PHOSPHORUS RISK ASSESSMENT IN SURFACE WATERS

Determination of phosphorus losses in the Romdrup Å catchment from surface erosion and drainage pathways.

AALBORG UNIVERSITET

Teresa Narciso
Master Thesis in
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Synopsis:

Determination of the risk of phosphorus leaching to surface waters through surface and land drainage transport. The project aims to analyze and measure the leaching of P to the aquatic environment through an evaluation of the surface erosion from surrounding soils and from agricultural drainage from the catchment. The chosen case area for field measurement and analysis is the Romdrup Å basin, located in the eastern Aalborg Municipality. Through a comparison of the different sources and their rates, the risk of P accumulation can be predicted. A visual combination of sources is carried out through GIS. Data is collected through water and measurement of suspended solids, input through runoff and drainage, and land use analysis. The Revised Universal Soil Loss Equation is used to account for the overall soil loss from the catchment. The NAM model (Mike11, DHI) is used to study the distribution of soil moisture through the different soil storages. In the final part, the chosen methodologies are discussed in terms of efficiency in answering the problem statement, and hypothesis on further improvements are presented.

Dansk Resumé

Udledning af næringsstoffer til overfladevand er en af de primære faktorer der har effekt på vandkvaliteten i ferskvand og marine systemer, i hele Europa. Vandkvaliteten i danske vandløb har været konstant overvåget i de seneste 20 år, for at sikre en reduktion af næringsstof udledning fra specifikke kilder samt fra diffuse kilder. Mens reduktion fra kendte kilder såsom urban afstrømning og vandværker har givet positive resultater, opnås kun nogle væsentlig reduktion fra diffuse kilder. Eksempler for diffuse kilder er landbrugsproduktioners afstrømning, og spredt dræning over landskabet. Disse er de mest dominerende faktorer der har effekt på fosfor koncentrationer i vandløb, fra diffuse kilder, jord tab og overflade afstrømning fra landbrugsjord, Dette er en undersøgelse om erosion og om hvordan fosfor bliver transporteret fra jorden til åer og vandløb. En kombineret undersøgelse af erosion og afstrømnings processer er foregået under hensyntagen til eksamen i et mindre opland i Nordjylland. Projektet undersøger afvandingsområdet ved Romdrup Å, beliggende i Aalborg Kommune. Analysen er gennemført for at besvare følgende spørgsmål:

"*How can the phosphorus leaching and accumulation to a stream from the catchment be predicted from runoff and erosion potential?"*

For at undersøge de processer der har effekt på fosfor koncentrationen i Romdrup Å, er erosion og hydrologisk modellering udført, samt feltmålinger til test af baggrundskoncentrationer. Erosion er undersøgt ved anvendelse af den reviderede universelle jord tab ligning (Revised Universal Soil Loss Equation -RUSLE), udviklet af USDA. Hydrologisk modellering for at undersøge afstrømning og vand bevægelse i jorden, er foregået gennem NAM (Nedbør-Afstrømnings-Model), udviklet af Dansk hydrologisk Institut (DHI). Jord tab over Romdrup Å afvandingsområde viser maksimale værdier af 240.614 (tons/han/år) i få steder i bække nettet, og betyder en værdi af 0.5503 (tons/han/år). Interflow og overflade afstrømning dominerer over infiltration over afvandingsområde, observeret fra NAM modellerings resultater.

Feltmålinger blev gennemført på angivne steder langs åen, for alt og opløst fosfor samt suspenderet sediment belastning. Højeste koncentrationer af total og opløst reaktiv fosfor blev observeret i slutningen af maj, med en maksimal værdi på 45.736 (µg/L), fundet i afsnittet opstrøms i Romdrup Å for total fosfor, og en maksimal værdi på 45.852 (µg/L), målt i nærheden af stream outlet. Resultaterne gør det ikke muligt for nøjagtig identifikation eller høj risikoområder til fosfor udvaskning, på grund af den lave opløsning af de enkelte parametre, og hvilken slags arealanvendelse der er over afvanding. Feltmålinger giver mulighed for at overveje afløbs kanaler som vigtige faktorer kontrollerende vand koncentrationer af fosfor, og bør undersøges yderligere.

