Slutrapport

Farmer as water manager – right diagnosis, proper location, effective countermeasure!

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Del 1: Utförlig sammanfattning

I detta projekt har vi kombinerat den bästa tillgängliga information kring lokalspecifika topografiska, hydrologiska, edafiska, agronomiska förutsättningar och modelleringsresultat med lantbrukarnas egna erfarenheter, kunskaper och visioner för att ta fram platsspecifika åtgärder för att minska förluster av fosfor (P). Vi har kombinerat distribuerad, högupplöst modellering och beräkningar av P-budget på gårds- och fältnivå med mätningar av relevanta kemiska parametrar i marken, i vatten, och i det fluviala sedimentet. Sensorer som möjliggör högfrekventa mätningar av vattnets grumlighet som en approximation för P-förluster har använts för att få en bättre bild av förlusternas dynamik. Sambanden mellan vattnets grumlighet uppmät med sensorerna å ena sidan, och vattnet grumlighet, halt av suspenderat material, partikulärt P och total P uppmätta i laboratoriet i vattenprover har visat sig vara väldigt starka vilket gav oss en klar bild över korttidsvariationer i P-halter och transporter i tid, men även samspel mellan vattenstånd, vattnets konduktivitet som en indikation av vattnets ursprung (grund- eller ytvatten) och P förlusterna. Passiva provtagare har använts för att fånga tidsintegrerade förluster av löst P (fosfat) och nitrat i dräneringsbrunnar samt fluvialt sediment i öppna diket. Förutom de vanliga agronomiska metoder att analysera P-halter i jordproverna har vi utfört extraktioner av P som används för miljömässiga bedömningar samt en kemisk P-fraktionering för att studera olika P-former i marken och i det fluviala sedimentet. Vi observerade att även moderata applikationer av stallgödsel kunde orsaka förhöjda N och P förluster i dräneringsvatten från sandiga jordar med relativt låg P-bindningskapacitet. Både de passiva provtagare och de högupplösta mätningarna visade att de högsta förlusterna av sediment och bundet P från lerjordsområden skedde under hösten. Den utförda P-fraktioneringen visade att de dominerande fraktionerna av P på det fluviala sedimentet var organiskt och järn bundet P. Projektet började med ett fokus på 16 Odling i Balans pilotgårdarna men en del av resultat kunde skalas upp för att täcka merpart av svensk åkermark. En första grov uppdelning i gårdar med styvare lerjordar sårbara mot snabbtransporter i form av ytavrinning, erosion och makroporflöde och lättare, sandiga jordar sårbara mot förluster av löst P kan vara berättigad. Då styrfaktorer bakom fosforförlusterna mellan dessa två grupper av gårdar är olika kan denna uppdelning hjälpa utformning av lämpliga åtgärdsplaner. Den höga variabiliteten i P-förlusterna kräver dock hänsynstagande till lokala förutsättningar för att optimera

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placering av motåtgärderna för att uppnå hög effektivitet. De framtagna högupplösta kartorna visade sig vara ett väldigt användbar underlag för diskussioner både kring möjliga orsaker till höga P-förlusterna och kring lämpliga motåtgärder. En korrekt identifiering av områden känsliga för förluster på högupplöst karta möjliggör både utveckling av en gemensam bild av problemen mellan lantbrukare, rådgivare, myndigheter och andra intressenter samt en fokusering av åtgärdsinsatserna där de gör mest nytta. Vi har visat att det finns en hög potential för förbättring av åtgärdernas effektivitet genom relativt enkla beräkningar av deras optimala placering i förhållande till läget i landskapet. Vidareutveckling av ett resultatbaserat stödsystem föreslås som ett effektivt sätt att minska kostnader och öka effekter av åtgärderna mot P-förlusterna.

Del 2: Rapporten (max 10 sidor)

Introduction

The majority (~80%) of phosphorus (P) losses originate from a small proportion of catchment area (~20%), a situation known as the 80:20 rule. These Critical Source Areas (CSAs) coincide with hydrologically active, interconnected areas where overland and/or shallow subsurface flow mobilize and transfer P from terrestrial to aquatic ecosystems. These CSAs are spatially variable over the watershed and even within individual fields, so different management levels are appropriate for different areas of the watershed/field. In spite of this extensive body of scientific evidence suggesting that P losses are episodic and spatially variable, current environment protection programs are designed and applied in a rather general way, without targeting the most vulnerable parts of the landscape. Advances in new remote sensing technologies and increased availability of high-resolution, accurate data can enable precise prediction and identification of hydrologically active areas.

In this project we further developed USPED model to make possible dynamic modelling and quantification of sediment and P transport. Beside high-resolution elevation data, we had also access to a better soil map of arable land in Sweden, based on the recently performed soil survey by Swedish Board of Agriculture (Paulsson, et al., 2015). The available high-resolution aerial and satellite images allows both a detailed mapping of the studied areas but can also be used to verify the results of for instance erosion modelling. Last but not least we have been able to acquire an insight in farmers' skills, knowledge and experience as well as willingness, ambition and creativity to target and develop site-specific countermeasures. Our strategy in this project was to consider all existing measures by farmer involvement, evaluate measures' placement, potential and functioning, and based on that create measurement programs and modelling scenarios to quantify effects and further optimize P abatement strategies.

