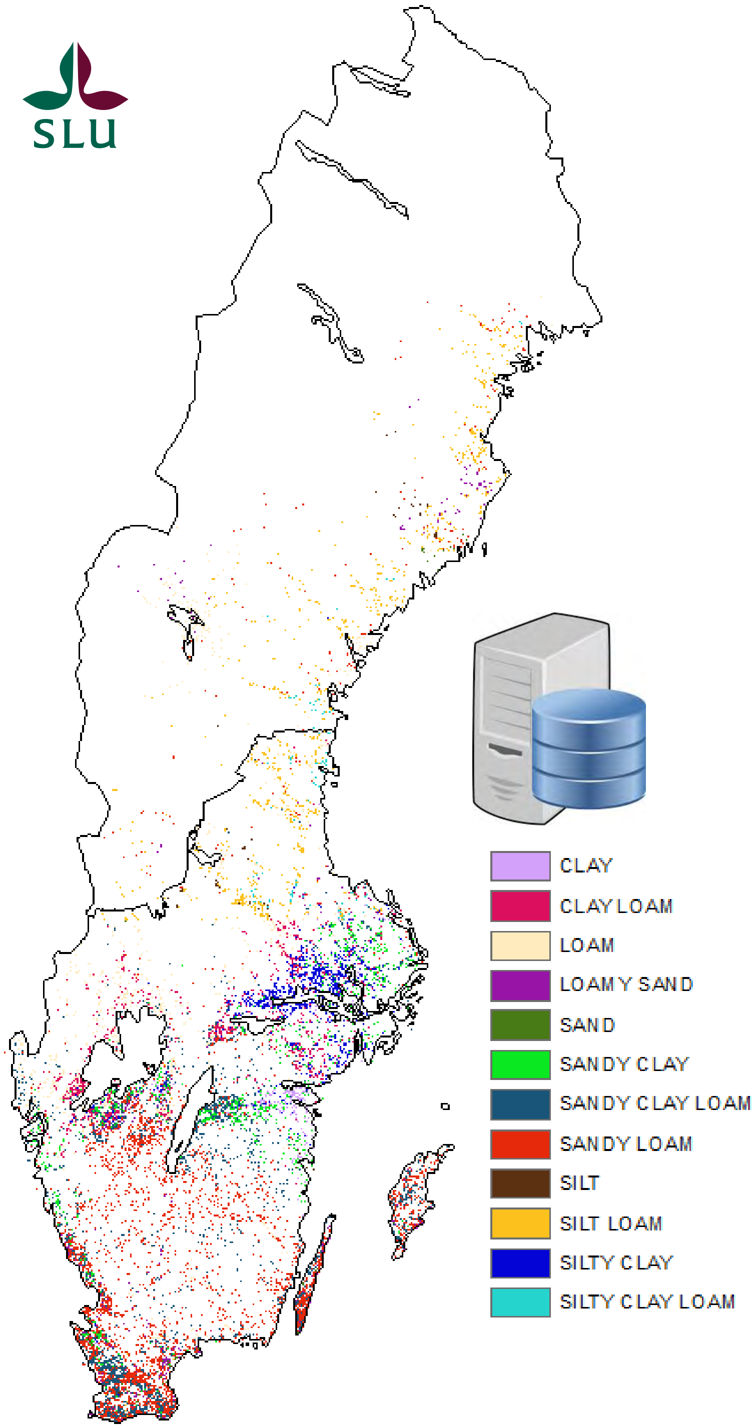
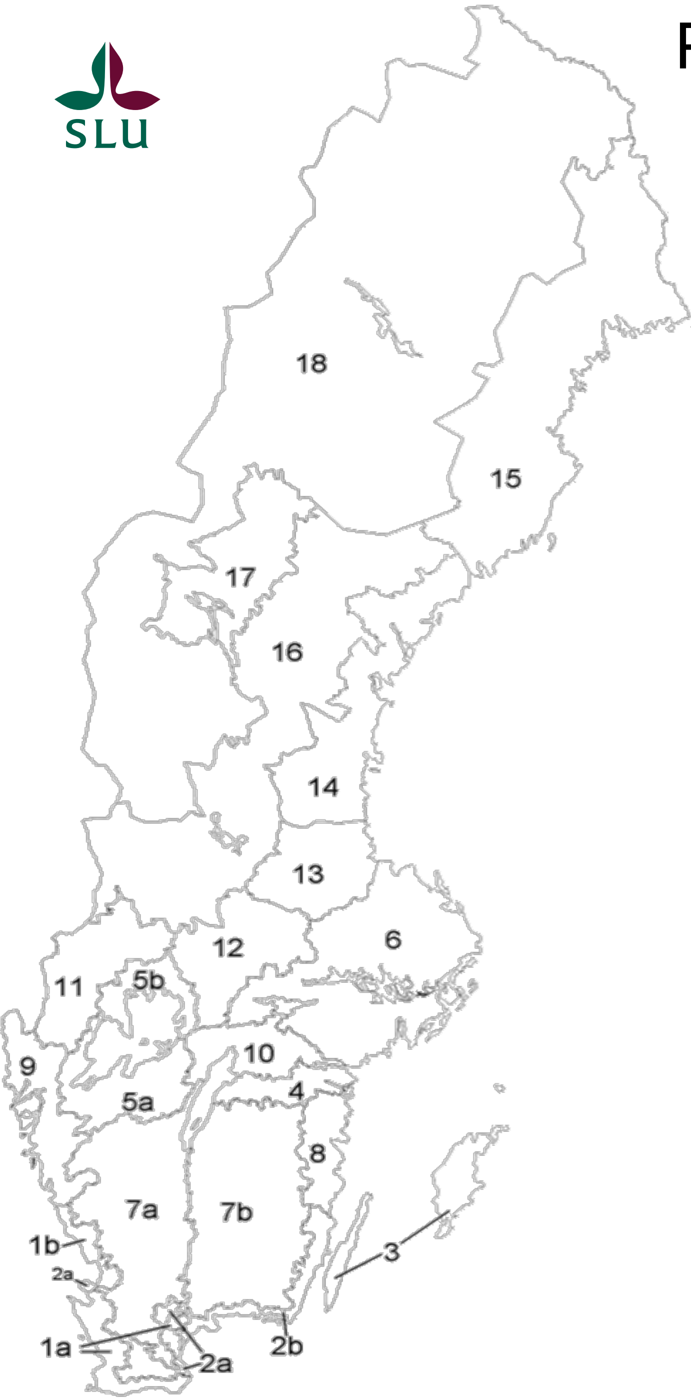