Preface

This report has been written during the 3rd and 4th semester of the Master Program in Physical Geography at Aalborg University.

The chosen referencing method is the Harvard Referencing system.

Special thanks is given to the following for assistance in the realization of the project and help during fieldwork and supervision:

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- **Vincent Jimmy Hieu Duy Ngo** – Assistant, Department 6-Department of Civil Engineering, Fredrik Bajers Vej 7, Aalborg
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1 Introduction

Nutrient loading in surface waters is one of the major contributing factors to the loss in biodiversity and water quality, a process known as eutrophication. Alterations in water quality have occurred since the 1950s extensively throughout Europe, in particular in areas most effected by nutrient rich discharges (Danish Environmental Protection Agency & National Environmental Research, 2016). A portion of the current threat to surface waterways, is represented by the excessive amount of surface runoff carrying dissolved phosphorus and nitrate, and the consequent loss of biodiversity and often severe alterations of aquatic ecosystems. The sources often outnumber the effects, and can vary significantly according to the intensity and distribution of human activities and environmental pressures.

Phosphorus concentrations in streams has been extensively monitored in Denmark for the past 20 years, with observed general reductions in concentrations both in small streams and estuaries (Windolf, et al., 2014). Losses from cultivated areas as non-point sources of pollution are difficult to predict and to quantify (Danish Environmental Protection Agency & National Environmental Research, 2016). According to the European Environment Agency major sources of phosphorus are wastewater plants and household drainage, while main sources for nitrate are surface runoff from agricultural catchments (European Environment Agency, 2016). Since 1989 significant improvements have been made in reducing phosphorus inputs from point sources, with a reduction of 40% of total phosphorus concentrations (Kronvang, et al., 2001). At the same time, leaching occurring from open countryside and scattered housing has not shown significant decline (Kronvang, et al., 2001), underlining the importance of non-point sources from the catchment level. Examples of primary non-point sources of phosphorus are also represented by runoff from agriculture and pasture, urban runoff from surface water drainage and sewage, as well as runoff from construction areas and abandoned mines (Johnson B, 1998).

In general point sources are the dominant factor to the cumulative effect of phosphorus and nitrate to surface waters (Johnson B, 1998), however non-point sources still represent a significant percentage of the total monitored concentrations. Uncertainties in non-point leaching are related to many factors, such as spatial distribution and extensiveness of the processes involved. In this project it is attempted to analyze the catchment processes involved in the transport of phosphorus to streams, through a relevant case area. In its natural dissolved form orthophosphate is considered a limiting nutrient to vegetation, for it reacts easily to mineral compounds found in soils (Forbes, 2015). Municipalities carry out constant monitoring of active and newly constructed drainage channels, yet there can be lack of continuity over long periods of time, and channels may alter their functionality if not maintained or monitored on a regular basis. For these mentioned reasons the drainage and input from channelized drains, will be taken into consideration in this report.

In naturally occurring concentrations, phosphorus does not pose a threat, yet its extensive use as a chemical fertilizer has led to unnatural increases in concentrations (Forbes, 2015).

Processes responsible for the transport of dissolved and particulate phosphorus may vary significantly over the landscape. It is therefore necessary to examine the multiple geographical, hydrological and morphological processes involved. In summary leaching of phosphorus is a naturally occurring phenomenon, yet accelerated by human activity. Specifically generating an unbalanced phosphorus concentration in nature (Beegle, 2016).

Objectives to control and identify risk areas from which phosphorus leaching represents a hazard to water quality must take into consideration soil concentrations derived from agricultural practices, and vulnerability of the catchment to surface runoff and soil loss (Beegle, 2016). Therefore it is expected that a close investigation of the erosion potential from a defined watershed, and hydrological models represent viable tools to identify sensitivity of certain areas.

