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Risk mapping of phosphorus leakage -

Improved method using a Digital Elevation Model

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Risk mapping of phosphorus leakage- Improved method using a Digital Elevation Model
Riskkartering av fosforförluster- en utvecklad metod med tillämpning av digital höjdmodell
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Front page: Standing water after snowmelt in a natural sink in a field at Fru Alstad catchment.
Photo: Hanna Ekström, March 2018

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Bachelor thesis, 15 credits, in *Physical Geography and Ecosystem Science*

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Foreword

This bachelor thesis in Physical Geography and Ecosystem Science has been written in cooperation with Ekologgruppen, with data from Sege river project. First of all, thank you to my supervisor at the Department of Physical Geography and Ecosystem Science, Harry Lankreijer, for discussions, support and inputs along the way. Thank you, Torbjörn Davidsson, Ekologgruppen for your enthusiasm for this project and for answers to all the questions. Apart from my supervisors, Andreas Persson has contributed with very useful ideas.

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Abstract

Eutrophication is an ongoing problem in the Baltic Sea and is therefore found as a topic of the Baltic Sea Action Plan as well as the environmental goals of Sweden. One source to eutrophication is the leakage of phosphorus from agricultural lands. This study was aimed to map risk areas of phosphorus leakage from surface runoff in a catchment located in the southern parts of Sege river, Scania. The process of mapping risk areas was carried out both with and without preprocessing a digital elevation model by filling sinks and the outcome of the two methods was compared against each other. Flows of clay rich sediment in and out of a sedimentation dam located in the study area was compared with climate data over a period of 4 months. The results indicate that highest risk of surface runoff erosion is in an area in the south, where clay content is 35-40 % and the topography highly varying with several natural depressions. The origin of clay rich sediments from surface runoff erosion was best shown by analysis on a filled digital elevation model. Correlation values of single climate parameters with measured phosphorus leakage were weak but indicate that the risk periods may be best described by the combined effect from several parameters.

Key words: *surface runoff, erosion, phosphorus leakage, agriculture, sinks*

Populärvetenskaplig sammanfattning

Övergödning är ett pågående problem i Östersjön och tas upp i bland annat the Baltic Sea Action Plan och inom ramen för Sveriges miljömål. Övergödningen beror på tillförsel av näringsämnen som kväve och fosfor, vilka når havet från flera olika källor. Dels från punktkällor som industriutsläpp och dels från mer diffusa källor som förbränning av fossila bränslen, skogsbruk och jordbruk. Från jordbruksmark är det överskott av gödning som delvis läcker från marken på grund av vattenerosion genom ytavrinning. I vattenmiljöer fungerar fosfor som en begränsande faktor för tillväxt av organismer. Att minska läckaget av fosfor till åar och sjöar är därför en effektiv metod för att minska övergödningen i stort.

Ett projekt där det aktivt arbetas med att minska risken för övergödning är Segeå-projektet, där sju kommuner i sydvästra Skåne samarbetar för att förbättra vattenkvaliteten i ån och dess avrinningsområde. Denna studie fokuserar på ett delavrinningsområde till Segeå som heter Fru Alstad och ligger i Trelleborgs kommun. I en anlagd damm i området gör miljökonsultföretaget Ekologgruppen mätningar av bland annat kväve och fosforhalter i vattnet. Dessa mätningar visar att det periodvis förekommer höga halter av ler- och fosforrika sediment i dammen. Om man vet var och när dessa sediment eroderar från åkermarken är det lättare att planera rätt åtgärder för minskade fosforförluster.

En riskkartering av fosforförluster genom ytavrinning har därför genomförts i denna studie. Metoden för att identifiera riskområden, som ursprungligen utvecklats av Ekologgruppen, bygger på en digital höjdmodell som innehåller sänkor. Sänkorna kan vara naturliga eller bara existera i den digitala höjdmodellen till följd av mätfel. En jämförelse har gjorts mellan två varianter av denna metod för att undersöka effekten på slutgiltiga riskområden av att använda höjdmodellen som den är eller digitalt fylla sänkor till närliggande nivå. Genom dessa två varianter av samma ursprungliga höjdmodell har områden för höga vattenflöden lokaliserats och dessa bildar, tillsammans med områden med hög lerhalt, riskområden för fosforförluster genom ytavrinning och erosion. Dessutom har uppmätta värden av fosforförluster jämförts med väderförhållanden under en period från december 2017-april 2018.

Resultaten visar att avrinningsområdet har högst lerhalt i den västra och södra delen, där också höga vattenflöden ansamlas. Dessutom finns ett område i öster som har höga vattenflöden, men mindre lerhalt och därför relativt mindre risk för förlust av fosfor via ytavrinning. Dessa områden var bäst identifierade när analysen utfördes på en höjdmodell med fyllda sänkor. Fosforläckaget var som mest i början på januari och mars, samtidigt som medeltemperaturen var över 0°C och regnmängderna stora. Statistiskt sett visades dock svaga samband mellan de enskilda väderparametrarna och fosforläckage. Resultaten pekar dock på att regn, temperatur och snösmältning samverkar och tillsammans skulle kunna förklara vilka perioder som har högst risk för fosforförluster via ytavrinning.

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1.Introduction

Eutrophication has for a long time been known as a threat against the Baltic Sea (Teutschbein et al. 2017). A large portion of the eutrophication has its origins in leakage of nutrients from agricultural lands (Naturvårdsverket 2006), and phosphorus leakage is here of special concern. Within Sege river catchment in southern Scania, Sweden, seven municipalities cooperate through the Sege river project, with the aim to improve the water quality of the catchment and reduce the eutrophication. This is mainly done by establishing wetlands and dams to catch the leaking phosphorus and nitrogen from cultivated lands. Water bodies like these can catch both the phosphate transported as solutes in the water, and the particle bound phosphorus that travels with the sediments. When the speed of the water is reduced by the dam, the particles sediment and can be taken up by vegetation before they are transported away (Alström and Wedding 2013).

The practical work in the catchment of Sege river is being monitored by Ekologgruppen. Within other catchments, it has been found out that predictions of surface runoff and mapping of risk areas of erosion by surface runoff can be an important step towards better understanding of how to best prevent leakage of phosphorus and nitrogen through water induced processes. Wind induced erosion is another process that globally has an important influence on transportation of soil particles (Eriksson et al. 2005). This study is however limited to water erosion. It has a specific purpose to contribute to the preventive eutrophication work done by Ekologgruppen in the study area. It has also a more general purpose, to examine the method used for risk mapping of phosphorus leakage, as described in the following section.

1.1 Aim

Because of the high amounts of phosphorus and clay rich sediments that are reaching the dam in Fru Alstad catchment, it is of interest to investigate from where and when the risk of surface runoff erosion is highest. This study thus aims to answer the question: from where and when does surface runoff erosion occur within the Fru Alstad drainage area? This will be done through the three following specific objectives:

I. Map the risk areas of surface runoff erosion affecting phosphorus leakage in Fru Alstad.
II. Compare the risk areas identified in a Geographic Information System when using an original digital elevation model, compared to a preprocessed model where sinks have been filled.
III. Correlate data of phosphorus leakage from the catchment with recorded weather data from the same time period.

1.2 Expected results

In the following section the processes affecting surface runoff erosion and phosphorus leakage will be further developed, as well as the background for the methodology used in this study. It is expected that:

- a filled DEM will most accurately identify the risk areas

- risk periods for sediment and phosphorus leakage will be controlled by heavy precipitation and snow melt

2. Background

2.1 Eutrophication: causes and consequences

Eutrophication of the Baltic Sea is happening as a result of over fertilization from nitrogen and phosphorus (Naturvårdsverket 2006). The nutrients are added to the aquatic ecosystems from atmospheric deposition of fossil fuel combustion, point sources such as industries and non-point anthropogenic sources such as agriculture (Chislock et al. 2013).

The consequences for the Baltic ecosystems are several, from large scale algal blooms of cyanobacteria, anoxic dead zones on the bottom, changes in food chains which affect the marine ecology and to the disappearance of important key species such as eelgrass, *Zostera marina* in shallower waters (Naturvårdsverket 2006).

Efficient mitigation measures have been discussed, and countries around the Baltic Sea have mainly focused on the removal of nitrogen deposition (Naturvårdsverket 2006; Schindler et al. 2008) However, it has been indicated that eutrophication may be mitigated more efficiently by reduction of phosphorus. This is due to phosphorus being a limiting factor for primary production in aquatic ecosystems (Schindler et al. 2008).

2.2 Phosphorus

2.2.1 Phosphorus in soils

Phosphorus, P, is an essential element for living organisms required in the process of photosynthesis, breakdown of carbohydrates and energy transfer (Sharpley and Rekolainen 1997; Pagliari et al. 2017). It is highly reactive which means that it is very seldom found in its natural form but rather as orthophosphate ions: HPO_4^{-2} or $H_2PO_4^-$ (Bergström et al. 2007). The presence and binding of P in soil is complex but can a little simplified be divided into three pools: the solution pool, the active pool and the fixed pool. The solution pool is relatively small and consists of the phosphorus available for plants as orthophosphate ions in the soil water. These are the simplest structured phosphorus acids. (Sharpley and Rekolainen 1997). The plants take up the orthophosphate ions through an energy consuming active process, so when there are other energy consuming processes such as lower temperatures and lower amounts of soil moisture, the phosphorus uptake is limited (Mikkelsen 2013).The phosphorus bound to very stable chemical compounds constitutes the fixed pool. These compounds can be divided into organic and inorganic compounds. The inorganic is considered the major part in most agricultural soils (Sharpley and Rekolainen 1997). The active pool of phosphorus consists of bound phosphorus that more readily is released to the soil water. Hence, when phosphorus from the soil solution is taken up by plant roots, the equilibrium of phosphorus is adjusted by release of some phosphorus from the active pool (Pagliari et al. 2017).

Because of its important for plant development, phosphorus is classified as a macronutrient. In comparison with other nutrients important for plant growth, the content of phosphorus in Earth's crust and in mineral topsoils are relatively small. Out of that portion, phosphorus available to plants is even smaller (Sharpley and Rekolainen 1997). It is for this reason phosphorus is a common component of artificial fertilizers.

2.2.2 Agricultural lands and phosphorus

In the post-war era, from 1950's to 1970's, high amounts of phosphorus from artificial fertilizers were added to agricultural lands in Sweden. A decrease in artificial fertilizers has made the levels of total addition of phosphorus today being the same as 100 years ago (Eriksson et al. 2005; Bergström et al. 2007). The binding force between phosphorus and soil particles vary depending on chemical structure and pH of the soil (Eriksson et al. 2005). This means that although fertilization has decreased, phosphorus bound to the soil could still be relatively high but plant available phosphorus low (Eriksson et al. 2005),which leads to continued fertilization. Concentrated phosphorus in rocks, the source of P in fertilizers, are cycling at rates of millions of years between the hydrosphere and the lithosphere, therefore considered a finite resource. The estimated time for phosphorus reserves to last are varying, but there is a general agreement in the research community of a 'peak phosphorus', the point in time when the extraction of phosphorus as mineral resource has reach its maximum. The issue of phosphorus leakage is thus not only an issue of eutrophication but also about sustainable agriculture in the future (Cordell and White 2011; Johannesson 2015).