CLAY
CLAY LOAM
LOAM
LOAMY SAND
SAND
SANDY CLAY
SANDY CLAY LOAM
SANDY LOAM
SILT
SILT LOAM
SILTY CLAY
SILTY CLAY LOAM



Production regions

Statistics Sweden

- Yields (nutrient content)
- Fertilizer (manure or synthetic)
    - Rate
    - Method
    - Timing
- Field operations
    - Plowing
    - Sowing
    - Harvest
- …

Swedish Meteorological and Hydrological Institute

- Weather/climate
    - Temperature
    - Precipitation
    - Wind speed
    - Humidity
    - Solar insolation
- Water discharge

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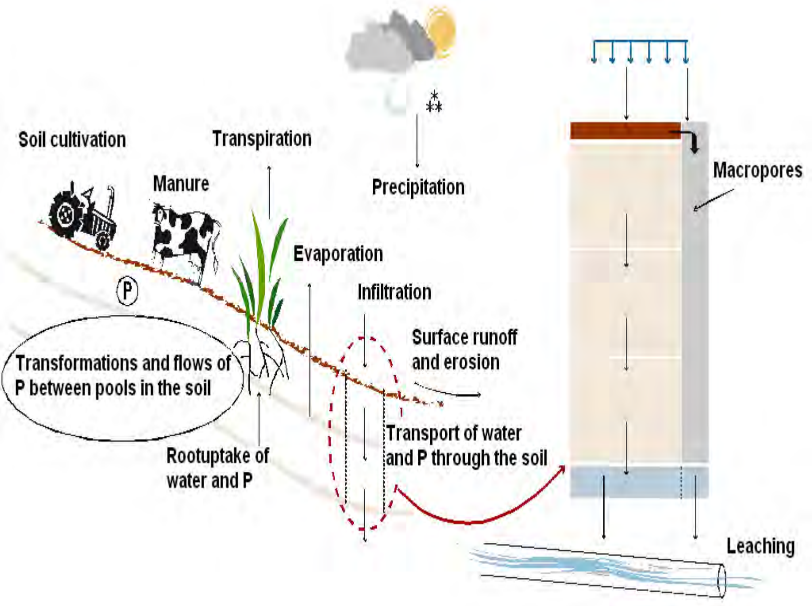
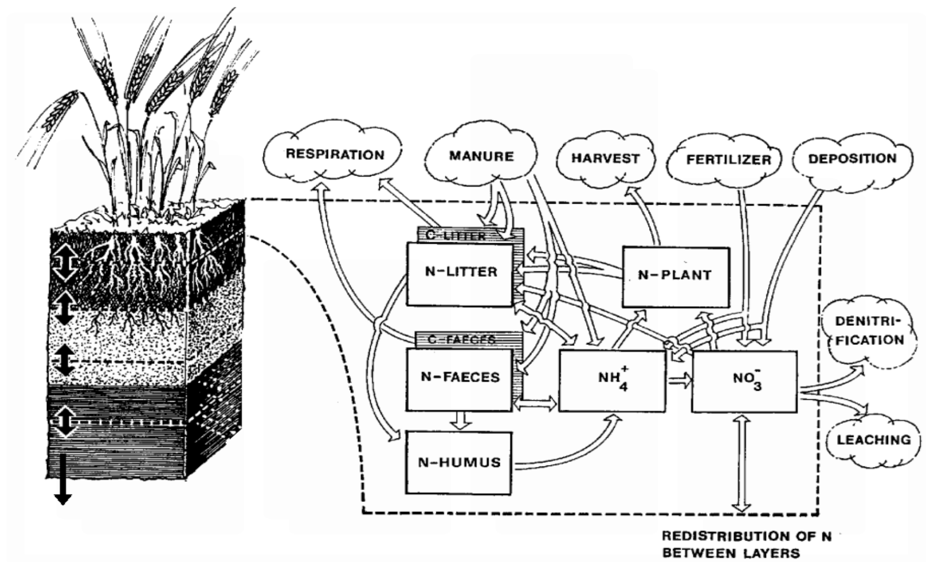
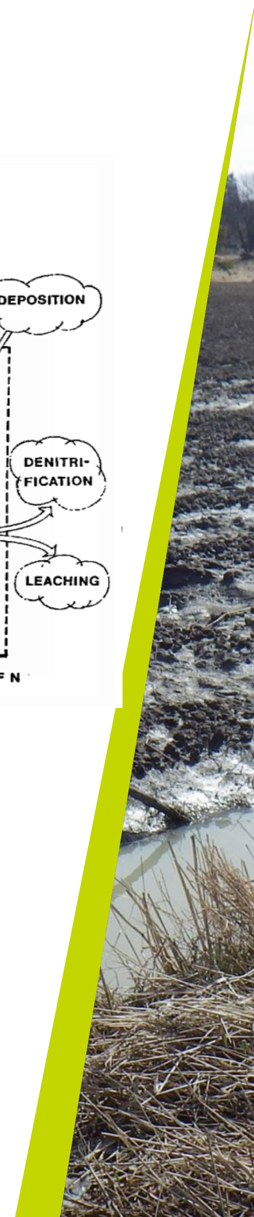
Phosphorus
ICECREAMDB