Material and methods

The farms selected for the study were 16 demonstration farms included in the project Farming in Balance (FiB, http://www.odlingibalans.com/). These farms are located in arable areas of southern and central Sweden stretching from Skåne in the south to Dalarna in the north. The characteristics of each farm are summarised in Table 1. They cover a wide range of climate, edaphic, hydrological and production conditions. These particular farms within the FiB project are intended to serve as a bridge between research and practical farming, making them very suitable as study areas for the present analysis. Data on all fields and parcels belonging to each farm were downloaded as GIS vector layers from the Swedish Board of Agriculture database in the form of agricultural blocks. These blocks were then imported to Google Earth to create high-resolution images of each farm.

The project was implemented through 5 work packages:

- WP1. Collection and evaluation of existing data based on existing "Focus on Nutrients Phosphorus Strategy" and mapping of existing countermeasures
- WP2. Development and application of distributed, high-resolution modelling to identify CSA:s and quantify suspended sediment and P losses.
- WP3. Development of measurement programs for soil/water sampling and analyses, based on data evaluation from WP1 and results from high-resolution modelling in WP2
- WP4. Development of alternative scenarios with optimized placement of countermeasures, scenario modelling and up-scaling
- WP5. Development of a base for adaptive advisory services through improvements and updating of "FoN Phosphorus Strategy"

In **WP1**, All the existing relevant data and mapping of the existing countermeasures was collected by Farming in Balance and SLU. This data included topographic, hydrological, edaphic and agronomic conditions. The farmers own data (soil mapping, cultivation practices, existing countermeasures, crop statistics, fertilization practices and nutrient balances, status of field drainage etc...) was collected through farmer interviews and from existing farm documentation.

In WP2, modelling was performed for 16 farms included in Farming in balance project.

Table 1. Characteristics of the 16 farms included in this study.

Farm	County	Production	Area (ha)	Soil texture
Egonsborg	Skåne	Crop production	450	Sandy loam, sandy clay loam
Löderop	Skåne	Crop production, pig and beef	165	Loam, sandy loam
Norregård	Skåne	Crop production	90	Loam, sandy loam
Södervidinge	Halland	Crop production, vegetables	135	Loam, sandy loam
Västraby	Skåne	Crop production and dairy	650	Sandy clay loam, clay loam
Bottorp	Kalmar	Crop production, chickens	411	Sandy clay loam, clay loam
Stenastorp	Halland	Crop production	58	Sandy loam
Fårdala	Västra Götaland	Crop production and dairy	160	Sandy loam, loam
Badene	Västra Götaland	Crop production and pigs	237	Silty clay, clay
Broby	Östergötland	Crop production and hens	320	Sandy loam, clay loam
Bäcken	Västra Götaland	Crop production and pigs	670	Silty clay loam, silty clay
Hidinge	Örebro	Crop production and pigs	180	Silty clay, silty clay loam
Wiggeby	Stockholm	Crop production	600	Clay, clay loam
Hacksta	Uppsala	Crop production, grazing anim.	350	Clay, silty clay
Tisby	Uppsala	Crop production	168	Silty clay, clay
Hovgården	Dalarna	Crop production, pigs and beef	330	Silt loam, silt

The basis for the modelling work was a digital elevation model (DEM) in raster format. A 2-m grid based on LiDAR data was used, with a density of 0.5–1 point m^{-2} and accuracy usually better than 0.1 m (Lantmäteriet, 2014). The modified USPED model was implemented within a frame of PCRaster software for environmental modelling. In brief, USPED is a simple model which predicts the spatial distribution of erosion and deposition patterns based on the change in overland flow depth and the local geometry of terrain, including both profile and tangential curvatures. Thereafter, slope profile (ProfCurv) and tangential curvature (TanCurv) calculated from DEM were used to account for the effect of slope form on erosion and deposition patterns. Uniform, nose and convex linear slopes yield more sediment than concave linear and head slopes, where sediment is deposited on toe slopes. To account for these patterns, erosion/deposition (ED) was calculated as:

$$ED = R*LS*K*C*(1+ -1*ProfCurv)* (1+ -1* TanCurv)* 4$$

where R is erosivity factor (here average water discharge, mm), K is soil erodibility factor (t ha-1), C is vegetation cover factor and 4 is a scaling factor (equal to map resolution, 2x2 = 4 m^2).

In order to evaluate the modelling results, all farmers were first given a short introduction and examples of how to consider and report (describe and draw on the map) different types of CSAs, such as frequent overland flow pathways, erosion channels and routes, frequent occurrence of flooding and ponding water on the fields, inadequate drainage and compacted soils. All observations drawn on maps by farmers were thereafter digitised for comparison with the modelled values.