2.2.3 Transportation of phosphorus

When it comes to the leakage, or transportation, of phosphorus from the soils, it happens in two forms: as dissolved phosphorus and particulate phosphorus. In the water, dissolved phosphorus can be directly taken up by stream biota, whereas particulate phosphorus works as a long-term reserve of phosphorus in the aquatic ecosystems. Particulate phosphorus consists of organic matter eroded during storm events and the phosphorus bound to inorganic soil particles (Sharpley and Rekolainen 1997). It is the major portion of P transported from cultivated lands. The dissolved and particulate phosphorus are constantly altered along its way from the field to the water due to aquatic processes such as uptake of dissolved phosphorus by stream biota and deposition of suspended particulate phosphorus (ibid).

Regardless of whether the phosphorus is dissolved or bound to particles, the transportation of P from agricultural lands to streams can take three pathways, through:

a) Surface runoff, or overland flow. The rain water picks up phosphorus and carries it over the surface to a nearby stream. Increases where soil surface has low infiltration capacity.
b) Subsurface flow, or drainage, where infiltrated rain water containing P leaches to streams before reaching the groundwater table.
c) Groundwater flow, where infiltrated rain water percolates to the groundwater table and enters the stream as seepage (Heathwaite 1997).

In this study, the phosphorus transportation due to surface runoff (a) will be in focus. The highest risk of phosphorus transport from arable land is from the uncovered fields after harvest to the new growing season in spring, when there is now vegetation that take up the phosphorus and counteract the erosion. For arable land in the county of Scania, Swedish Board of Agriculture prescribes that 60 % of a farmers fields must be covered during winter, which includes autumn sowing and stubble fields (Swedish Board of Agriculture 2015). For uncovered soil, the intensity of precipitation and presence of water or snow during the season of late autumn to early spring has a large impact on the phosphorus loss (Puustinen et al. 2007).

2.3 Surface runoff and erosion

2.3.1 Surface runoff

As explained above, surface runoff is an important mechanism when it comes to transportation of phosphorus from agricultural lands to aquatic systems (Sharpley and Rekolainen 1997). Surface runoff occurs when rainfall rate exceeds the infiltration capacity of the soil, so called Hortonian overland flow, or in very wet conditions where the soil gets saturated from below, so called saturation overland flow (Rose 2004). The infiltration capacity of the soil is affected by soil texture and structure, soil porosity and soil moisture content (Pinheiro et al. 2009). Sand has the highest infiltration capacity and clay the lowest due to the larger pore spaces in sandy soils and due to the cohesion forces between the clay particles. Activities that affect the soil porosity such as trampling by cattle and compaction by heavy machines decreases the soil porosity and thus the infiltration capacity (Heathwaite 1997). Apart from low infiltration capacity, the subsurface drainage system through pipes in agricultural areas can be another source of surface runoff, if clogged with sediments for example. The resulting overland flow of water carries soil material to the streams, acting as a force of erosion (Alström and Bergman 1991).

2.3.2 Erosion

Erosion is a natural process of the geological circulation on Earth, where the surface of Earth is degraded and transported by wind or water to the streams and further out to the oceans. The transported minerals are being transported as solute ions in the water and the sediments and become the building parts of new rock types. On cultivated land however, the erosional process becomes a problem since the sediments transported away from the soils contain nutrients that are necessary for the vegetation (Eriksson et al. 2005).

Heavy rains and melting of snow can initiate the transport of sediments such as fine soil particles and organic matter to be eroded away from the soil. The surface runoff induced erosion can be of the type called sheet erosion, where a film like layer of water flushes the surface, see Figure 1. If the flow increases, the surface runoff can be concentrated to rill erosion, see Figure 2. The sediments gathered by sheet erosion are often transported away by the concentrated paths of rill erosion. In arable land in southern Sweden, rill erosion is considered the most affecting erosion type (Alström and Bergman 1991).

Figure 1: Effect of sheet erosion in field

Figure 2: Rill erosion following a depression in the landscape
Photo: Hanna Ekström

In depressions in the landscape where water is gathered, heavy water flows can lead to ephemeral gully erosion. Gully erosion is a type of erosion that moves in the opposite direction of the stream flow and is causing severe traces in humid climates. In Scandinavia these are less common, but temporary gullies can emerge after heavy spring or autumn rains and snow melt (Alström and Bergman 1991). Erosion through surface runoff depends on rainfall amounts and intensities, soil texture, topography and in the case of agricultural land, the management (Heathwaite 1997).

2.3.3 Soil types and erosion

Highest risk of erosion is found in soil textures that allow the particles to readily be released and transported away. Soils in the range from clay to coarse silt, with particle sizes <0.06 mm, are considered as cohesive soils which decrease the risk of erosion. Silt and loess with larger particle sizes are bound by the less strong adhesion forces and more easily erode. Clay soils can however have characteristics that increase the sediment erosion. If it is organic rich clay, aggregates increase the erodibility. The low infiltration capacity of clay soils also increases the risk of overland flow and hence the risk of phosphorus transport (Alström and Wedding 2013). Clay particles thus need higher water velocities to be released, but once they are, the small particles have large surface area for phosphorus binding. In nonmoving water, the larger sand particles have an average sedimentation rate of 10 seconds/m, while it takes 8 days/m for clay particles to sink (Alström and Wedding 2013). Hence, the clay particles have higher probability to follow the water flows to the surface water. Erosion from clay soils has thus higher risk of leading to phosphorus loss (Alström and Bergman 1991; Alström and Wedding 2013).

2.4 Digital analysis of surface runoff and erosion

2.4.1 Models for risk mapping of phosphorus loss

Research about phosphorus and its leakage from agricultural lands is extensive and several models with varying complexity exist for estimating risk of phosphorus loss from soils. Examples of these are a P-index developed with slightly different approaches in Denmark, Norway and Sweden respectively, and the erosion model Unit Stream Power Erosion Deposition, USPED (Alström and Wedding 2012; Ahlstrand 2014). For the purpose of practical work with maintenance and mitigation of phosphorus loss from cultivated lands, Ekologgruppen has developed a simple tool focused on estimation of risk areas for phosphorus loss due to surface runoff. Ekologgruppen's tool for surface runoff is based on the topography and soil type of the study area and excludes in the analysis step other influencing factors that are included in USPED such as precipitation intensity, the erodibility of the soil, agricultural methods and vegetation cover. These are still considered important for a complete understanding of the transport of phosphorus from agricultural lands and are, even if not incorporated in the model as such, taken into account in a later stage where field observations and local observations add information to the final map of risk areas. This has been found to be an efficient method with less required data compared to P-index method and USPED (Alström and Wedding 2013; Ahlstrand 2014). A comparison between Ekologgruppen's tool and USPED, indicated that the method by Ekologgruppen is giving a reliable estimation of surface runoff erosion of phosphorus, but parts of the digital processing have potential to be improved (Ahlstrand 2014). Therefore, this study focuses on the possible improvements within the tool developed by Ekologgruppen.

2.4.2 Ekologgruppen's tool for phosphorus loss from surface runoff

Ekologgruppen's tool is based on a digital elevation model combined with data and field observations of soil types and land use. It is a qualitative DEM method, meaning that the results will show where the areas of surface runoff are, but not the volume of rain or sediments that pass through the system (Ahlstrand 2014). The digital elevation model is used to calculate flow accumulation and the risk areas are based on the areas with 5 % of highest flow accumulation. The 5 % was developed from the Danish P-index calculations and in Ekologgruppen's method defined as corresponding with risk areas after a comparison with real areas of surface runoff erosion (Alström and Wedding 2013).

A digital elevation model contains depressions, from here on called sinks. They are single cells that have a lower elevation value than any of their surrounding cells. The sinks in the digital elevation model can either be existing depressions or appear in the model due to calculation errors (Nilsson 2017). In any case, the flow will stop at these locations. If they are natural sinks however, in reality rain water will drain to these areas and either pour over to adjacent areas when filled to the brim, or the water will percolate through the soil and reach the ground water table. For this reason, the possibility exists to fill the sinks. When filled, the simulated pathway of water will continue, and highest flow accumulation will be found in the lower part of the catchment. Ekologgruppen argue that for the purpose of finding sources of phosphorus leakage, regions located higher up in the drainage area are of interest, to catch the leakage as early as possible. Larger volumes of water further down in the system also requires larger sedimentation dams and mitigation measures that may not be reasonable to build in reality (Ahlstrand 2014).

Another way to think about it however is to see the filling of sinks as a simulation of the process that occurs when precipitation rate is exceeding infiltration rate so that the natural sinks are filled, and water continues as overland flow downstream. A digital elevation model is commonly used for identifying hydrological pathways in the landscape but has in most cases not a resolution that could be comparable to the particulate scale that phosphorus leakage is happening on (Sonneveld et al. 2006). It is therefore of interest to find the method that best simulate the real processes and it is hypothesized that filling the sinks could be one such improvement.

2.4.3 Estimation of flow accumulation

A digital elevation model represents the elevation above sea level in equally sized cells. It can be further analyzed in a GIS to estimate the steepest changes in elevation and thus the pathways of water in the landscape. The standard tool Flow direction in ArcGIS (ESRI ArcMap 10.5, Redland, California, US) is an efficient tool but as all models it gives a simplified version of reality and in this case, the simplification means that flow from one cell can only be lead to one other cell. In reality, for example on the top of a ridge, rainwater that falls on a certain spot will probably drain partly to one side of the ridge and partly to the other side (Nilsson 2017). This has been taken into account in the development of a Triangular form-based Multiple Flow algorithm, TFM (Pilesjö and Hasan 2014). As it is a more advanced and precise model of reality, the MATLAB routine (MATLAB R2017a, MathWorks, Natick, Massachusetts, US) will be incorporated in the analysis done in this study, further explained in the *Material and methodology* section below.

2.5 Study area

The study area is located in the southern part of Sege river catchment, a sub catchment in hilly terrain with the name Fru Alstad, Trelleborg municipality, see Figure 3. The 100 ha large area drains into a 0.3 ha large sedimentation dam built on former wetland area, with the purpose of gathering phosphorus (Ekologgruppen 2009). The drainage area is situated in an elongated clay rich depression between two ridges where the depressions and ridges are due to kettles, created by the retrieving glacial ice in the latest ice age, 110 000-10 000 years ago. These valleys are filled with lime rich till and the ridges are built up of sediments deposited by the melt water (Nilsson 1959). Because of this, the water in the present dam has often a high clay concentration and in the continuous measurements of inflow of water to the dam, peaks of sediments are reaching the dam (Davidsson, 2018, personal comment). A system of culverts is draining into the sedimentation dam, but water occurs in open ditches following the roads and between fields as well (Ekologgruppen 2009), however not large enough to be found as water streams on maps over the area, see Figure 3.