Figure 1. Romdrup Å (photo taken by author)

1.1 Case study

All in all, an analysis of how diffuse sources of runoff and drainage, carrying potentially high concentrations of nutrients from an agricultural and urbanized catchment, is carried out. Specifically the catchment area of Romdrup Å, located in Northern Denmark, will be analyzed for erosive processes, hydrological modelling of surface runoff, and presence of drainage channels along the stream. Generally acclaimed processes representing a threat to numerous waterways in similar areas, will be investigated in a specific location, considered at risk for the above mentioned pressures.

2 Research Question

Phosphorus is the primary nutrient responsible for algae and weed growth in freshwater environments, making it the primary cause of increased productivity and consequent eutrophication in Danish waterways (Perlman, 2016). Due to great emphasis from Water Framework Directive to limit and possibly reverse the processes of eutrophication, effecting the ecological condition and biodiversity in most European waterways, the problem of nutrient loading must be taken into consideration (Chave.P, 2001).

This project will focus on the transport and input of nutrients from the catchment, which includes verified land use, with non-point phosphorus sources in the forms of drainage channels and drainage from agricultural fields. A component is also represented by sewage and wastewater. Nutrients such as nitrate and phosphorus are responsible for the eutrophication processes in surface waters. Different compounds follow specific transport pathways and are derived from these both localized and diffuse sources. In this report, an attempt to analyze the rate of phosphorus leaching from catchment diffuse sources will be conducted. Phosphorus, both in particulate and dissolved form, is derived from surface erosion and transported bound to sediment. Surface runoff and wastewater channels, also represent an important factor. In order to analyze the specific risk of such inputs to the streams, a study of the erosion risk along a stream will be conducted, through a combined study of soil properties, and rainfall intensity.

Thereby the purpose formulation of this project can be states as the follows:

"How can the phosphorus leaching and accumulation to a stream from the catchment be predicted from runoff and erosion potential?"

As stated in the above research question, an attempt is made to identify the various components to the nutrient loading to the stream. This is done through numerical modelling of the processes at the catchment level, and combined with field measurements to verify the presence of dissolved reactive phosphorus and total phosphorus concentrations in Romdrup Å.

3 Location description

In this report the case area chosen for the erosion and phosphorus leaching analysis is Romdrup Å. a stream located within the municipality of Aalborg. The stream is roughly 11 km long and the catchment covers an area of 28km^2, located in the areas of Aalborg Øst, Klarup and Gistrup. The stream has its outlet in the Limfjord in proximity of the Aalborg harbor.