Although the high resolution erosion maps have been developed, the corresponding tools for P losses are still lacking. In the national pollution load compilations, P export coefficients are calculated using field-scale ICECREAMDB model for the 22 regions in Sweden, 15 crops, 10 soil textural classes and with consideration taken to field slope and soil P content. These export coefficients are thereafter used to estimate diffuse P loads from agriculture to surrounding seas, but the highest resolution of presented results of these calculations is sub-catchment level. In this project, we combined expert coefficient together with high-resolution elevation data, soil textural distribution and measured monthly flow to estimate P loads at scales varying from cell (2x2m) to field and catchment scale. The approach has been tested with dynamic modelling for 6 small agricultural catchments included in the water quality monitoring programs with available data on water flow and nutrient concentrations. In two of the catchments exists even monitoring results at one field within each catchment.

In **WP3**, collection, analyses and measurements of soil properties and water quality parameters was conducted to describe spatial and temporal variability of phosphorus losses. Each soil sample (10 cm deep) consisted of 15 soil cores collected from an area of 1 m^2. These soil samples were air-dried, gradually broken down by hand and sieved (<5 mm) before analysis with DESPRAL test and the content of plant-available P determined by extraction with ammonium lactate⁄acetic acid (P-AL) at pH 3.75 (Egnér, et al., 1960). The risk of sediment, dissolved and particle-bound P mobilisation was estimated with the DESPRAL test, performed as described by Withers et al. (2007), who shown that the results of the DESPRAL test correlated well (R^2 = 0.7–0.8) with the amounts of SS, total P and dissolved P in overland flow generated by indoor simulated rainfall. Suspended solids (SS), total P (TP) and dissolved P (DP) were determined in DESPRAL aliquots in accordance with methods issued by the European Committee for Standardization (European Committee for Standardization 1996). Suspended solids were determined by filtration through 0.2-μm pore membrane filters dried at 105 °C while turbidity, which is highly correlated to SS, was measured on post-dispersion aliquots using a Hach 2100AN instrument (Hach Company, CO) and expressed as nephelometric turbidity units (NTU). Total phosphorus was analysed as soluble molybdate-reactive P after digestion in acid persulphate solution, DP was determined on filtered samples (0.2-μm pore membrane filters) using Gallery Plus Photometric Analyzer Thermo Fisher. Unreactive P (UP) was calculated as the difference between TP and DP. Plant-available soil P, potassium (K), calcium (Ca) and magnesium (Mg) concentrations were determined by extraction with ammonium lactate⁄acetic acid (P-AL) at pH 3.75 (Egnér et al. 1960), which is the standard agronomic soil P test used in Sweden. The same extraction was also used to analyse iron (Fe) and aluminium (Al) as indicators of soil P sorption capacity (Ulén, 2006). For analyses of easily soluble P, soil samples were equilibrated with 0.01 m $CaCl_2$ (1:10 w⁄v), centrifuged at 503.1 g for 10 min and then filtered. The P sorption capacity of the soils was estimated by a singlepoint P sorption index (PSI [mmol kg^{-1} soil]) (Börling, et al., 2001). For this, 2 g of air-dried soil were equilibrated with 50 mmol P kg^{-1} soil in 20 mL 0.01 mol L^{-1} $CaCl_2$, and PSI was determined as:

$PSI = X/\log C$

where X is the amount of P sorbed by the soil (mmol P kg^{-1} soil), and C is the equilibrium P concentration in the solution (mmol P L^{-1}). Phosphorus was also extracted in 0.5 mol L^{-1} sodium bicarbonate at pH 8.5 (Olsen-P). Further, a sequential chemical extraction, P fractionation, was used to estimate different P pools in soil. The procedure begins with weak extractants, removing loosely bound P, and proceed stepwise toward stronger extractants. Here, we have used the sequential fractionation procedures to investigate the role of the most important binding partners of P, such as for instance Fe and Al, and their numerous oxides, hydroxides, and oxyhydroxides (Jan, et al., 2015).

High-frequency measurements of water turbidity were also performed as a proxy for the content of suspended material and P. Turbidity is a parameter that is cheap to measure and is easily

collected remotely as a "continuous" reading, and shows high correlation with others parameters, above all suspended solids and total P. Turbidity, as well as conductivity, temperature and water level was monitored every 15th minute during a time period of more than one year, at two FiB farms (Hacksta and Wiggeby). Monthly grab water samples were collected and analysed to establish correlations with turbidity. Total phosphorus was analysed as soluble molybdate-reactive P after digestion in acid persulphate solution, DP was determined on filtered samples (0.2-μm pore membrane filters) using Gallery Plus Photometric Analyzer Thermo Fisher. Unreactive P (UP) was calculated as the difference between TP and DP. Further, simple passive samplers were also tested and used. Firstly, two Philiphs samplers (Phillips, et al., 2000) were deployed for the time-integrated sampling of fluvial sediment at Wiggeby farm. Fluvial sediment samples were collected approximately every second month and different P pools in sediment were estimated according to same P fractionation procedure for the soils (Jan, et al., 2015). Secondly, at Löderup farm, dominated by sandy soils, passive samplers for measurements of nitrate and phosphate (De Jonge, 2007) were installed at 5 different drainage wells. The passive samplers were collected approximately every six weeks during one year.
In **WP4**, high-resolution distributed modelling was used to test possibilities to improve placement and thereby even cost-efficiency of the common agricultural countermeasures as riparian buffer strips, and constructed wetlands/P-ponds. We suggest use of high-resolution erosion maps in combination with soil clay content as guidance for the prioritisation of structural liming operations. Further, based on calculated flow accumulation lines, predicted surface runoff pathways and modelled transport of suspended sediment and P, we suggest placement of cost-effective buffer zones. Finally, through calculations of hydraulic and P load, optimal locations for wetlands and P-ponds of various sizes are proposed. While targeting of critical source areas and possible locations of mitigation options is done on sub-field scale, the performed modelling covers the whole catchments and river basins with a potential to national up-scaling.
In **WP5**, we were active on spreading the knowledge and results received in the project to the important stakeholders. We were part of a writing the scientific article with a review of use of decision support systems for phosphorus management around the globe. We also participated in workshops, conferences, meetings with farmers, municipalities, water authorities, catchment managers and other stakeholders.