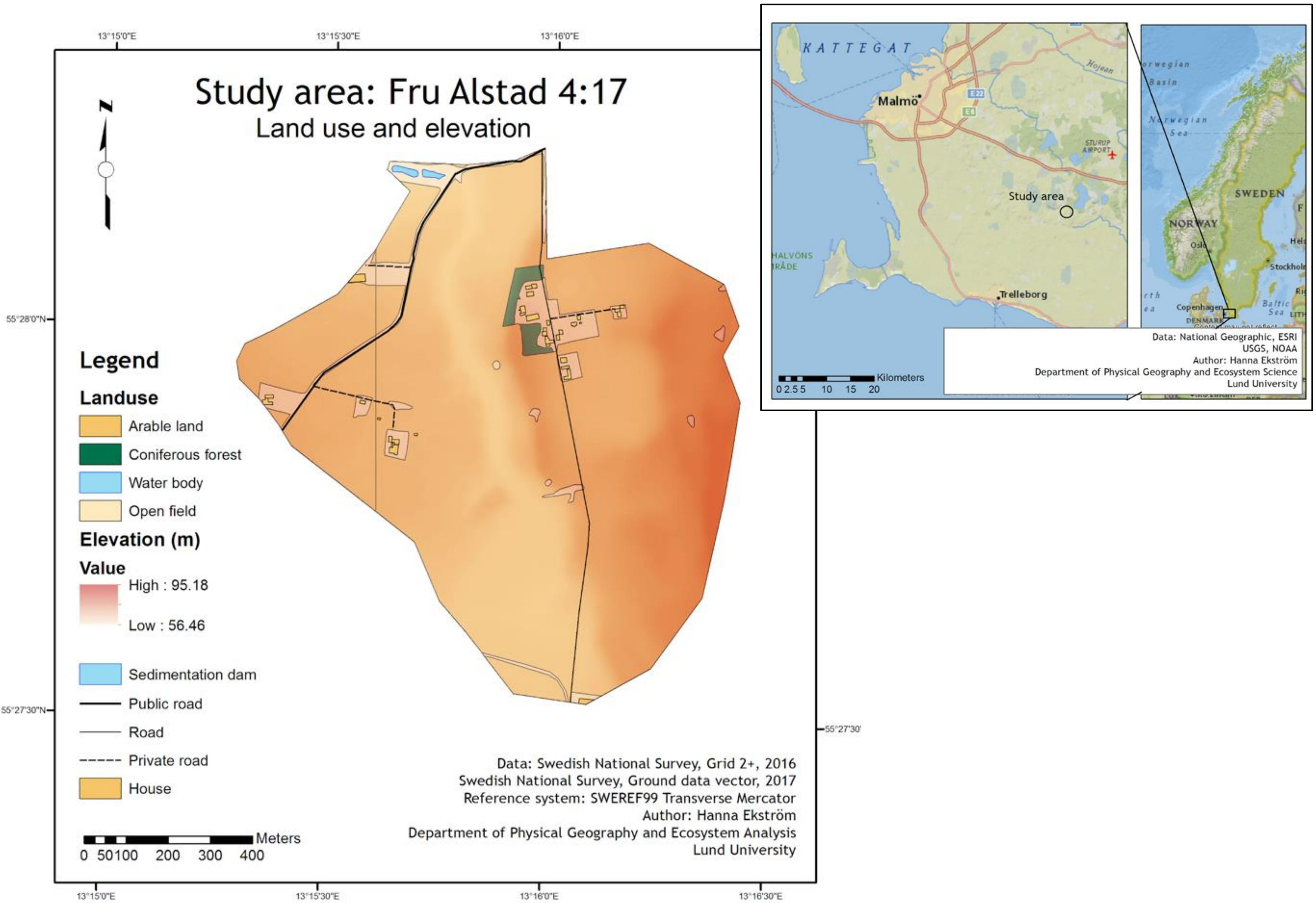

Figure 3: The study area of Fru Alstad is located in the municipality of Trelleborg in Scania, southern Sweden and characterized by hilly terrain caused by glacio-fluvial sediments.

The major part of the area is arable land and pasture by cows and horses is also practiced in the area. Soil types in the catchment area are silty clay loam, sandy loam, loam, clay and silt, following the FAO-soil classification(Söderström and Piikki 2016). The current water ecology status within Sege river catchment as a whole is classified as bad to unsatisfactory ecological quality (VISS 2018). Measurements for increased water quality includes the sedimentation dam in north west corner of the study area (Davidsson, 2018, personal comment).

3. Material and methodology

3.1 Material

Risk mapping of phosphorus leakage was done using a topography-based method. This section presents the data used for the analysis of risk areas and risk periods, see Table 1.

Table 1: Data with metadata and source.

Type of material	Metadata	Provider
Digital elevation model, DEM	Raster, 2+ grid, SWEREF99	© Swedish National Survey
Soil texture map	50 m, SWEREF99	© Swedish Geological Survey
Precipitation data	2017-2018, Skurup	SMHI
Temperature data	2017-2018, Skurup	SMHI
In- and outflow, Fru Alstad	2017-2018, Fru Alstad 4:17	Ekologgruppen

As the topography is a main component of the risk mapping method, a 2 m resolution digital elevation model was used (Swedish National Survey 2016). The soil data of soil texture contents in arable land in Sweden, retrieved from Swedish Geological Survey (Söderström and Piikki 2016) is based on modeled results with clay and sand content as primary raster layers. Soils classified as wetlands or organic soils were left outside the model and directly assigned organic soils. The standard deviation of the data within the location of the study area was reported to be 3.7 %, based on 208 reference points (Söderström and Piikki 2016). In the study area, only the soil in the sedimentation dam was marked as organic. Observational data of weather parameters were retrieved from the closest active weather station, in Skurup, about 20 km from the study area (SMHI 2018). Data retrieved was precipitation amounts, precipitation type, average daily temperature and snow depth. Ekologgruppen provided measured data of inflows from the catchment to the sedimentation dam (Davidsson, 2018, personal comment). Measurements of phosphorus were taken as a 50 ml water sample for every 100 m^3 of water passing the measurement station by the sedimentation dam. Within a sampling period of a week the gathered samples were mixed and analysed. The phosphorus measures are hence flow weighted average values for the sampling period (Davidsson, 2018, personal comment). Field observations included traces of erosion through surface erosion and location of natural sinks. For the data analysis, software used included MATLAB R2017a (MathWorks, Natick, Massachusetts, US), Microsoft Excel 2010 (Microsoft Corporation, Redmond, US) and ESRI ArcGIS 10.5 (ESRI, Redland, California, US).

3.2 Study design

To achieve the risk areas and the risk periods, the study can be divided in two main parts. Part one in the following section, *Risk areas for phosphorus*, describes the methodology developed by Ekologgruppen for risk mapping of phosphorus leakage through surface runoff (Alström and Wedding 2013). Part two, *Risk periods for phosphorus leakage*, describes the comparison between weather parameters assumed to affect the timing of sediment transport and phosphorus leakage from the catchment.

3.2.1 Risk areas for phosphorus leakage

The digital elevation model, see Table 1, was processed through the MATLAB routine developed by Pilesjö and Hasan (2014) in two versions, to a) identify and fill sinks b) not fill sinks. The two outcomes were used as input for generating flow accumulation in the same MATLAB routine, through the multiple flow algorithm as described in section 2.4.3. The retrieved flow accumulation from the filled and unfilled DEM respectively was further processed in Excel, to calculate the 5 % of areas with highest flow accumulation. The retrieved limit value of the highest flow accumulation was used in ArcGIS to localize risk areas of surface runoff depending on flow accumulation.

To get the final risk areas, the highest flow accumulation needed to be combined with the clay content of the soil. Based on soil texture data, the clay percentage in the catchment was retrieved. As higher clay content of a soil leads to higher risk of phosphorus leakage through surface runoff, clay content was divided into 5 classes, 16-20 % clay content, 21-25 %, 26-30%, 31-34% and 35-40%. All resulting risk areas have high flow accumulation but is classified as higher risk the more clay content there is. The risk mapping was complemented with visits in field, where location of sinks and traces of erosion and surface runoff where noted whenever observed, with coordinates in WGS84 from a handheld GPS.

3.2.2 Risk periods for phosphorus leakage

Based on data of weather parameters retrieved from SMHI, four different parameters were compared with leakage of phosphorus/phosphate measured in the sedimentation dam in Fru Alstad 4:17, retrieved from Ekologgruppen for the period of December 2017- March 2018.

Firstly, precipitation data was converted to weekly averages to correspond to the measured data of phosphorus leakage. The second parameter related to precipitation was the precipitation intensity. The precipitation intensity is a measure of the precipitation rate which if exceeds infiltration capacity of the soil is the reason for Hortonian overflow, as described in section *2.3 Surface runoff and erosion* (Rose 2004). Precipitation intensity is normally measured in mm/h, but has here been estimated based on data of precipitation type from SMHI (2018) since measured precipitation intensity data was not available. Precipitation types included light rain, rain, pouring rain, snow and snow hail. The precipitation types were assigned a category depending on their intensity, see Table 2**.** The categories aimed to describe the pressure on the soil that each precipitation type assert as a simulation of rainfall kinetic energy, which is commonly used parameter of soil erosion prediction (Lobo and Bonilla 2015).

Table 2: Categories of intensity, based on precipitation type data from SMHI (2018).

Precipitation type	**Intensity**
Light rain	1
Rain, snow, snow/rain mix	2
Pouring rain, snow hail	3

As the precipitation intensity thus becomes a categorical variable, the relation to leakage of total phosphorus and phosphate was checked by using a one-way ANOVA-test. From the results, η^2 was calculated which tells the explained variance between the variables, see Equation 1. Eta squared, η^2, can be interpreted as an equivalent to regression coefficient R^2 when comparing a categorical variable with one or more continuous variable (Brown 2008). In Equation 1 below, *SS between* stands for the sum of squares between the compared variables, and *SS total* for the total sum of squares and thus the total variation seen in the comparison.

$$\eta^2 = \frac{\mathrm{SS_{between}}}{\mathrm{SS_{total}}} \qquad \text{Eq.1}$$

The temperature data was used for achieving two different parameters: diurnal temperature range and average temperature. The diurnal temperature range was calculated by taking the range between the temperature from the day of observation to the day before to get an approximation of the effect from change in temperature. The average temperature was calculated for the periods corresponding to the measured flow data. The last parameter was snow depth, where weekly averages of snow depth in meter were calculated. The weather parameters were correlated with the series of phosphorus/phosphate leakage and coefficient of determination was calculated.

4. Results

In the following chapter, the conditions for the identification of risk areas and the final mapping of risk areas for phosphorus leakage is presented, followed by field observations of surface runoff and erosion. The outcome of how sinks in the digital elevation model affect the risk mapping is then shown. To answer the question of when and under which conditions the phosphorus rich flows of sediments are originating from, the correlation of sediment measurements with climate and discharge data from the area are finalizing the result section.

4.1 Risk areas for phosphorus leakage

As described above, the analysis of risk areas is based on topography and clay content in the study area, shown in Figure 4. The DEM shows the elongated depression in the middle of the catchment and clay content is highest (35-40 %) to the west of this depression. From the unfilled DEM and filled DEM was 5 % of highest flow accumulation retrieved, also shown in Figure 4.

The final risk mapping of phosphorus leakage combines the 5 % of highest flow accumulation and the soil clay content, see Figure 5. Highest risk class is identified by the filled DEM in the southern part of the catchment. High risk is also identified along the elongated depression, seen in both the unfilled and filled DEM. Both the filled DEM and unfilled DEM identifies risk areas of high flow accumulation to the east of the road in the middle of the study area but here the clay content of the soil is less.