Nitrogen
SOILNDB





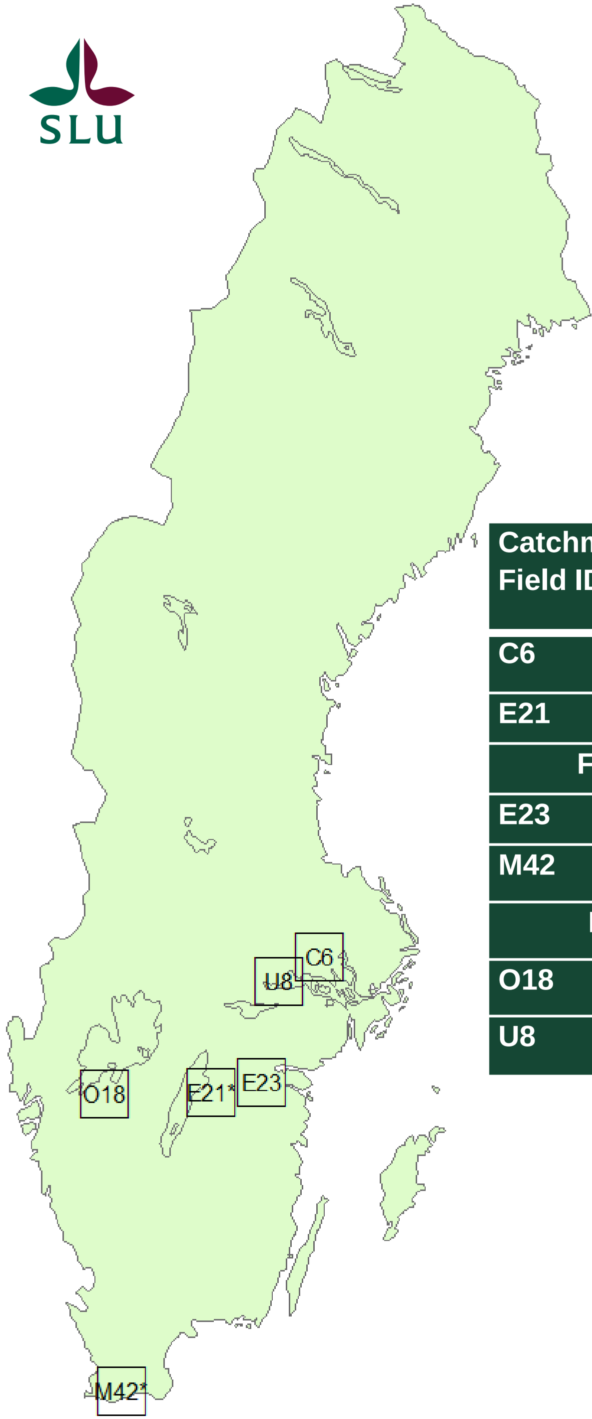
Daily time step → 20-30yrs crop rotation sequences → Repeated ca 10 000 yrs

N 22 regions x 16 crops x 10 soil texture = 3520 type concentrations

e.g. Winter wheat on clay soil in southeast Sweden = 3.8 mg/l

P 22 regions x 16 crops x 10 soil texture x soil P content x field slope

Clay Spring barley ←	**Clay Spring barley ←**	**Silty clay Spring barley ←**
Clay Spring barley →	Clay Spring barley ↑	Silty clay Spring barley ←
Loam Winter wheat →	Loam Winter wheat ↑	Loam Winter wheat ←



Catchment/ Field ID	Area (ha)	Arable land (%)	Dominant soil texture class (USDA)	Precip. (mm)	Temp. (^{0}C)	Runoff (mm)	TP (mgL^{-1})
C6	3310	59	Clay loam	623	5.5	220	0.21
E21	1630	89	Sandy loam	506	6.0	157	0.06
Field 21E	4.4	100	Sandy loam	500	6.0	123	0.01
E23	740	54	Clay	594	6.3	181	0.28
M42	820	93	Sandy loam, loam	709	7.7	282	0.15
Field 2M	33.8	100	Loam	650	7.7	234	0.10
O18	770	92	Clay	655	6.1	332	0.50
U8	570	56	Clay	539	5.9	206	0.26

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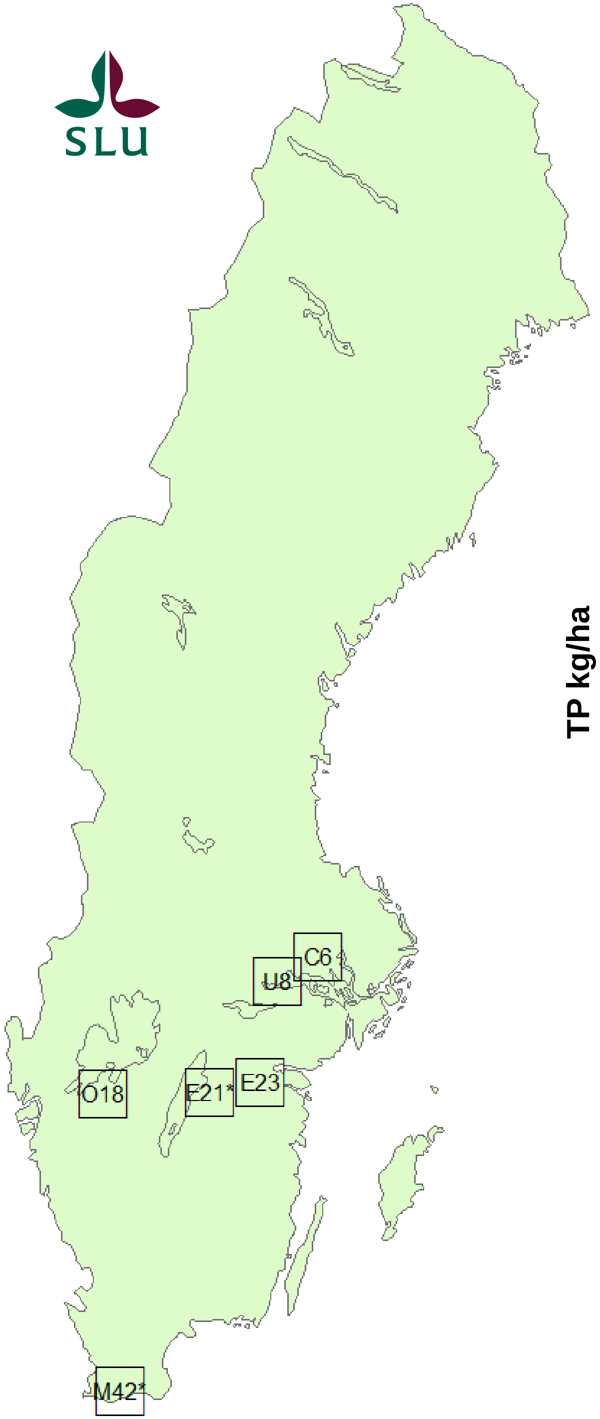