Results and discussion

WP1 Nutrient balance method is used by the farmers in FiB to analyse the effects of fertilisation on yields and the soil P content status in the soil. The nutrient balance method is an relatively easy way to analyse the efficiency in fertilisation, by calculating input and output of phosphorous to the production. It is a fairly rough method but it gives an indication on P status and flows. However, to be more accurate, this budget method needs to be calculated on field scale rather than solely on farm level. It needs also to be done every year to be able to follow yearly changes.
WP2 Farmers listed and sketched a total of 128 problematic areas in their fields (Djodjic, et al., 2018). The average area of these areas was 1.8 ha, but with wide variations (range 0.024-35.3 ha), emphasising the spatial variability of these features in the landscape. Spatial comparison of observed and modelled features showed that the top 2% of all 2mx2m cells with the highest modelled erosion values intersected 109 of the 128 (85%) problem areas identified by farmers. While the study estimate of the high intersection between farmers' observations and modelled lines reported above is technically correct, it is however difficult to interpret it in terms of goodness of fit. Farmers used different symbols and sizes to illustrate CSAs. Therefore, while presenting the validity of the modelling results compared with farmers experience based observations in statistical terms might be weak, the following quotes give an indication of the farmers' own judgement of the goodness of fit;

“Modelling results are in very good agreement with my observation of ponded fields” (Västraby farm), “Model was accurate in identifying risk areas” (Hidinge farm), “Results from the model are useful in daily drift” (Bottorp farm), “Modelled maps are not lying” (Fårdala farm), “The modelled red lines are ‘dead on target’!” (Norregård farm).
The general impression was that the two separately conducted assessments were complementary and can be used to identify CSAs. Farmers’ observations can be used both to confirm/reject modelled results and to better delimit areas of visible impact. Modelling results which coincide well with farmers’ own observations and experience can strengthen farmers’ knowledge, motivate them to target their problem areas and give them valuable data support in discussions with authorities. More about this part of the project can be found in Djodjic et al., 2018.

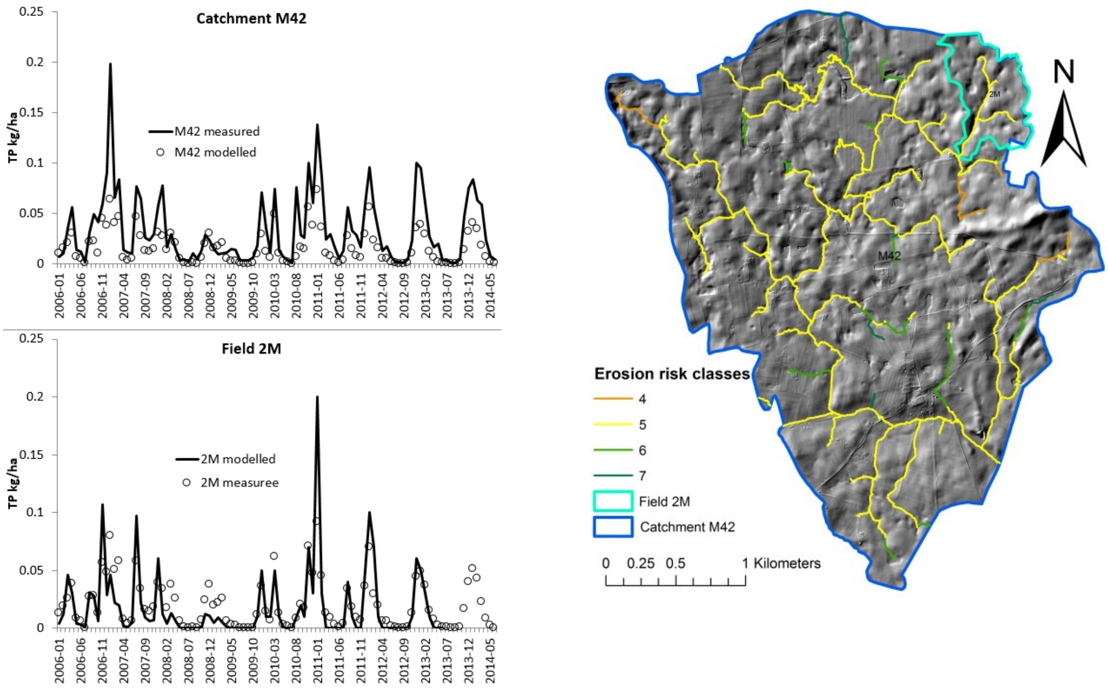

Figure 1. Measured and modelled loads of total phosphorus for catchment M42 and field 2M and a map showing fields location within the catchment.