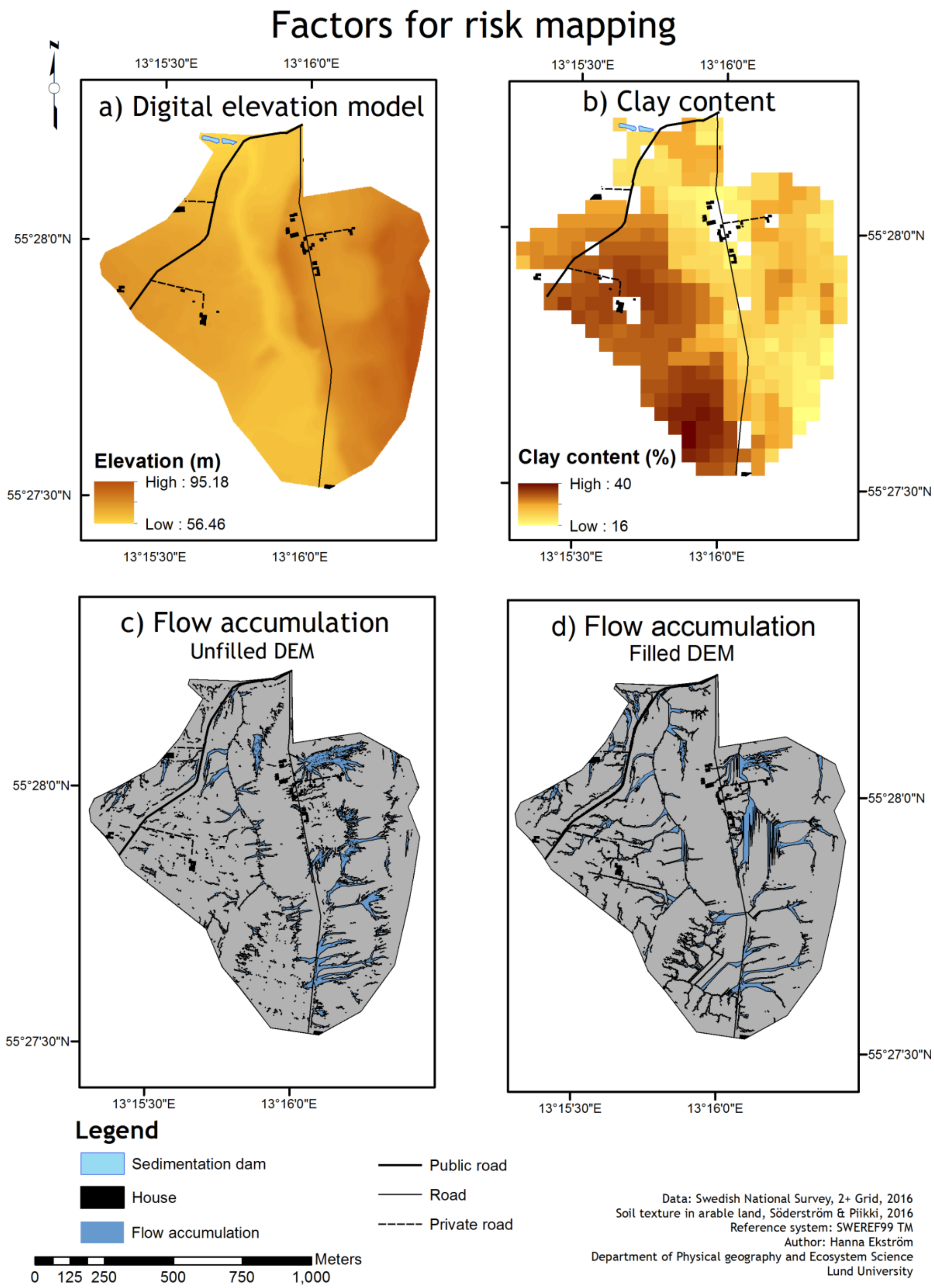

Figure 4: Factors behind the risk mapping includes information regarding clay content for the catchment draining into the sedimentation dam, elevation and calculated flow accumulation based on a Triangular form-based Multiple Flow algorithm, TFM (Pilesjö and Hasan 2014). Elevation data: © Swedish National Survey, soil data from Swedish University of Agriculture.

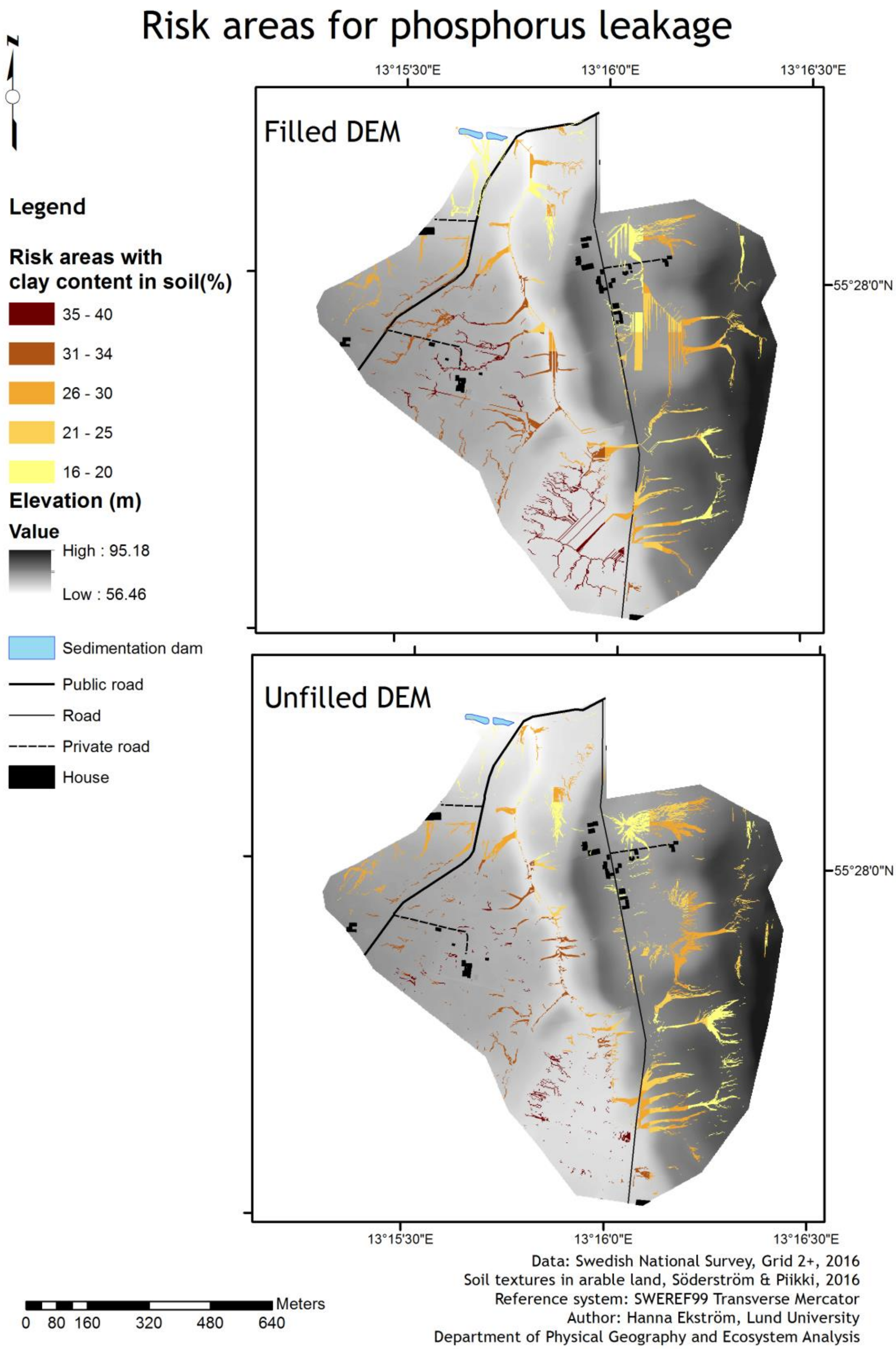

Figure 5: Risk areas of phosphorus leakage through surface runoff erosion, with increasing risk following increasing clay content.

4.1.1 Surface runoff and erosion in field

During the first field observation, on the 21st of March 2018, two fields close to the coniferous forest in the middle of the catchment were covered with crops, see Figure 3, and a larger area in the south was stubble field. Information on type of crops was not possible to gather. Traces of erosion and surface runoff as well as standing water were recorded. Recurrent observations were erosion along the edges of the fields, as shown in Figure 6, sheet erosion on larger areas as shown in Figure 7 and different magnitudes of rill erosion, Figure 8. An interesting finding was a sinkhole in the south west of the catchment, Figure 9 and No 16, Figure 10. The location of all the field observations can be seen in Figure 10. Not the whole area was possible to access due to the start of the growing season, which means that erosion traces may exist even in areas where not indicated, such as in the middle and southern parts of the catchment.

Figure 6: Sheet erosion in edge of a field, 17th of April 2018.

Figure 7: Sheet erosion on larger area, 17th of April 2018.

Figure 8: Rill erosion observed in field above the sedimentation dam, 17th of April 2018.

Figure 9: Sink hole in edge of field, seen just after snow melt, 21st of March 2018.