Catchment/ Field ID	Area (ha)	Arable land (%)	Dominant soil texture class (USDA)	Precip. (mm)	Temp. (^{0}C)	Runoff (mm)	TP (mgL^{-1})
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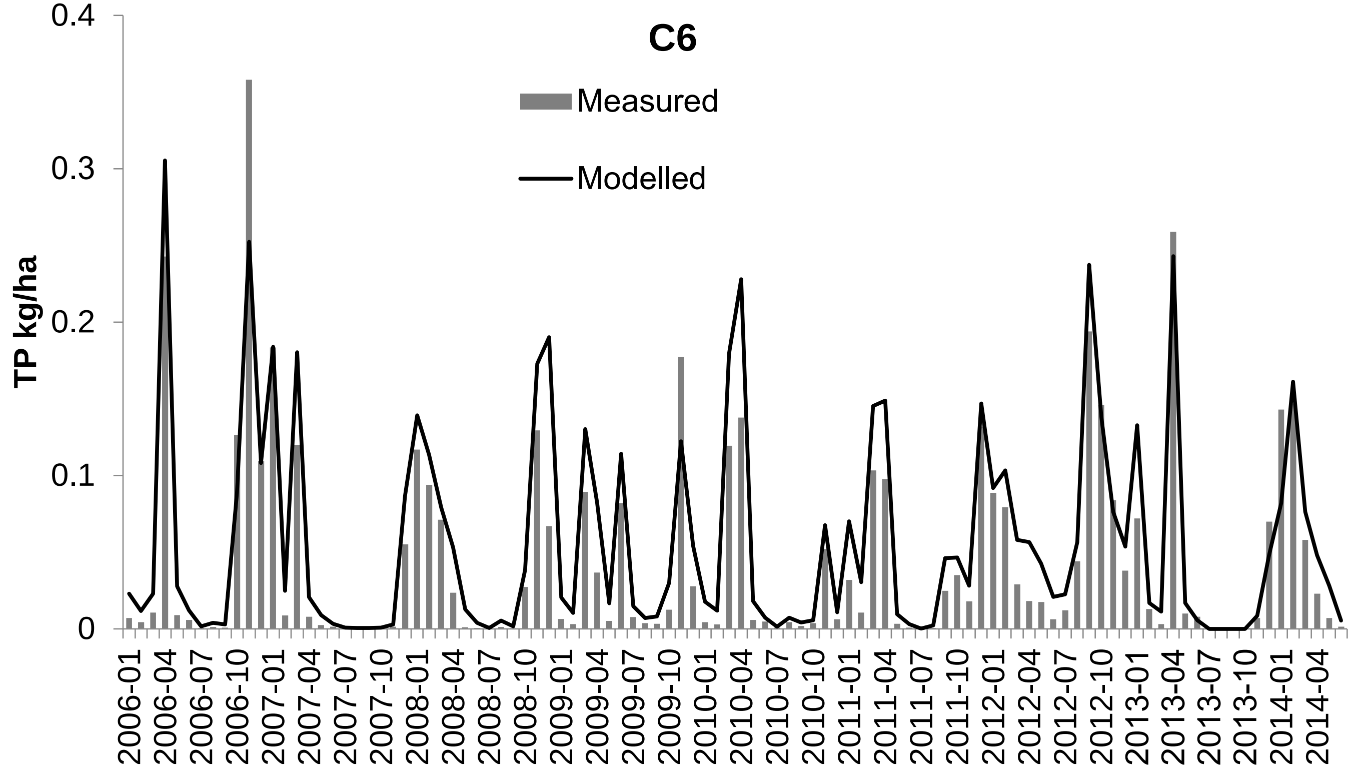
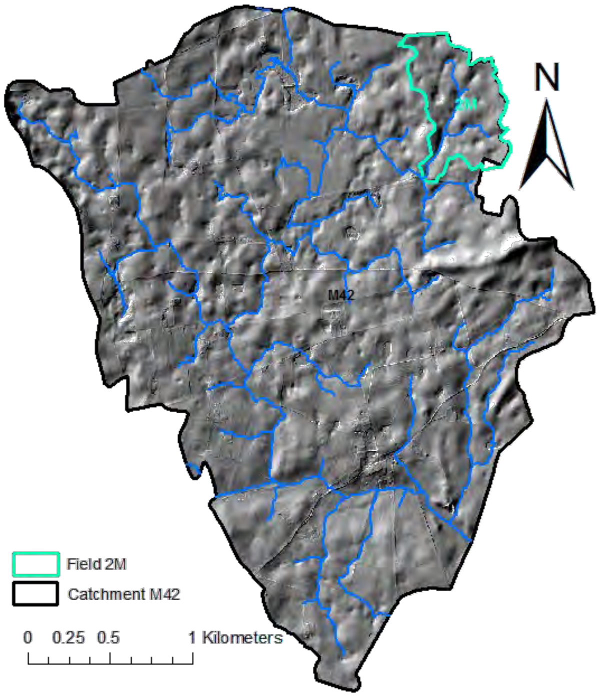
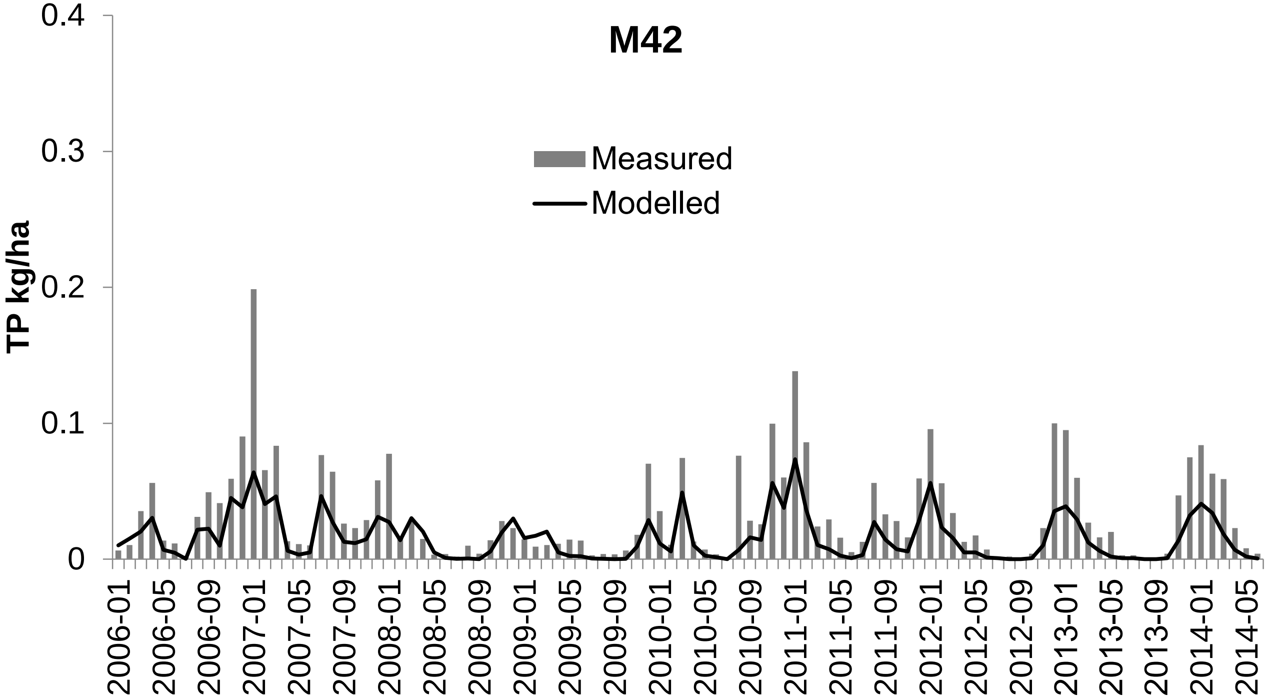