The comparisons of dynamic modelling of P loads at field and catchment scale have shown satisfactory results and model was able to capture high variation between catchments. Calculated R^2 values between measured and modelled values of total phosphorus varied between 0.61 and 0.85, with a good agreement in dynamics. Figure 1 illustrates the comparison between modelled and measured loads of total phosphorus for two out of the 8 modelled objects, catchment M42 and an agricultural field situated in the north-eastern corner of the catchment. The six small agricultural catchments and 2 fields represent quite wide range of soil textures and are located from Skåne in the south to the Uppland in central Sweden. The promising results regarding good agreement with highly varying measured loads of total P for different catchments and fields, as well as good temporal dynamics and integration of field-to-catchment scales makes further development of this approach highly interesting for possible applications for quantifications of phosphorus fluxes across the landscape and estimations of possible P reductions based on incoming concentrations and loads. An abstract regarding this work was submitted and is accepted for oral presentation at Catchment Science Conference in Wexford, Ireland, in November 2019.

WP3 Assessment of the potential mobilisation of soil particles and particulate P with the DESPRAL test confirmed earlier results regarding the vulnerability of different soils to erosion

(Villa, 2014), with a rather clear pattern with lower levels of mobilised particles for lighter soils (loamy sand, sandy loam, sandy clay loam, loam). The UP concentrations showed a strong correlation with both turbidity and SS levels, meaning lower potential mobilisation of UP in lighter, sandy soils. The multiple regression showed that P-AL values affected the levels of potentially mobilised PP, but the UP levels were mainly dependent on the mobilisation of soil particles. Thus it is important to emphasise that the level of UP losses is controlled to a lower degree by soil P concentration and is more dependent on soil vulnerability to erosion. Although there is some overlap, the results of this project indicate two main groups of farms with differing opportunities for reducing P losses:

1. Farms with lighter, well-drained sandy soils. The main problem in this group is usually linked to P sources, with high P-AL levels in the soil and/or high animal density and manure application rates, which lead to high P losses, primarily in the form of DP. The main focus on such farms should be to optimise manure management and embrace "4R" nutrient management (right form, right time, right place, right amount (Sharpley, et al., 2015) to enable optimum fertilisation based on crop demands, thus eventually reducing high soil P-AL concentrations. Two key uncertainties for these farms are the lack of data on soil P binding capacity and the suitability of P-AL as a method for assessment of plant-available P and P release. Abatement options on these farms should focus on stepwise reduction of P-sources (optimised fertilisation, manure trade, cooperation with neighbours to reduce manure surpluses) and purification of water leaving the fields. Manure application should be performed under optimal conditions, followed quickly by incorporation. The question is whether ordinary wetlands and P sedimentation ponds would be effective, since they mainly reduce UP losses. General buffer strips and structure liming would have very limited effect in these soils and should not be recommended. Optimised buffer zones may be effective in relatively small parts of fields experiencing problems with surface runoff, erosion and flooding.
2. Farms with heavier soils with higher clay content. The main problem for this group is usually connected to P transport pathways, where the topography and poor drainage lead to overland flow and erosion, with UP as the main form of P. The main focus for these farms should be on identifying and addressing hydrologically active parts of the landscape. The lack of data on soil erosion vulnerability could be solved by DESPRAL analysis. Structure liming (amendment of quicklime or slaked lime to clay soils to improve soil stability, aggregate strength and porosity), optimised buffer zones, grassland farming, adjusted crop rotation and improved drainage are adequate measures for reducing UP losses in these cases. Wetlands and P dams may also reduce levels of UP in water leaving the farm. Well-functioning ditches between forest and arable land can help prevent water flowing from forest over to farmland and reduce runoff-driven mobilisation of P-rich small particles. It is important to know that high P losses can arise from hydrologically active parts of the landscape, even if the P content in the soil is low or moderate.

The average concentrations of nitrite N and phosphate P measured with Sorbisense passive samplers showed high and significant differences in five drainage wells (Figure 2). Especially two of the wells (No 8 and 9) had significantly higher concentrations of both nutrients whereas P concentrations were somewhat higher also for the well number 7. The consecutive analyses of soil samples showed that these three wells also had higher P release capacity measured by soil extraction with $CaCl_2$, Figure 2, but due to high variations within fields, none of the differences was significant. At the same time, soils draining to well no 7 had significantly ($p < 0.05$) higher P-AL content and P saturation degree, expressed as P-AL content divided by P sorption index (PAL/PSI, Figure 2). The explanation for higher values of P loss from wells 8 and 9 is possibly the application of the liquid slurry manure and not the soil properties. Higher losses of N from these two fields support this as well. Generally, all the samples taken from these fields have rather low P sorption capacity which emphasizes need for caution when applying fertilizer and manure. Further, the P fractionation of top and subsoil samples revealed that soil samples from field draining to the well 7 had significantly ($p<0.05$) higher content of mobile P (sum of dissolved and Fe-bound P) compared to other fields whereas soil samples from field draining to the well 7 had significantly ($p<0.0001$) higher content of organic P. The organic P content was also considerably higher in samples from field draining to the well number 8, but due to high variations the difference was not statistically significant.