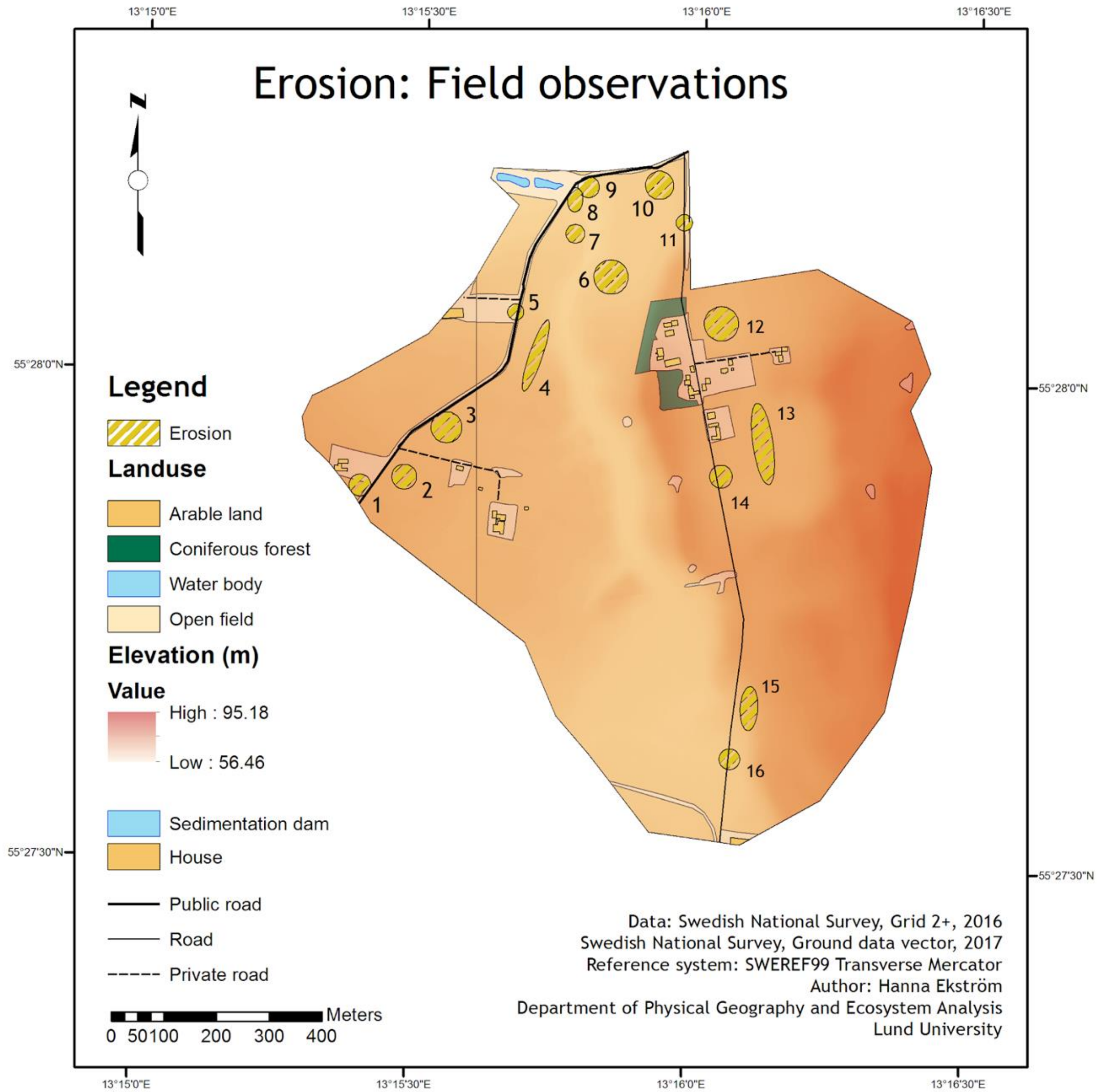

Figure 10: Field observation of erosion and surface runoff, recorded at Fru Alstad on the 21st of March 2018 and on the 17th of April 2018. 1) Erosion of field edge into dike 2) Standing water and signs of sheet erosion 3) Signs of sheet erosion 4) Clear rill erosion in north direction 5) Eroded material into dike 6) Standing water and signs of sheet erosion 7) Surface runoff patterns towards inlet to sedimentation dam 8)Erosion in connection to drainage inlet 9)Signs of sheet erosion in edge of field 10) Standing water 11) Eroded material from field above 12) Standing water 13) Signs of sheet erosion 14) Rill erosion over road 15) Rill erosion in N-S direction 16) Sink hole, 1,5 m depth, in connection to drainage system

4.2 Filled DEM vs unfilled DEM

The location of the digitally identified sinks in the catchment can be seen in Figure 12. Sinks are identified along the elongated depression in the middle of the catchment, along roads where dikes are present and in the hilly part in the south. The effect of the resulting flow accumulation on an unprocessed DEM and a filled depression DEM can be seen in Figure 5. In general, the flow accumulation on the filled DEM generates more connected flow paths. Moreover, analysis done on the DEM which was processed to fill sinks identifies more risk areas in the clay rich western part of the catchment, see Table 3.

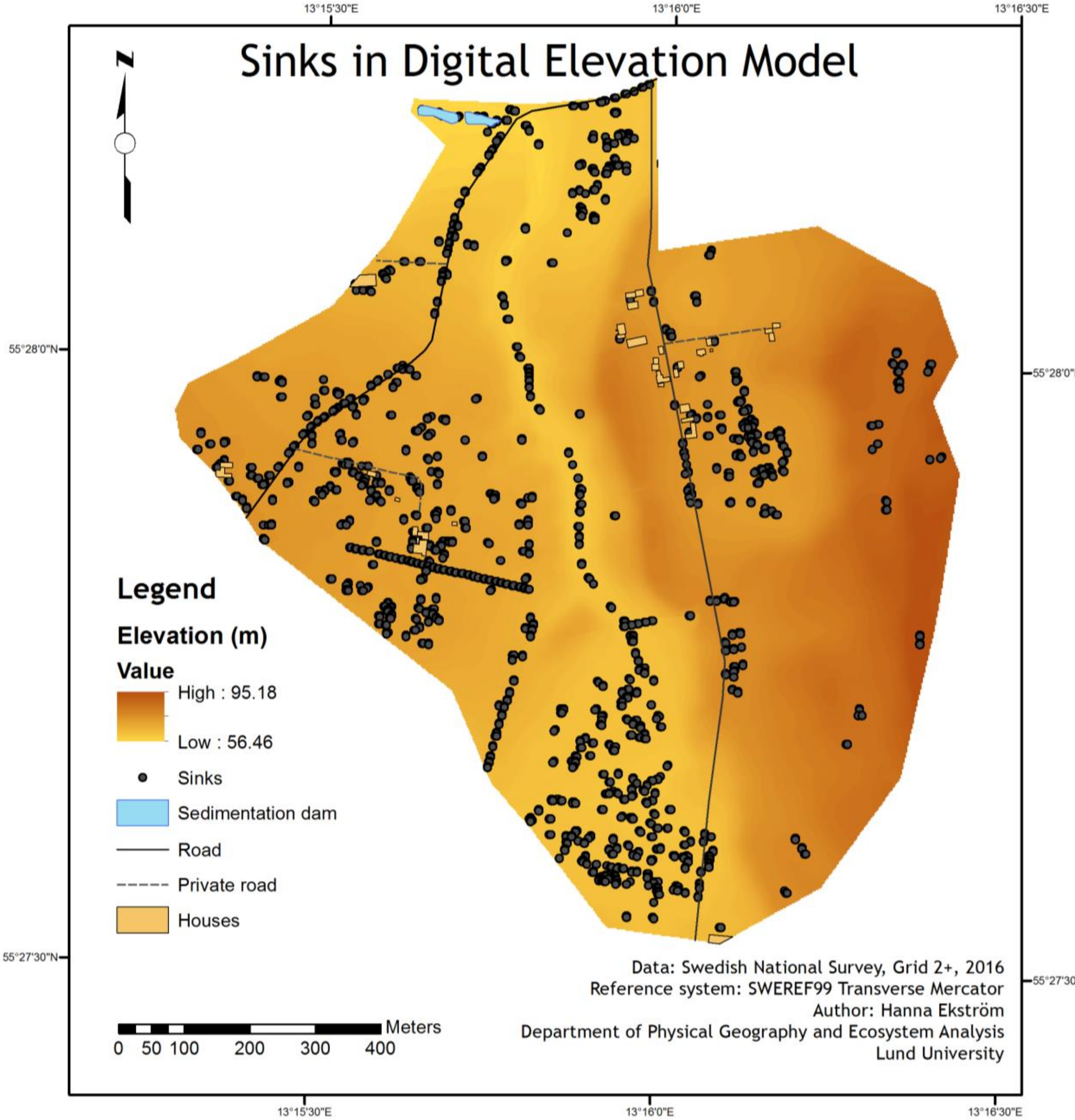

Figure 11: Sinks identified in the digital elevation model, mainly following the main depression in the catchment and identifying dikes in the western part of the study area.

Table 3: Clay content in the risk areas identified by the analysis done on a filled DEM and unfilled DEM respectively.

Clay content in soil	Risk areas in filled DEM	Risk areas in unfilled DEM
25%	70%	62%
30%	54%	39%
35%	29%	15.50%

4.3 Risk periods of surface runoff

The results of the measurements of phosphorus leakage in form of plant available phosphate to the sedimentation dam showed peaks of flow on the 2 of Jan 2018, 9th of Jan and 13th of March, see Figure 12. When looking at the total phosphorus, additional peaks are recorded on the 26th of Dec 2017, 30th of Jan 2018 and 6 Feb, see Figure 13. Lack of data can be observed on the 6th and 20th of March, and is due to weather conditions.

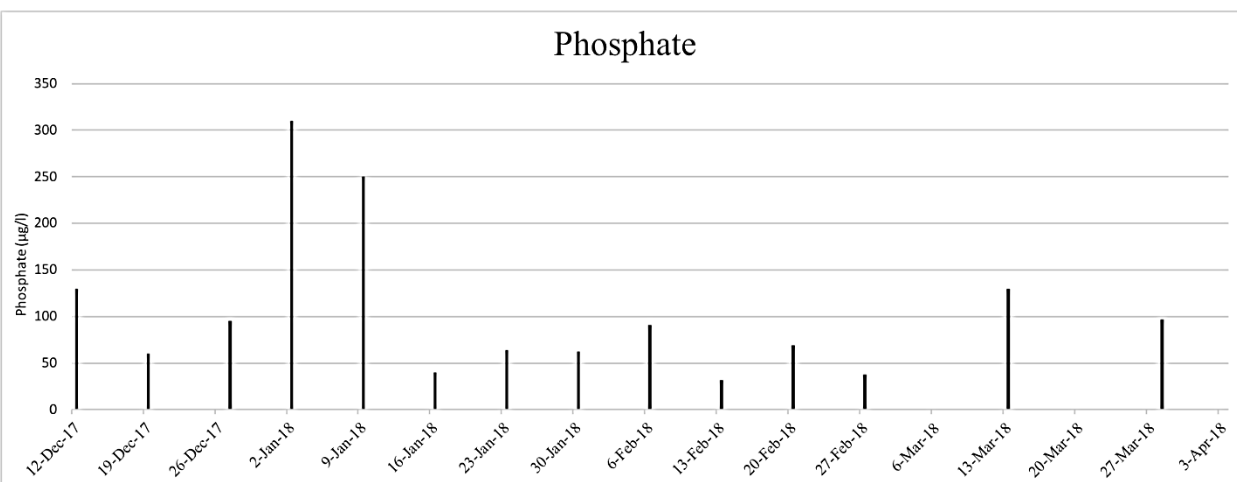

Figure 12: Measured leakage values of phosphate into the sedimentation dam from the catchment in Fru alstad, recorded from December 2017 to April 2018.

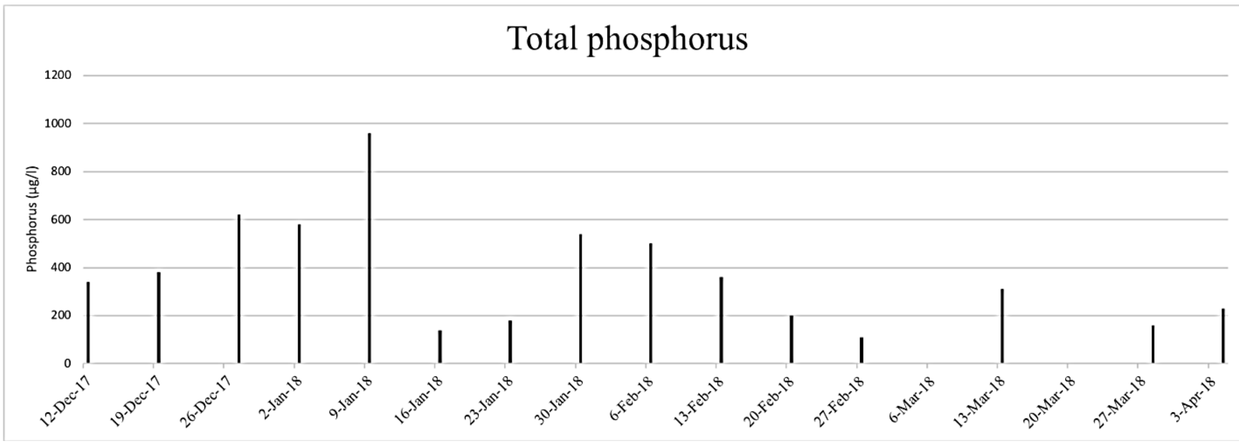

Figure 13: Measured leakage of total phosphorus from December 2017 to April 2018.