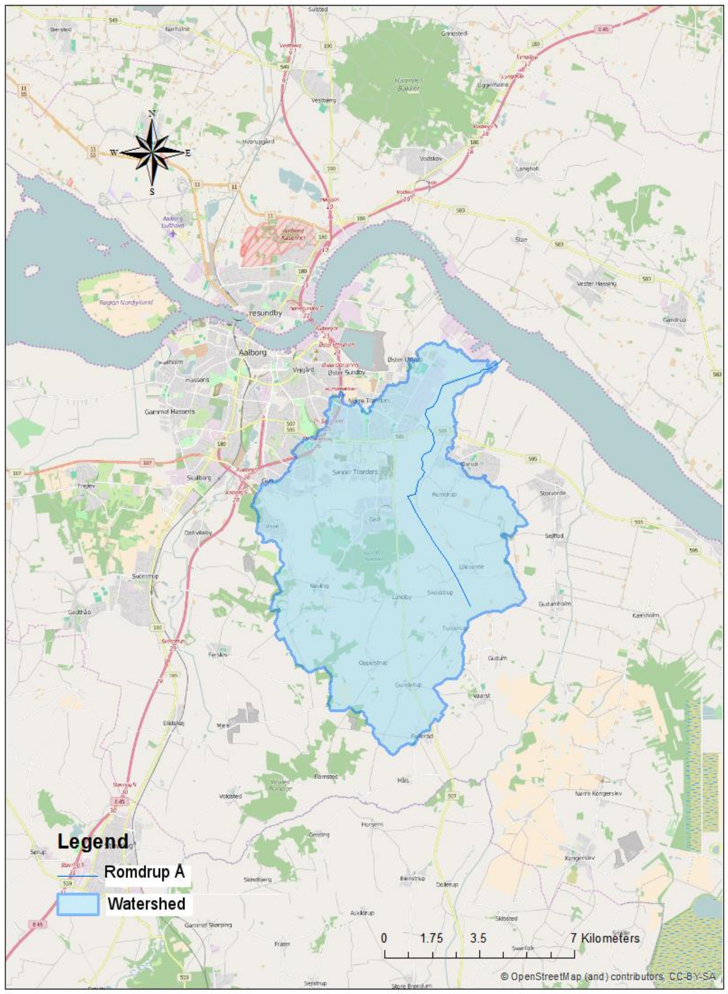

Figure 2 Watershed of Romdrup Å and location

The catchment presents a variety of land uses constituted primarily by agricultural areas and to a smaller extent urban areas. In this section the characteristics of the catchment will be looked upon in relation to climate, soil properties and land use. The Romdrup Å basin is comprised of agricultural and urban/industrial land use forms, making it diverse in relation to the processes described in this project. The presence of numerous drainage channels intersecting Romdrup Å, collecting rainwater, surface runoff and occasionally sewage from scattered building, urban areas or industrial areas, is an important element to of focus in the report.

3.1.1 Land Use and Soil description.

The catchment presents a variety of land uses, comprising both urban residential areas, as well as open cultivation and agricultural areas- The majority of the basin area is constituted of grown non-irrigated fields. Land use based on CORINE geodataset (Corine, 1995) data can be seen in figure 3.The dominant soil variety in the area shows a diverse range of soil types. Open areas with low slopes are characterized by humus soils. In the northern part of the basin, close to the boundary with the Limfjord, there are predominantly clayey and coarse sandy soils, while inland predominantly sandy and loamy soils. The dominant soil texture class is represented by loamy sand and humus soils, as shown on Figure 2.

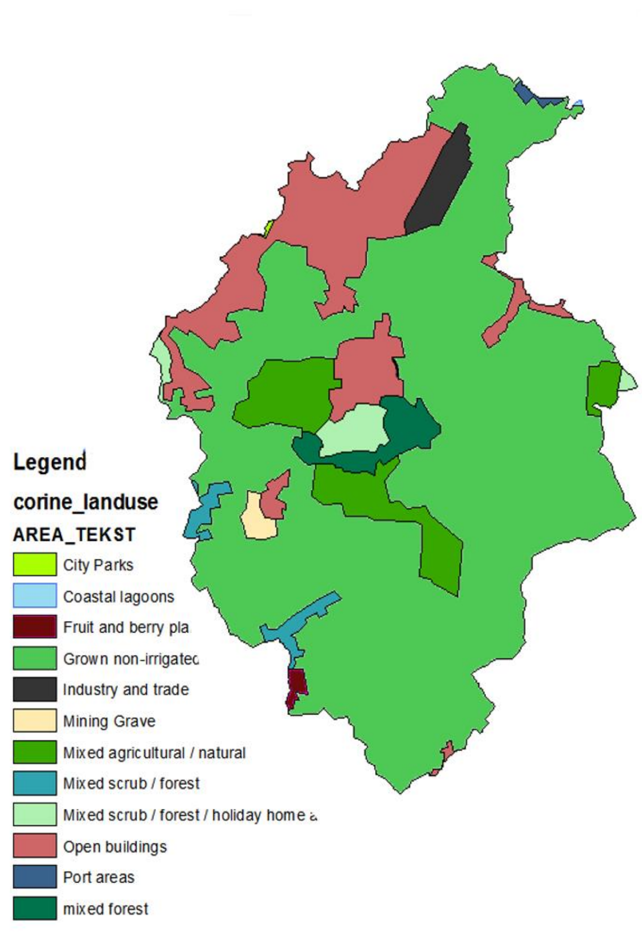

Figure 4 Land Use map of Romdrup Å (DJF, geodata, 1995)