Catchment/ Field ID	R^2	Nash–Sutcliffe	MOD/OBS (%)	TP (mgL^{-1})
C6	0.85	0.80	127	0.21

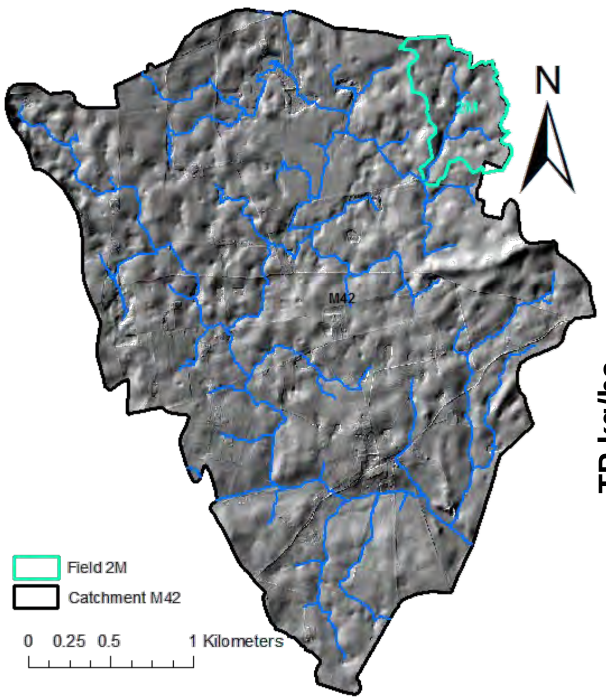
Catchment/ Field ID	Area (ha)	Arable land (%)	Dominant soil texture class (USDA)	Precip. (mm)	Temp. (°C)	Runoff (mm)	TP (mgL^{-1})
M42	820	93	Sandy loam, loam	709	7.7	282	0.15
Field 2M	33.8	100	Loam	650	7.7	234	0.10