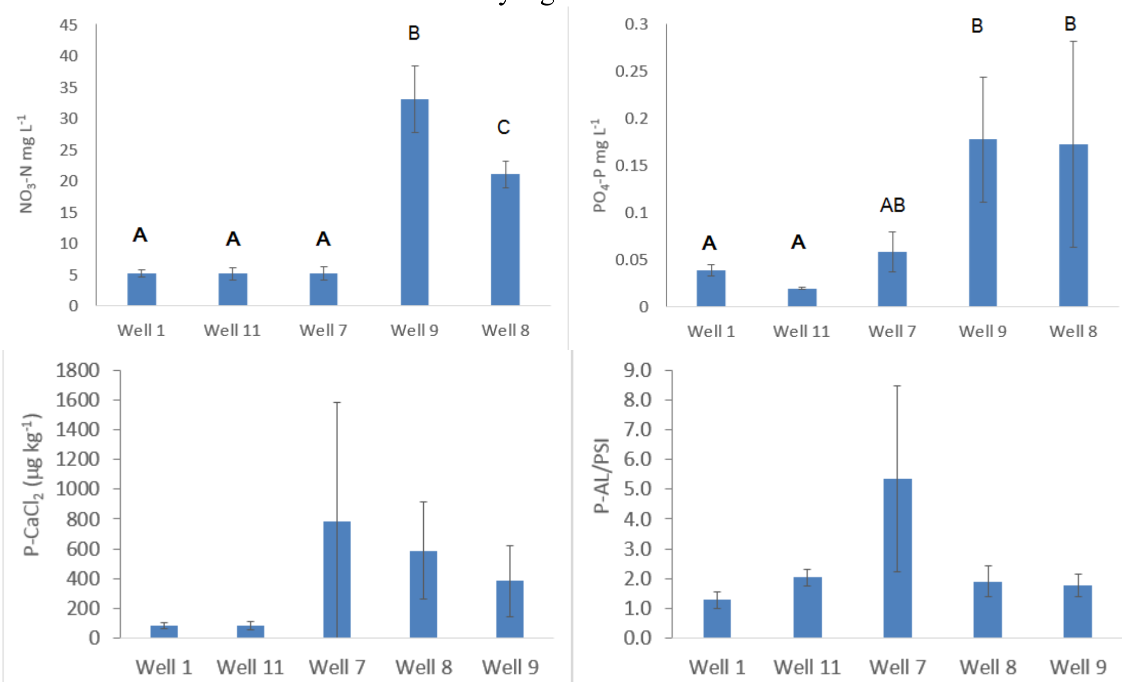

Figure 2. Average nitrate (upper left) and phosphate (upper right) concentrations measured in water collected with Sorbisense passive samplers in five wells at Löderup farms. Average readily soluble phosphorus (P-$CaCl_2$, lower left) content and degree of P saturation in soil samples originating from fields draining to the wells.

High-frequency measurements of water turbidity combined with manual grab samples and analyses of turbidity and concentrations of suspended sediment (SS) and different forms of phosphorus showed high correlation for some of the measured parameters, which can be used to increase our knowledge base regarding the dynamics of phosphorus losses. For instance, turbidity measured in water samples at Wiggeby and Hacksta farm were strongly and positively correlated to SS (R^2=0.99), PP (R^2=0.75 and 0.99) and TP (R^2=0.55 and 0.98). Similarly, PP (R^2=0.81 and 0.98 for Wiggeby and Hacksta, respectively) and TP (R^2=0.53 and 0.98 for Wiggeby and Hacksta, respectively) concentrations were strongly and positively correlated to SS. Somewhat higher correlation for Hacksta can be explained by higher proportion of TP consisting of PP, whereas concentrations of DP, with weak correlation to turbidity and SS, were higher at Wiggeby.

Analyses of high-frequency (15-minutes intervals) data revealed some interesting correlations between turbidity, water level and conductivity. Overall, turbidity was strongly and negatively (R^2=0.44, $p<0.005$) and strongly and positively (R^2=0.25, $p<0.005$) correlated to actual conductivity and water depth, respectively. However, much stronger correlation between turbidity and two explanatory variables, water depth and actual conductivity, was recorded during some episodes (Figure 3). The strongest correlation was recorded during the autumn months, when the variations in water depth, conductivity and turbidity were the strongest. Turbidity usually peaked before the water depth, indicating rapid mobilisation of the suspended sediment from the ditch bottom. As the water depth increased, the contribution of the surface water with low conductivity increased and the contribution of deeper groundwater with higher conductivity decreased leading to an overall decrease in conductivity. Increased contribution of surface water lead to an increased turbidity as well.