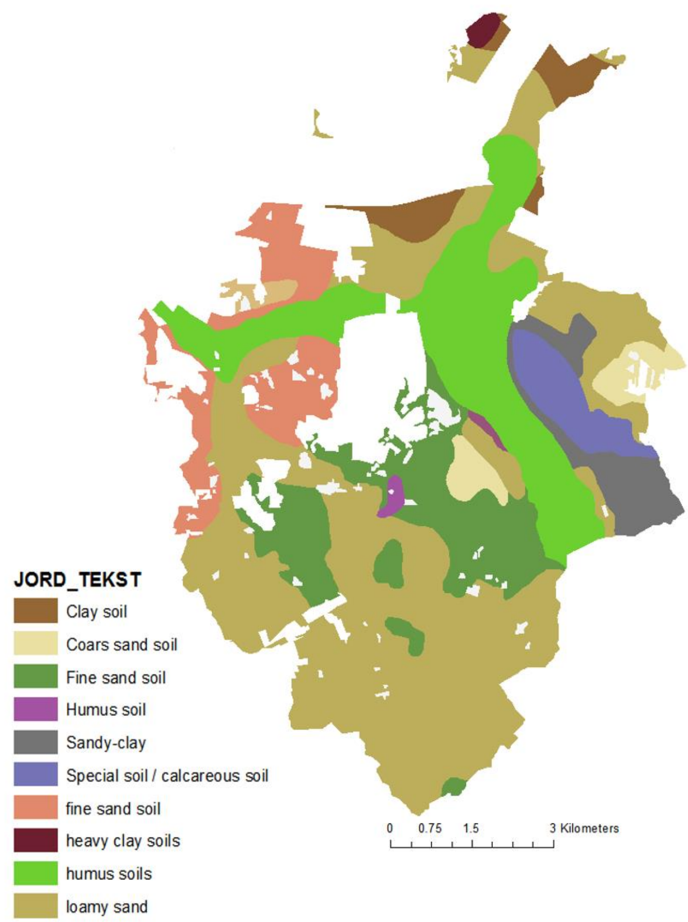

Figure 3 Soil type distribution (DJF, geodata, 1989)

3.2 Climate

In the eastern part of Northern Jutland the climate can be described as more continental than areas located in the western part. According to Danish Meteorological Institute (DMI), mean annual precipitation between the years 2001 and 2010 shown an average of 765mm, with August and October representing the wettest months, while March and April those with the least rainfall. Average annual temperature is 11.9ºC with July representing the warmest month (21ºC) and January the coldest (3.3ºC) (DMI Vejr, 2016).

3.3 Land Use drainage

Along the stream channel there is a high density of drainage channels, intersecting Romdrup Å. According to the surveying conducted by *Aalborg Kommune Miljø og Energiforvaltning* (2016), the streams channel presents many scattered drainage outflows. The drainage pipes entering the stream are classified as wastewater, surface water drains, and private drains. There is one wastewater drain and one surface water drain along the stream channel, both located close to the outlet, conveying wastewater and runoff from the near industrial area and port. Upstream of these outlets, only surface water drains are found, which represent both agricultural drainage and private drainage from scattered housing sites.

*Figure 5 Location of major drainage pipes and channels along Romdrup Å**Invalid source specified.***

4 Phosphorus dynamics and transport in soils and surface waters.

In this section the theoretical assumptions used to validate the problem statement will be described. Specifically the processes linking soil phosphorus and sediments erosion at a catchment level.

High concentrations of phosphorus entering streams from agricultural catchments have been linked to the increasing problem of eutrophication in water bodies, therefore representing a threat to biodiversity and maintenance of good ecological status (Jensen, et al., 2006). Agricultural soils, rich in added nutrients and fertilizers, result in a high release of nutrients such as nitrate and phosphorus. Nutrient losses from agriculture and non-point sources have gained importance in management practices (Jensen, et al., 2006). Due to the fact that phosphorus has been linked to sediment loss (Sharpley, et al., 2001) making it possible to establish a link between source and concentration in streams. The leaching of P to surface waters therefore linked to soil erosion, drainage and water movement through interflow and surface runoff. These processes will be looked upon, as well as the different human and non-human processes influencing P losses.