The temperature data shows that highest temperatures in the range from December 2017 to March 2018 were reached around the 23 of December 2017, and the lowest around the 3 of March. It has generally low correlation values with total phosphorus and phosphate, see Table 5. The peaks of precipitation are around the first days of January 2018. Similar values of precipitation, around 11 mm/day fell in beginning of March 2018, see Figure 14. The recorded precipitation types for each event which works as the base for the precipitation intensity parameter are shown in Table 4. Average precipitation partly explains the variation in leakage of phosphorus, see Table 5.

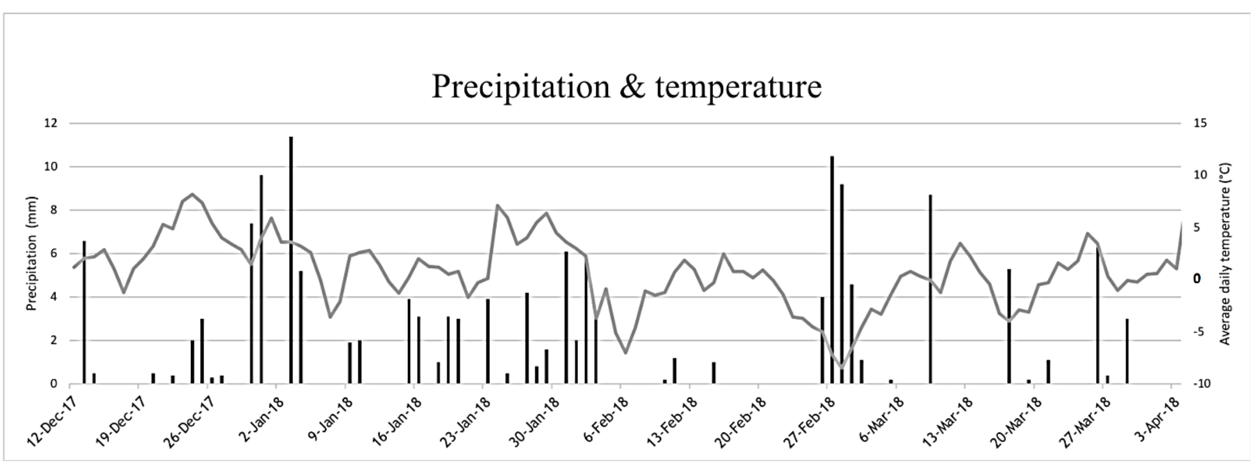

Figure 14: Precipitation and temperature during the measurement period December 2017- April 2018, measured at SMHI climate station in Skurup.

Table 4: Precipitation type for each precipitation event in the period from December 2017- April 2018. Precipitation type is used as the base for the factor of precipitation intensity.

Date	Precipitation (mm)	Precipitation type
16-Dec-17	0	Snow hail
20-Dec-17	0,5	Light rain
22-Dec-17	0,4	Pouring rain
24-Dec-17	2	Rain
25-Dec-17	3	Light rain
26-Dec-17	0,3	Rain
27-Dec-17	0,4	Light rain
30-Dec-17	7,4	Rain
31-Dec-17	9,6	Rain
3-Jan-18	11,4	Pouring rain
4-Jan-18	5,2	Rain
6-Jan-18	0	Snow/rain mix
9-Jan-18	1,9	Rain
10-Jan-18	2	N/A
15-Jan-18	3,9	Pouring rain
16-Jan-18	3,1	Snow hail
18-Jan-18	1	Snow hail
19-Jan-18	3,1	Snow hail
20-Jan-18	3	Snow
23-Jan-18	3,9	Rain
25-Jan-18	0,5	Light rain
27-Jan-18	4,2	Snow/rain mix
28-Jan-18	0,8	N/A
29-Jan-18	1,6	Pouring rain
31-Jan-18	6,1	Pouring rain

Date	Precipitation (mm)	Precipitation type
1-Feb-18	2	Pouring rain
2-Feb-18	5,7	Snow
3-Feb-18	3,2	Snow
10-Feb-18	0,2	Snow
11-Feb-18	1,2	Snow
15-Feb-18	1	Snow
26-Feb-18	4	Snow
27-Feb-18	10,5	Snow
28-Feb-18	9,2	Snow hail
1-Mar-18	4,6	Snow
2-Mar-18	1,1	Snow hail
5-Mar-18	0,2	Snow hail
9-Mar-18	8,7	Snow
17-Mar-18	5,3	Snow
19-Mar-18	0,2	Snow hail
21-Mar-18	1,1	N/A
26-Mar-18	6,3	Pouring rain
27-Mar-18	0,4	Snow
29-Mar-18	3	Snow

Water discharge from the catchment measured at the inlet to the sedimentation dam, see Figure 15, correlated with average precipitation data by a Pearson correlation value of 0.49, and a coefficient of determination of 0.24. Snow depth reached maximum in the beginning of March and melted quickly off, see Figure 16.

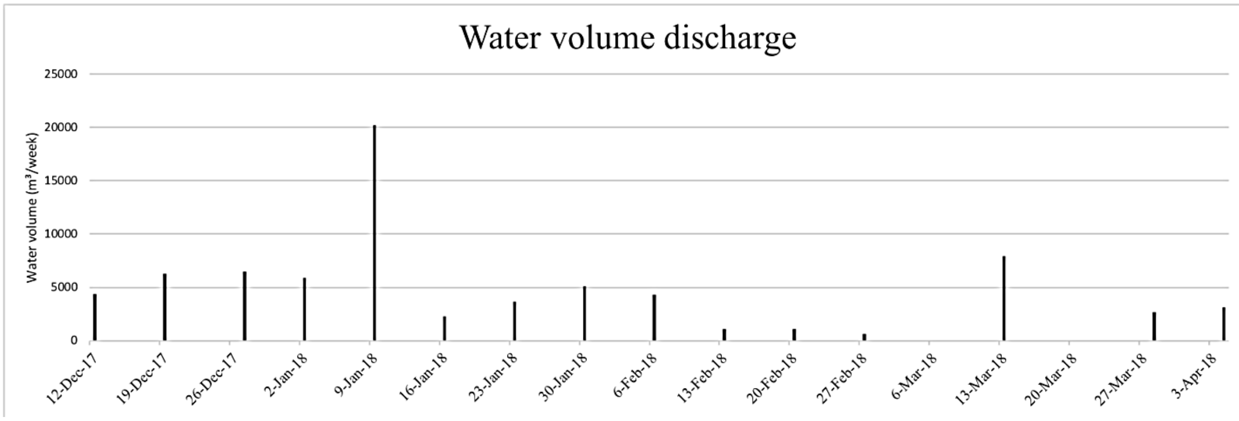

Figure 15: Water volume discharge, measured at the sedimentation dam in Fru Alstad, by Ekologgruppen. December 2017-April 2018.

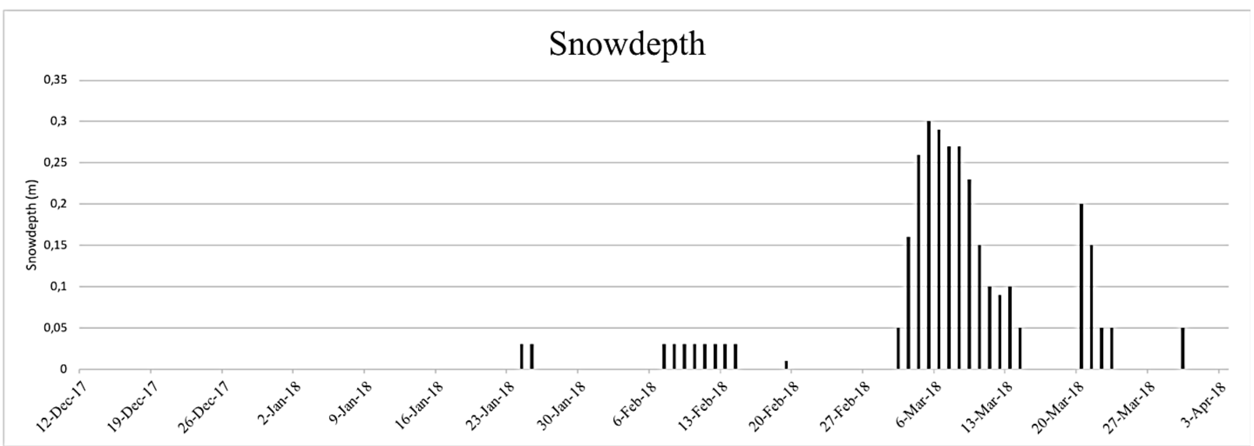

Figure 16: Depth of snow measured at Skurup climate station, located 20 km from study area, December 2017-April 2018.

Table 5: Correlation values for leakage of total phosphorus and plant available phosphate respectively compared to climate affecting parameters of a) average temperature, b) temperature change during the last 24 hours, c) average precipitation and d) snow depth.

	Total phosphorus		**Phosphate**	
	Correlation	Coefficient of determination	Correlation	Coefficient of determination
a) Average temperature	0.38	0.15	0.03	0.00
b) Diurnal temperature change	-0.04	0.00	0.19	0.04
c) Average precipitation	0.40	0.16	0.68	0.47
d) Snow depth	-0.17	0.02	0.04	0.22

Precipitation intensity in relation to total phosphorus gave a η^2 of 0.60, which means that the variance between the two variables explain 60 % of the total variance, see Table 6. In comparison to phosphate leakage, the precipitation intensity explains 47 % of the variance in leakage.

Table 6: The relationship between precipitation intensity and leakage of total phosphorus and phosphate respectively, described with the value of eta squared, η^2 , with a significance level of 0.05 and a p-value for Total phosphorus of $p < .00001$, and for Phosphate of $p < .000033$.

	Total phosphorus	**Phosphate**
$\boldsymbol{\eta^2}$	0.60	0.47
p-value	< .00001	< .000033

5. Discussion

To summarize, high-risk areas for phosphorus leakage through surface runoff have been shown to be located in the southern part of the catchment. Risk periods for phosphorus leakage were harder to detect, but correlation to precipitation was found. The risk areas were clearest identified by the outcome from a filled digital elevation model. The results indicate that if the step of filling the sinks is added to the methodology, the outcome is easier to interpret and information about the possibilities of transport of phosphorus from eroded fields is gained. At the same time, filling sinks can be done relatively quickly, and the method will continue to be time efficient if that is of interest. A simple yet efficient method for risk mapping of phosphorus leakage could be an important alternative to more data intensive methods now used such as the different Nordic variations of P-index and USPED (Alström and Wedding 2010). For the implementation of mitigation techniques for nonpoint phosphorus leakage, effective methods are of importance not only for Sweden but for all countries in the Baltic Sea region (Elofsson and von Brömssen 2017). If the phosphorus leakage can be reduced and risk areas identified on a local scale, the usage of artificial fertilizers can be reduced which is an important step towards sustainable use of phosphorus mineral resources, needed for mitigation of the global challenge of peak phosphorus (Johannesson 2015).