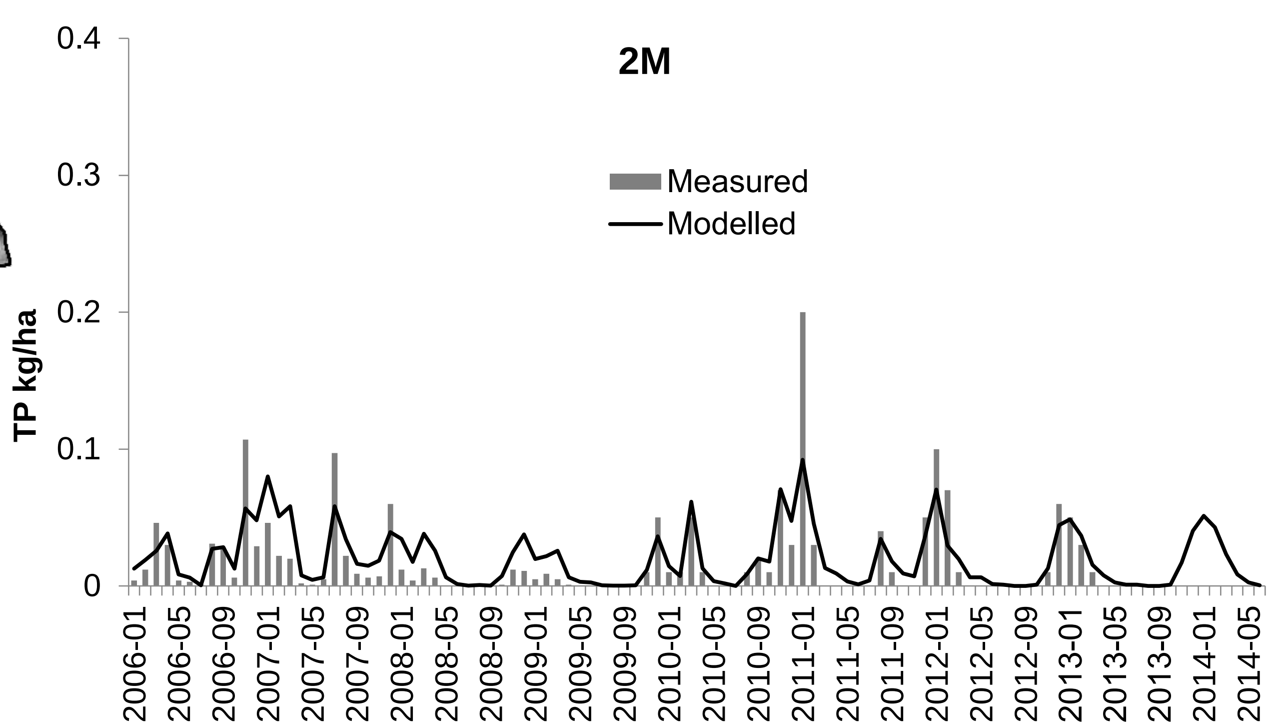




Catchment/ Field ID	R^2	Nash–Sutcliffe	MOD/OBS (%)	TP (mgL^{-1})
M42	0.81	0.38	48	0.15

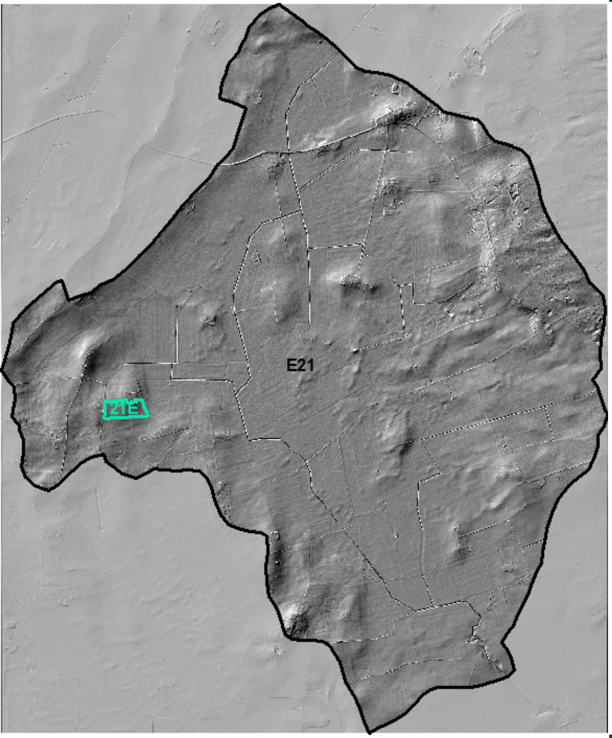
Catchment/ Field ID	Area (ha)	Arable land (%)	Dominant soil texture class (USDA)	Precip. (mm)	Temp. (°C)	Runoff (mm)	TP (mgL⁻¹)
M42	820	93	Sandy loam, loam	709	7.7	282	0.15
Field 2M	33.8	100	Loam	650	7.7	234	0.10

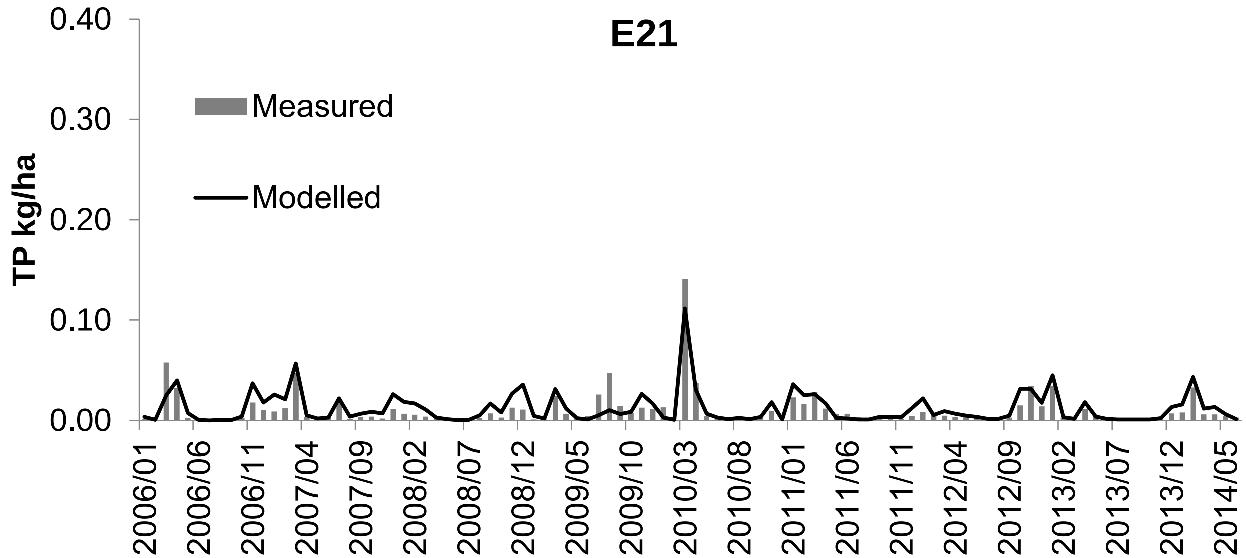




Catchment/ Field ID	R^2	Nash–Sutcliffe	MOD/OBS (%)	TP (mgL⁻¹)
2M	0.68	0.65	113	0.10