4.1 Phosphorus cycles and forms

Primary source of phosphorus is the weathering of calcium phosphate (apatite) found extensively in soils and rocks. In nature phosphorus is found as phosphate ($PO4^{3-}$), being a negative charged phosphorus atom bound to an oxygen atom. It can be found bound to minerals or to organic particles (Lenntech, 2016). The main flux of phosphorus occurs through riverine transport, as bound to sediments, which deposit most of P in the sediments and only a small percentage is available to organisms (Bernhardt, 2013).

The natural phosphorus cycle occurs slowly over long time periods, through erosion and weathering of sedimentary rocks, as well as through plant and animal decay. Due to the low solubility of phosphate, the element tends to remain bound to particles, thus concluding its cycle once again in rock formation through deposition (Bernhardt, 2013). Phosphorus is added as a fertilizer, and is rapidly removed due to its uptake by crops. As stated in (Joseph L Domagalski, 2012) cultivations of soybean, corn and wheat are the crops in which the highest amounts of phosphorus are employed in the harvest.

Phosphorus presents itself in various chemical forms in different processes. With dissolved P (DP) reference is made to the orthophosphate, which is available to plants as a nutrient. Dissolved P is usually depleted is the pool is not replenished (Busman, et al., 2009). According to (Busman, et al., 2009) higher phosphorus concentrations are associated with finely textured soils and not coarser soils. Active P is the inorganic form of P which is found bound to soil particles, which is also available for plant uptake when dissolved (Busman, et al., 2009). This form of P is retained into soils, binding to smaller particles through a process known as absorption. The concentrations increase in relation to the phosphate in solution concentrations, through mineralization of the solute phosphate (Busman, et al., 2009). For this reason P can be mobilized through the erosion and weathering of the smaller soil particles, such as silt and fine sand. In the diagram below created by (Busman, et al., 2009) this relationship is shown.

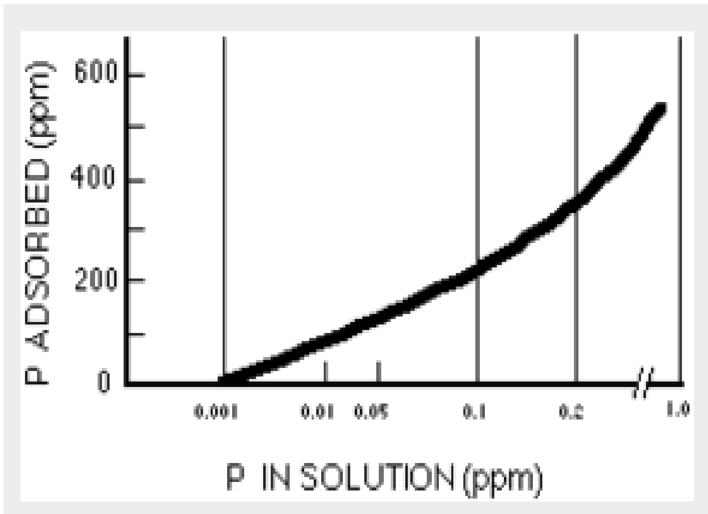

Figure 6 Solute P and Soil P relationship (Busman, et al., 2009)

Phosphorus losses are imputable to Dissolved Phosphorus (DP) and Particulate Phosphorus (PP), entering stream through erosion and runoff. Particulate Phosphorus (PP) represents the majority of the P entering waterways and contributing to the overall threat of eutrophication by approx. 75% to 90% (Randall, et al., 2016).

Phosphorus occurring in the form of dissolved reactive phosphorus primarily derives from the drainage of sandy or loamy catchments, which are commonly found in Denmark (Jensen, et al., 2006). Particulate phosphorus primarily derives from inputs of inorganic and organic matter bound to sediments (Jensen, et al., 2006). The addition of manure and fertilizers will add plant available P to the soils. Depending on several factors such as acidity, temperature and moisture content, the available P will decrease in availability as it is absorbed by the soil particles and mineralized (Busman, et al., 2009). This will result in a decrease in available P over time. Soils with pronounced acidic ($pH<5.5$) and alkaline ($pH>7.3$) will result in a more rapid P depletion, therefore making soils with a pH between 6 and 7 more suitable for P utilization (Busman, et al., 2009). When P is not utilized by plants due to of it's binding to the soil particles, the soil will result potentially fertile, but the conditions do not allow for an efficient use of the nutrient (Busman, et al., 2009).