In the following section, the results of the risk areas analysis and their relative importance are discussed, as well as how the choice of filling the sinks in the digital elevation model affected the results, what patterns could be seen between weather parameters and phosphorus leakage despite weak correlation values and what uncertainties that still remain.

5.1 Risk areas for phosphorus leakage

Two main risk areas draw the attention in the analysis, one in the south with high clay content and one in the east where flow accumulation is large but clay content less, see Figure 5. The following section starts by relating the results with the factors of flow accumulation and clay content, which as described earlier affect the possibilities of particles to be transported away once eroded. Secondly, focus is put on the field observations. A major part of the high-risk area in the south is located in the region which was not possible to visit. However, from the part that was examined less traces of erosion were seen compared to other locations. A discussion about the reason for this possible contradiction between data analysis and field observations is finalizing this section.

The risk area in the south has high clay content, see Figure 5, which, as mentioned earlier, means that the soil is easily saturated leading to overland flow (Heathwaite 1997). Moreover, the soil in this area have high clay content and the light clay particles may travel far before they sediment in the stream (Pinheiro et al. 2009). The area in the south is also connected to the sedimentation dam through the elongated depression in the middle of the catchment. This is an important aspect, as an area may be a high-risk area for erosion, but for the nutrients to be transported there need to be some kind of connection with the water network. This is supported by earlier studies looking at the connectivity between a source area for phosphorus leakage and the stream outlet, showing the relative importance of one source area to contribute to the final nutrient loads compared to other areas (Kovacs et al. 2012).

In comparison to the area in the south, the connectivity between the areas with high flow accumulation in the east and the sedimentation dam is less clear. As shown, erosion traces were found with large patterns of surface runoff, but the runoff from those fields has to pass the other risk areas before reaching the dam. Coming from soil with relatively larger soil particles that sediment quicker (Alström and Wedding 2013), it is less probable that the areas in the east contribute directly to the loads of clay rich sediments measured in the sedimentation dam. The area could still have an impact on the fields further down in the system if surface runoff occurs. One example was seen as overland flow over the road, No 14 Figure 10. The importance of understanding the water patterns in the whole catchment should be kept in mind for the following section *5.2 Filled DEM vs. unfilled DEM* about whether to fill the sinks in the digital elevation model or not.

Going back to the high-risk area in the south, apart from having high connectivity it was also one of few areas that were covered with stubble during the first field visit. Although not green and growing, stubble is counted as a valid cover crop for a field during the winter period (Logardt 2015). As several uncovered areas were seen during the first field visit, this could be one reason for the loads of clay rich sediments that reach the dam in periods. Even though the regulations stated by Swedish Authority of Agriculture (2018) says that 60 % of a farmer's area should be covered, it does not guarantee that 60 % of the study area is covered, as several land owners are present in the catchment. Indicated risk areas could be considered prioritized for winter growing as the vegetation cover slows down the erosion processes (Logardt 2015).

5.2 Filled DEM vs. unfilled DEM

In general, the risk areas identified from a filled DEM and an unfilled DEM are similar but they appear more connected in the filled DEM, and a larger portion of the flow accumulation in clay rich areas are identified, which was of special interest in this study. Filling a DEM is thus concluded to be an improvement of the tested methodology.

While the unfilled DEM isolates depressions higher up in the catchment, an overall understanding of the flow pattern as gained by the filled DEM is important to being able to see how the phosphorus eventually can be transported away from the eroded fields. The analysis done on a filled DEM shows how the water is connected in a clearer way than the more scattered outcome from the analysis done on the original, unfilled DEM, see Figure 5. When looking at the identified risk areas in the filled DEM, the risk area with high flow accumulation in the east is assumed to have an impact on the surface runoff on adjacent fields, although having relatively low clay content. The importance of looking at the whole picture of water flow paths as done when working with a filled DEM can therefore also be connected to what is mentioned in study of measured stream water nutrients from an area of agriculture in Scotland. Nutrients eroding from an arable field may not have a large effect in the area they are originating from but can when accumulating in more sensitive areas further down in the stream network have a large impact on these habitats (Stutter et al. 2008). The more isolated picture of sinks high up in the catchment that is the result from an unfilled DEM does not show the connectivity and transport pathways of phosphorus to the same extent.

For the specific purpose of this study, the filled DEM, apart from giving a clearer picture of the flow accumulation, was the method that clearest identified the clay rich areas contributing to the measured peaks of sediments, see Table 3. To work with an unfilled DEM, as suggested in the original risk mapping method (Alström and Wedding 2013) could hence mean that information about the pathways of water is lost as sinks that are not filled to the neighbouring cell's level become traps for the flow accumulation, whether they are caused by computational errors or natural depressions. The results thus indicate that the choice of filling sinks may improve the methodology for risk mapping of phosphorus leakage through surface runoff.

5.3 Risk periods of phosphorus leakage

Agreements between field measurements of phosphorus leakage and weather parameters were generally low, but precipitation intensity and average precipitation indicates a relationship with phosphorous leakage. There is however a difference between the correlation of total P and plant available phosphate, which is discussed below. The discussion related to the precipitation parameters are followed by reasoning about the snow depth and temperature respectively.

5.3.1 Leakage of total phosphorus and phosphate

An interesting result is the difference between leakage of plant available phosphate and total phosphorus, with different peak periods, see Figure 12 and Figure 13. As the surface runoff is an important transport process of sediments and thus the phosphorus bound to those sediment particles (Stutter et al. 2008), the results may indicate that occasions where the total phosphorus have relatively higher records than the phosphate, such as on the 9th of January 2018, a larger portion of the leached phosphorus may be particle bound and the process behind it to a larger extent be surface runoff. The 2nd of January 2018 shows the opposite pattern when measured phosphate leakage has its highest peak, which could tell that a larger portion of the phosphorus is leached through the soil water and through the tile drainage systems. The type of leakage could thus be an indicator of which mitigation techniques that are suitable in different parts of the year and on different areas within the catchment.

5.3.2 Precipitation, discharge and surface runoff

The correlation between water discharge and average precipitation indicates that the discharge is partly explained by the amounts of direct average precipitation. Understanding the relations between precipitation and runoff is important for grasping the patterns of phosphorus runoff, and precipitation is considered since it is assumed to lead to higher discharge rates. In catchments like Fru Alstad, where the drainage is mainly through drainage pipes and dikes, the response time from precipitation event to discharge is assumed to be quick (Alström and Bergman 1991; Bergström et al. 2007). Since the average precipitation does not explain the total volumes of discharge, it is probable that several parameters cooperate, such as temperature, type of precipitation and infiltration capacity of the soil which in turn depends on earlier precipitation events and soil type (Rose 2004). The results of this study thus indicate that the used method is too simple to completely explain the observed runoff erosion. A similar pattern is visible when continuing by comparing the measured phosphorus leakage with the two different precipitation parameters: average precipitation and precipitation intensity.

Highest correlation was found between phosphate and average precipitation, indicating that average precipitation partly explains the leakage of phosphate. There is however a difference between the results for phosphate and total phosphorus, with total phosphorus having weaker correlation value. This could possibly be explained by the different processes that total phosphorus and phosphate is going through in the soil and soil water. As mentioned above, phosphate in the solution pool is the only form of phosphorus that is available for algae and other plants and is thus what directly contributes to the eutrophication. It has however been shown that phosphorus is a highly reactive substance, and the phosphorus that arrive to the water streams as particular bound phosphorus in the active pool can quickly be turned over to the soluble phosphate. In a study in a eutrophic part of Chesapeake Bay in US, the total P in surface waters increased from 20 to 50 mg/L to 150 to 200 mg/L during an 8-year period, while the phosphate was only ranging between 5 to 8 mg/L and had almost no change at all. An analysis limited to the plant available phosphate concentration in surface runoff could therefore be misleading since it may be valid for just a short period of time (Correl 1999).

Changing focus to the total phosphorus correlation values with average precipitation, the weak correlation standing alone does not support the expected results of higher precipitation amounts leading to more surface runoff, which stands in contrast to earlier studies stating that P-transport is controlled by peak flow (Stutter et al. 2008; van der Grift et al. 2016). The average precipitation amount may not be a reliable indicator of the pressure precipitation asserts on the soil, comparable to the findings of Alström & Bergman (1991), who also found weak correlation values for erosion and precipitation amounts. The precipitation intensity gives however a larger explanation value which indicates that precipitation intensity is a more accurate indicator of surface runoff than the average amount of precipitation.

5.3.3 Snow depth

The snow depth did not show strong correlations with either total phosphorus or phosphate leakage. By visual comparison, it can however be noted that the melting off of the study period's deepest snow cover in March was followed by a peak in phosphate leakage. The importance of snow melt and processes of thawing has earlier been concluded as a main factor for phosphorus leakage from arable land in Northern Europe (Alström and Bergman 1991; van der Grift et al. 2016). The weak correlations values to the single parameter of snow depth may point toward the phosphorus leakage being more accurately explained by looking at the combined effect of snow depth and temperature. Earlier research has shown that leakage increases with quick thawing of surface soil layer and precipitation on thawing soil (Alström and Bergman 1991; Bergström et al. 2007).

5.3.4 Temperature

Similarly to snow depth neither the average daily temperature nor the diurnal temperature range do show strong correlation values with phosphorus leakage. High average daily temperatures are needed to produce runoff, since cold nights may be enough for keeping the soil frozen (SMHI, 2018). Taking the 27th of February as an example, high amounts of precipitation fell but did not seem to induce an increased leakage of phosphorus, as the average temperature was below 0°C. When the temperature increases in the beginning of March however, runoff is generated. This illustrates that the changes in temperature in relation to time, both in terms of how quickly the temperature change and how many times it goes from below 0°C to above 0°C, might be interesting to consider to be able to explain the variance in phosphorus loads (Alström and Bergman 1991; Bechmann et al. 2005).

Apart from increasing temperatures being a flow inducing process if leading to snow melt, there might be an effect on the leached phosphorus from repeating freezing-thawing cycles. Increased leakage of phosphorus was shown on plant scale by Bechmann et al. (2005), and it was reasoned to be due to destruction of the cell walls within the plants. If this effect is possible to see on a landscape level would be an interesting topic for future studies.

To summarize, highest agreement was found between phosphate leakage and precipitation intensity. The generally weak correlation values indicate that the leakage is not a result of one single parameter, but rather a combination of several parameters. For future studies, the temperature effects may be of great importance to understand nutrient leakage and their effect in a changing climate with higher yearly temperatures. In a recent experiment increased temperatures have shown to give higher base flow of phosphorus and increasing the P limitation of algae, leading to increased phosphorus content in streams (McDowell et al. 2017). Gaining knowledge about the processes controlling phosphorus leakage will thus continue to be important.

5.4 Sources of error and future considerations

Ekologgruppen points out the importance of taking local conditions into account in their method for risk mapping of phosphorus leakage through surface runoff. In this study it was done by communicating with the landowners before the field visits, and the field visits served for getting an overall picture of the drainage patterns, topography and vegetation cover of the study area. However, the type of crops could not be determined and constraints thus a lack of data, since it is assumed to have an effect on the magnitude of erosion (Puustinen et al. 2007). For future studies, the cooperation with land owners could be one way to achieve this information and would have other benefits as well: to get specific information about the study area during the research and to improve the possibilities for implementation of mitigation techniques (Stutter et al. 2008; Alström and Wedding 2013).