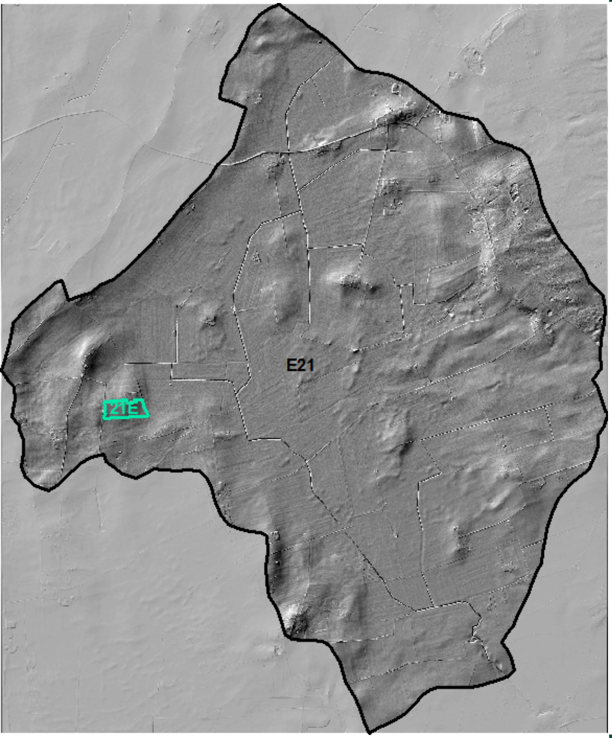
Catchment/ Field ID	Area (ha)	Arable land (%)	Dominant soil texture class (USDA)	Precip. (mm)	Temp. (^{0}C)	Runoff (mm)	TP (mgL^{-1})
E21	1630	89	**Sandy loam**	506	6.0	157	0.06
Field 21E	**4.4**	100	Sandy loam	500	6.0	**123**	**0.01**

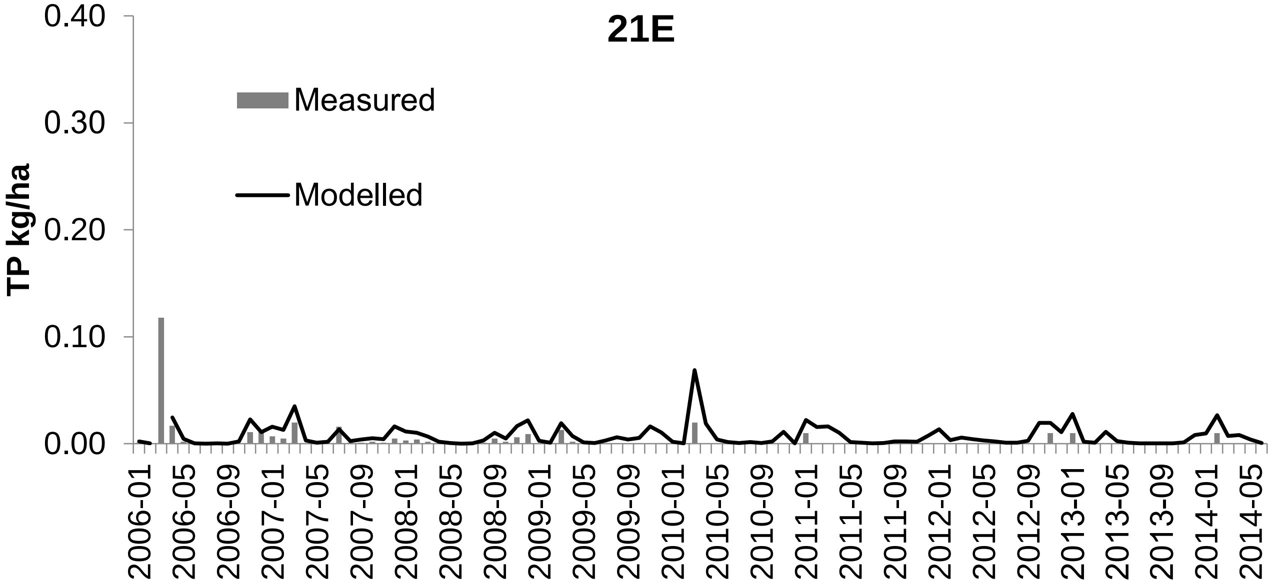




Catchment/ Field ID	R^2	Nash–Sutcliffe	MOD/OBS (%)	TP (mgL^{-1})	Comment
E21	0.74	0.73	122	0.06	