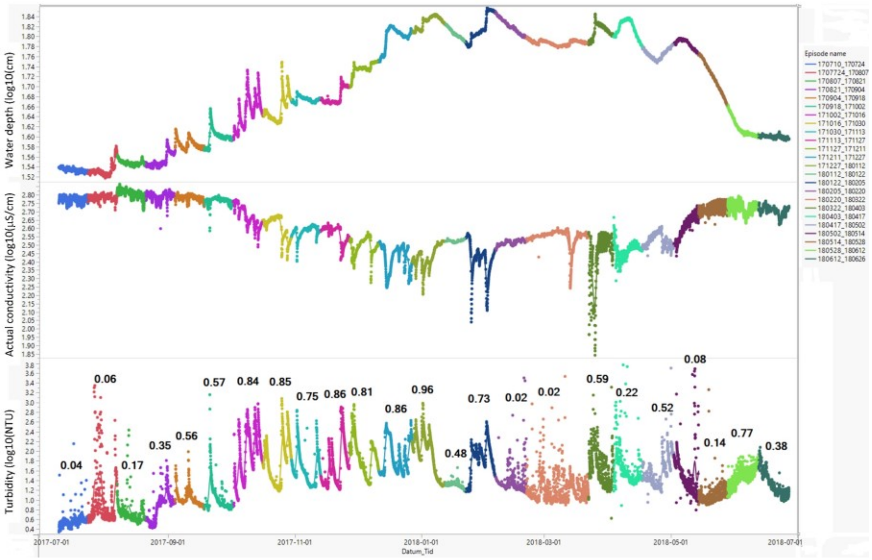

Figure 3. High resolution measurements of water depth, actual conductivity and turbidity in a ditch at Wiggeby farm.

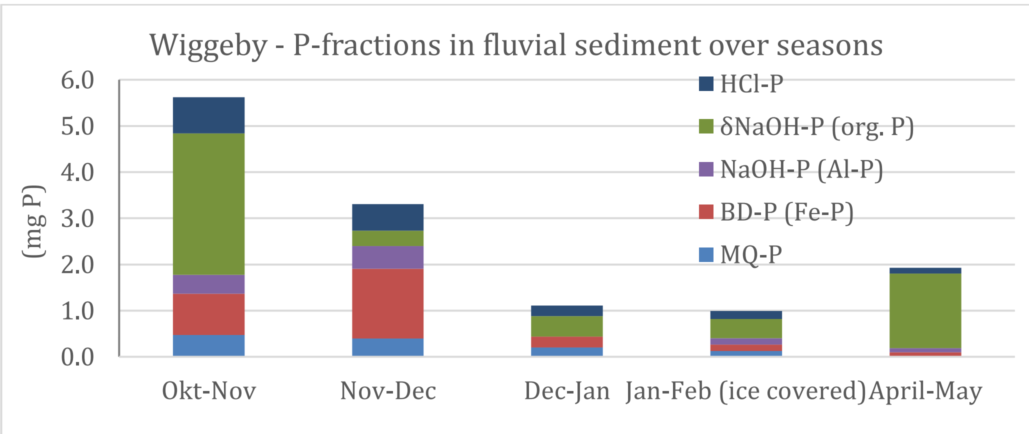

Figure 4. Phosphorus fractions in fluvial sediment.

Based on the results from analyses of fluvial sediment samples collected with Philip's samplers, most of the sediment-bound P was transported in autumn months. The performed P fractionation revealed that the organic and Fe-bound P were the largest fractions (Figure 4).

WP4 The high-resolution distributed modelling developed within a project has also been used in collaboration with the Swedish Board of Agriculture to produce erosion risk maps for the southern half of Sweden (Djodjic and Markensten, 2018), covering more than 90% of Swedish arable land. These results are made available to everyone through Swedish Board of Agriculture web page. We have also shown that the calculated losses of suspended sediment are reasonably in agreement with the measured values at both field and small catchment scale (Djodjic and Markensten, 2018). Further, the results of high resolution modelling was used to develop alternative scenarios regarding optimal placement of certain countermeasures, such as wetlands, P dams and buffer strips. The results show that there is a large potential in to increase cost-efficiency of the countermeasures by optimisation of their size and location (Figure 5) in relation to the volumes and P concentrations of incoming water (Djodjic, et al., 2019).

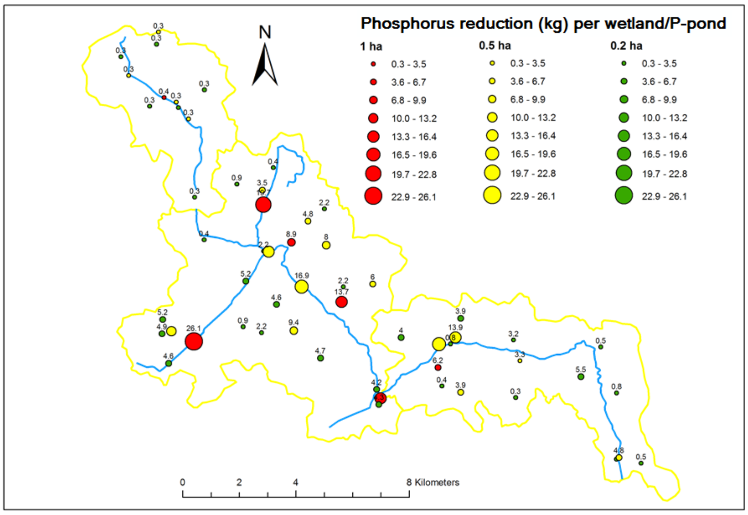

Figure 5. Suggested optimal placement of wetlands (0.2, 0.5 and 1 ha large) and modelled phosphorus reduction