As mentioned above, organic matter is working as substrate for particle phosphorus to bind to (Sharpley and Rekolainen 1997). Since the study area is used for agriculture it is assumed to have generally high concentrations of organic matter, but the fact that it has been excluded from the analysis must be noted. The reason for this is lack of data, as the soil data did only contain information about areas classified as complete organic soils, such as peat, and not as organic matter in percentage over the whole area. If available, it would be interesting to consider for future studies.

The importance of connectivity of a certain risk area and water pathways in the study area have been noted in field and discussed but could rather easily be incorporated in to the GIS analysis. As reviewed literature has shown, it has an importance for the contribution to the total leakage a specific area has.

Field observations were mainly possible to do from the existing roads in the study area, since the growing season had started. This means that not the whole study area was possible to examine for erosion patterns. Access to the whole study area would have made it possible to evaluate the risk mapping method to a larger extent.

Finally, if higher time resolution of weather parameters were available, and the phosphorus leakage could be measured as a flow on the same resolution, less averaging would have been necessary and more variation in the data would have been possible to detect. As an example, precipitation intensity is now approximated from the categories of precipitation types, but exists as hourly measured values at some climate stations in Sweden, which would have been a more accurate measure (Ding et al. 2017).

5.5 Conclusion

This study aimed to investigate the source areas and periods of phosphorus and clay rich sediments reaching the sedimentation dam in a subcatchment to Sege river. To do this, risk areas for phosphorus leakage were mapped following a methodology developed by Ekologgruppen, and the effect of filling or not filling sinks in the digital elevation model was compared. Lastly, risk periods were identified by correlating weather parameters with measured phosphorus leakage from the catchment.

Risk areas for phosphorus leakage through surface runoff erosion were identified as areas with high flow accumulation and high clay content, mainly located in the southern part of the catchment. This area was clearest identified in the filled DEM which also indicated the flow pattern of water in the landscape in clearest way. The results are thus supporting the expected results regarding the choice of filling the sinks in the DEM being an improvement of the tested method.

Phosphorus leakage peaked in the beginning of January, coinciding with high amounts of precipitation and temperatures above 0°C. Largest agreement was found between phosphate leakage and precipitation intensity, but in contrast to the expectations the phosphorus leakage can not only be explained by one single parameter such as heavy precipitation. Due to weak correlation results between individual parameters and phosphorus leakage it is assumed that the temporal patterns of phosphorus leakage are best explained by taking several parameters in combination in to account.

References

Ahlstrand, J. 2014. En jämförelse av två riskkarteringar av fosforförlust från jordbruksmark. PhD Thesis. Lund: Lund University

Alström, K., and Å. A. Bergman. 1991. *Vattenerosion i sydsvensk jordbruksmark*. Lunds universitets naturgeografiska institution.

Alström, T., and B. Wedding, 2012. Test av tre nordiska fosforindex för förhållanden i svensk jordbruksmark. Ekologgruppen, Report. [in Swedish, English summary]

Alström, T., and B. Wedding, 2013. Enkelt verktyg för riskkartering av fosforförluster via ytavrinning. Ekologgruppen, Report. [in Swedish, English summary]

Bechmann, M. E., P. J. A. Kleinman, A. N. Sharpley, and L. S. Saporito. 2005. Freeze-thaw effects on phosphorus loss in runoff from manured and catch-cropped soils. *Journal of Environmental Quality,* 34**:** 2301-2309. DOI: 10.2134/jeq2004.0415

Bergström, L., F. Djodjic, H. Kirchmann, I. Nilsson, and B. Ulén, 2007. Phosphorus from Farmland to Water. Swedish University of Agricultural Science, Report. [in Swedish, English summary]

Brown, J. D. 2008. Effect size and eta squared. In *JALT Testing & Evaluation SIG Newsletter.* , 38-43.

Chislock, M. F., E. Doster, R. A. Zitomer, and A. Wilson. 2013. Eutrophication: causes, consequences, and controls in aquatic ecosystems. *Nature Education Knowledge,* 4**:** 10.

Cordell, D., and S. White. 2011. Peak Phosphorus: Clarifying the Key Issues of a Vigorous Debate about Long-Term Phosphorus Security. *Sustainability,* 3**:** 2027.

Correl, D. L. 1999. Symposium: Focus on Phosphorus. In *Poultry Science,* 674–682. Edgewater:Maryland, US.

Ding, X., Y. Xue, M. Lin, and Y. Liu. 2017. Effects of precipitation and topography on total phosphorus loss from purple soil. *Water (Switzerland),* 9. DOI: 10.3390/w9050315

Ekologgruppen. 2009. Information från Ekologgruppens databas över anlagda våtmarker och dammar. Retrieved 2018-03-20, from http://83.233.227.100/eg/sege/sege_public.php?damm=999.

Elofsson, K., and C. von Brömssen. 2017. The revealed preferences of Baltic Sea governments: Goals, policy instruments, and implementation of nutrient abatement measures. *Marine Pollution Bulletin,* 118**:** 188-196. DOI: 10.1016/j.marpolbul.2017.02.014

Eriksson, J., I. Nilsson, M. Simonsson, and L. Wiklander. 2005. *Wiklanders marklära*. Lund : Studentlitteratur, 2005 (Lund : Studentlitteratur).

Heathwaite, A. L. 1997. Sources and Pathways of Phosphorus Loss from Agriculture. In *Phosphorus Loss from Soil to Water,* eds. H. Tunney, P. C. Brookes, O. T. Carton, and A. E. Johnston.

Johannesson, K. 2015. *Particulate phosphorus accumulation and net retention in constructed wetlands receiving agricultural runoff : Critical analysis of factors affecting retention estimates*. Linköping : Department of Physics, Chemistry and Biology, Linköping University, 2015.

Kovacs, A., M. Honti, M. Zessner, A. Eder, A. Clement, and G. Bloschl. 2012. Identification of phosphorus emission hotspots in agricultural catchments. *Science of the Total Environment,* 433**:** 74-88. DOI: 10.1016/j.scitotenv.2012.06.024

Lobo, G. P., and C. A. Bonilla. 2015. Effect of temporal resolution on rainfall erosivity estimates in zones of precipitation caused by frontal systems. *Catena,* 135**:** 202-207. DOI: 10.1016/j.catena.2015.08.002

Logardt, S. 2015. Åtgärder. Retrieved 2018-04-26, from http://greppa.nu/atgarder.html?Nytta_f%C3%B6r=Havet.

McDowell, R. W., K. R. Elkin, and P. J. A. Kleinman. 2017. Temperature and nitrogen effects on phosphorus uptake by agricultural stream-bed sediments. *Journal of Environmental Quality,* 46**:** 295-301. DOI: 10.2134/jeq2016.09.0352

Mikkelsen, R. 2013. A Closer Look at Phosphorus Uptake by Plants. Retrieved 2018-04-24, from https://www.ipni.net/publication/insights-na.nsf/0/324D239E9065F43385257CD800765F01/$FILE/INSIGHTS-NA-2013-07.pdf.

Naturvårdsverket, 2006. Övergödning av Sveriges sjöar och hav. Report, Stockholm. [in Swedish, English summary]

Nilsson, H. 2017. A dynamic and spatially distributed rainfall runoff mode. PhD Thesis. Lund: Lund Technical University

Nilsson, K. 1959. *Isströmmar och isavsmältning i sydvästra Skånes backlandskap*. Stockholm: Swedish Geological Survey.

Pagliari, P. H., D. E. Kaiser, C. J. Rosen, and J. A. Lamb, 2017. The Nature of Phosphorus in Soils. University of Minnesota, Report FO-6795-C. [in Swedish, English summary]

Pilesjö, P., and A. Hasan. 2014. A Triangular Form-based Multiple Flow Algorithm to Estimate Overland Flow Distribution and Accumulation on a Digital Elevation Model. *Transactions in GIS,* 18**:** 108-124. DOI: 10.1111/tgis.12015

Pinheiro, A., L. P. Teixeira, and V. Kaufmann. 2009. Water infiltration capacity under different land uses and agricultural management practices. *Ambiente e Agua-An Interdisciplinary Journal of Applied Science,* 4**:** 188-199.

Puustinen, M., S. Tattari, J. Koskiaho, and J. Linjama. 2007. Influence of seasonal and annual hydrological variations on erosion and phosphorus transport from arable areas in Finland. *Soil & Tillage Research,* 93**:** 44-55. DOI: 10.1016/j.still.2006.03.011

Rose, C. W. 2004. *An introduction to the environmental physics of soil, water and watersheds*. Cambridge University Press.

Schindler, D. W., R. E. Hecky, D. L. Findlay, M. P. Stainton, B. R. Parker, M. J. Paterson, K. G. Beaty, M. Lyng, et al. 2008. Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. *Proceedings of the National Academy of Sciences,* 105**:** 11254-11258. DOI: 10.1073/pnas.0805108105

Sharpley, A. N., and S. Rekolainen. 1997. Phosphorus in agriculture and its environmental implications. In *Phosphorus loss from soil to water,* eds. H. Tunney, O. T. Carton, P. C. Brookes, and A. E. Johnston. Wallingford : CAB International, 1997.

SMHI. 2018. Meteorological observations. Retrieved 2018-04-20, from https://opendata-download-metobs.smhi.se/explore/?parameter=0.

Söderström, M., and K. Piikki, 2016. Digitala åkermarkskartan –detaljerad kartering av textur i åkermarkens matjord. Swedish University of Agriculture, Report. [in Swedish, English summary]

Sonneveld, M., J. Schoorl, and A. Veldkamp. 2006. Mapping hydrological pathways of phosphorus transfer in apparently homogeneous landscapes using a high-resolution DEM. *Geoderma*, 133**:** 32-42.

Stutter, M. I., S. J. Langan, and R. J. Cooper. 2008. Spatial and temporal dynamics of stream water particulate and dissolved N, P and C forms along a catchment transect, NE Scotland. *Journal of Hydrology*, 350**:** 187-202. DOI: 10.1016/j.jhydrol.2007.10.048

Swedish Board of Agriculture, 2015. Föreskrifter och allmänna råd om miljöhänsyn i jordbruket vad gäller växtnäring SJVFS 2015:21. Swedish Board of Agriculture, Report. [in Swedish, English summary]

Swedish National Survey. 2016. GSD-Höjddata grid 2+. Retrieved 2018-03-26, from https://www.lantmateriet.se/sv/Kartor-och-geografisk-information/.

Teutschbein, C., T. Grabs, J. K. Hytteborn, K. Bishop, R. A. Sponseller, M. Blackburn, and E. W. Boyer. 2017. Future Riverine Inorganic Nitrogen Load to the Baltic Sea From Sweden: An Ensemble Approach to Assessing Climate Change Effects. *Global Biogeochemical Cycles*, 31**:** 1674-1701. DOI: 10.1002/2016GB005598

van der Grift, B., H. P. Broers, W. Berendrecht, J. Rozemeijer, L. Oste, and J. Griffioen. 2016. High-frequency monitoring reveals nutrient sources and transport processes in an agriculture-dominated lowland water system. *Hydrology and Earth System Sciences*, 20**:** 1851-1868. DOI: 10.5194/hess-20-1851-2016

VISS. 2018. Sege å. Retrieved 2018-04-13, from http://viss.lansstyrelsen.se/Waters.aspx?waterMSCD=WA58368107.