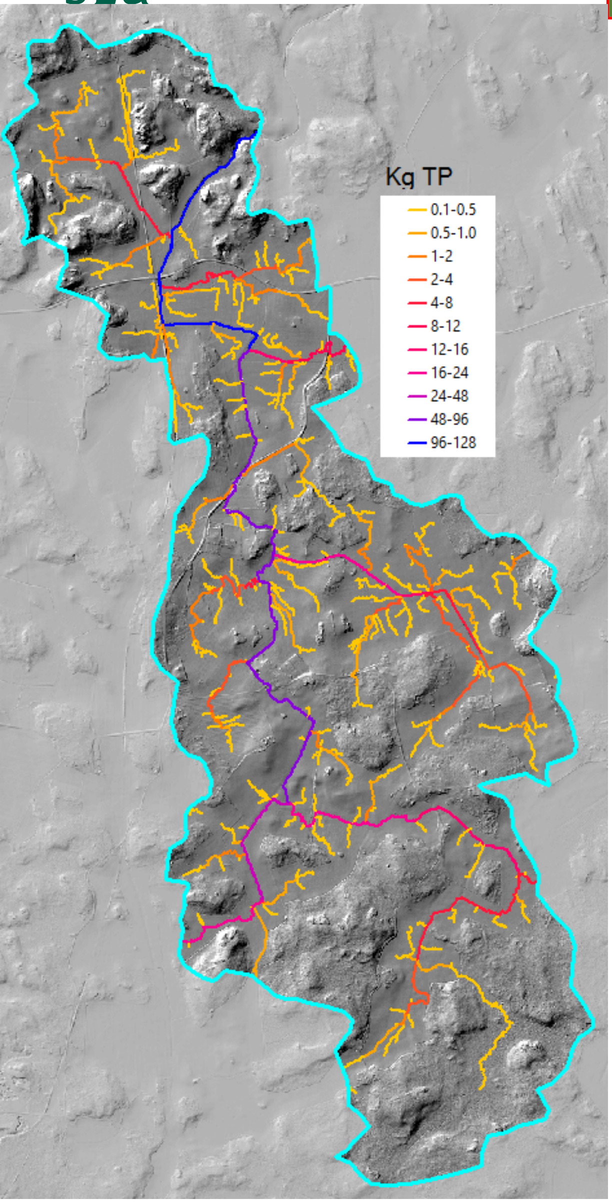
Catchment/ Field ID	Area (ha)	Arable land (%)	Dominant soil texture class (USDA)	Precip. (mm)	Temp. (^{0}C)	Runoff (mm)	TP (mgL^{-1})
E21	1630	89	Sandy loam	506	6.0	157	0.06
Field 21E	4.4	100	Sandy loam	500	6.0	123	0.01

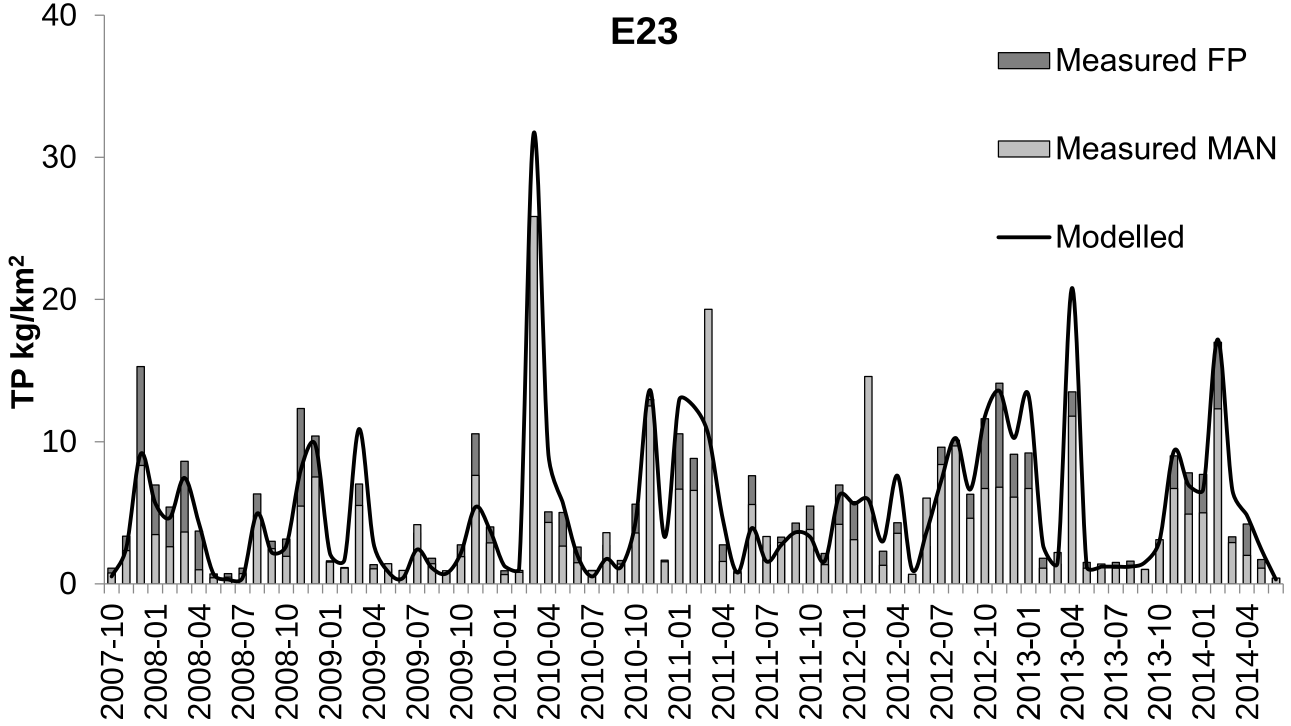




Catchment/ Field ID	R^2	Nash–Sutcliffe	MOD/OBS (%)	TP (mgL^{-1})	Comment
E21	0.74	0.73	122	0.06	
Field 21E	0.63	-0.39	228	0.01	Soil texture?

Catchment/ Field ID	Area (ha)	Arable land (%)	Dominant soil texture class (USDA)	Precip. (mm)	Temp. (°C)	Runoff (mm)	TP (mgL^{-1})
E23	740	54	Clay	594	6.3	181	0.28





Catchment/ Field ID	R^2	Nash–Sutcliffe	MOD/OBS (%)	TP (mgL^{-1})
E23	0.85	0.80	**103**	0.28

Possibilities and limitations

- Reliable separation of catchments with high and low nutrient losses
- Input data sensitive, especially at field level
- Visualisation of nutrient fluxes at landscape scale
- Risk for „the others should do it“
- Works quit well with fluxes/transports
- Concentrations?
- Tested for small catchments
- River basins? Need for retention calibration?
- Maps as communication tool with farmers and other stakeholders
- Not able to identify incidental losses / inappropriate field operations
- Optimal placement of countermeasures
- Calculate cost-efficiency and develop value-based subsidizes
- Do we have enough knowledge/data/tools for placement optimization and development of a value-based policy?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