Finally, in **WP5** we were active in result dissemination both nationally and internationally as we strongly believe that our results are useful to advisory services. The results were presented for instance at Farming in balance annual seminar gathering over 100 representatives from the farmer community, authorities, Swedish farmer organization and the research community. Additionally, the results were presented to the Catchment managers (April 2019) in a recently started project by The Swedish Marine and Water Authority with a goal that appointed Catchment Managers improve mitigation programs to reduce eutrophication, involving 20 catchments and catchment managers across Sweden. Further, we participated in the review article on P management decision support in agriculture, where we contributed with a Swedish part (Drohan, et al., 2019). The knowledge and methods gained in the project were also applied to improve calculations of the potential and effect of countermeasures (Aronsson, et al., 2019), with an active discussion with the water authorities regarding the upscaling of the suggested calculations.

Conclusions

- Distributed, high resolution modelling of erosion and P losses is a powerful tool in the process of identification of critical source areas
- The high mobilisation of soil particles may overrun the importance of soil P content meaning that high P losses may occur even in fields with low to moderate soil P content
- In sandy soils with lower particle mobilisation, soil P content and soil sorption capacity may be main factors governing P losses
- Annual P budget on field scale is a rough but helpful method to analyse the P fertilisation strategy
- Distributed high-resolution modelling can be used to optimize the proper placement of certain countermeasures to increase their efficiency
- High-resolution measurements of turbidity as a proxy for P losses can contribute to our process understanding
- Organic- and iron-bound P are the major P fractions on fluvial sediment from a clay dominated catchment in central Sweden

Benefits and recommendations

Based on the knowledge and model development within this project, we have produced erosion risk maps covering more than 90% of Swedish arable land. Swedish Board of Agriculture has now made these maps available for public at:

http://www.jordbruksverket.se/amnesomraden/miljoklimat/miljoutvarderingarforsokochutveckling/kartormedinformationomsvenskakermark/laddanedkartoromerosion.4.21625ee16a16bf0cc0a06cf.html. We have been, and still are, active in presenting the results of this project at workshops and seminars involving farmers, authorities and scientific community. It is, for now, difficult to predict the needs of support for the final users (farmers and advisory services) but we have already supported both catchment managers and water authorities in the early phases of their work. In parallel, further development of the model applications will take place in LIFE IP project Rich Waters and WATERDRIVE, in close collaboration with farmers, municipal authorities and Swedish Board of Agriculture.

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Del 3: Resultatförmedling

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	Distributed sub-field erosion modelling for the southern half of Sweden. F Djodjic, H Markensten. EGU General Assembly Conference Abstracts 20, 2758, Wienna 2018.
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	Focus on Nutrients webpage with information about research projects and results (http://www.greppa.nu/arkiv/nyhetsarkiv/2017-09-19-viktigt-ta-vara-pa-lantbrukarnas-kunskap-omfosfor.html).
	Focus on Nutrients webpage with information about the potential and effects of different countermeasures http://greppa.nu/arkiv/nyhetsarkiv/2019-10-08-slu-har-granskat-atgarderna-i-eus-vattendirektiv.html
Muntlig kommunikation	Tailored seminars/courses on P management and mitigation for farmers and extension workers in Kalmar (December 2017) and Visby (December 2018, https://www.lansstyrelsen.se/gotland/kalenderhandelser--gotland/2018-11-23-hur-greppar-vi-naringen.html), organized by County Administration Boards.
	Focus on Nutrients one-day course "Focus on phosphorus" (February 2017, http://adm.greppa.nu/kurser/kursdokumentation/kurser-2017/fosfor-i-fokus.html).
	Farming in balance annual seminar (January 2019) with focus on P in balance. Gathering over 100 representatives from the farmer community, authorities, Swedish farmer organization and the research community, these events are very effective not only to reach those attending the seminar, but also branch journalists and even broader audience (https://www.odlingibalans.com/temadagar-seminarium%C3%A5rsm%C3%B6ten/temadag-17-jan-19-38643962).

	Seminar talks on P management for the Catchment managers (April 2019). The Swedish Marine and Water Authority started a project with Catchment Managers to improve mitigation programs to reduce eutrophication, involving 20 catchments across Sweden.
Övrigt	Lectures on identification of Critical Source Areas and phosphorus abatement strategies are an integral part of the SLU course "Land use and watershed management to reduce eutrophication"
	Based on the model development within this project, high-resolution risk maps of erosion were modelled for three southern water districts and Dalälvens catchment. This maps are now publicly available through the Swedish Board of Agriculture website: http://www.jordbruksverket.se/amnesomraden/miljoklimat/miljoutvarderingarforsokochutveckling/kartormedinformationomsvenskakermark/laddanedkartoromerosion.4.21625ee16a16bf0cc0a06cf.html?fbclid=IwAR1Vg2ZBXykTGTJ2CZ6utOoo7ClRuWETYs0iw_gQwZcxTgpHFI1_hhx-UzI