4.2 Texture and Infiltration capacity

Soil composition is crucial in effecting the infiltration capacity of water. Texture and structure effect the movement of water through pores and determines the availability of water to the roots. Specifically, texture is determined by the dominant mineral fraction of a specific soil composition, effecting the porosity and aggregation of the soil structure. Fine textured soil have a predominance of clay, with low porosity (Brouwer, et al., 1985). Medium texture soils, silt is predominant, and are considered loamy soils. Sand is the predominant texture fraction in coarse soils, thereby classified as sandy soils. Soil structure is determined by the aggregation of the soil particles, combined with air filled porosity and organic matter. These factors combined, effect the infiltration capacity of soil, as well as water movement capacity through the soil layers (Brouwer, et al., 1985). Due to the presence of large spaces between soil particles, in coarse soils, water can flow easily through the structure, as well as reach vegetation roots more easily (Brouwer, et al., 1985).

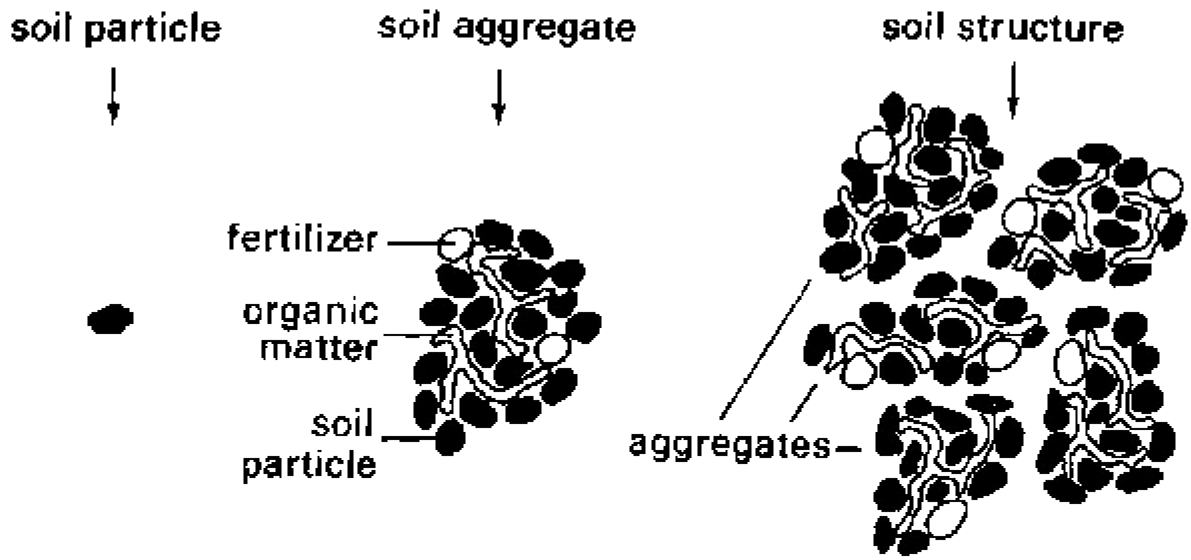

Figure 7: Soil aggregation and structure. Image from FAO Land and Water (Brouwer, et al., 1985)

4.3 Soil Loss Factors

Soil texture and particle size play greatly influence the soil erodibility when exposed to rainfall, surface runoff, or water movement within the soil column (Roose, 1996). According to the Hjulström's diagram, lighter soil will be soils consisting primarily of fine sine (100μ) are more easily eroded and transported, until transported longer distances before deposition than heavier soil particles. Soils with higher clay content and/or coarser particles, which will result in a shorter distance between take up and deposition (Roose, 1996).

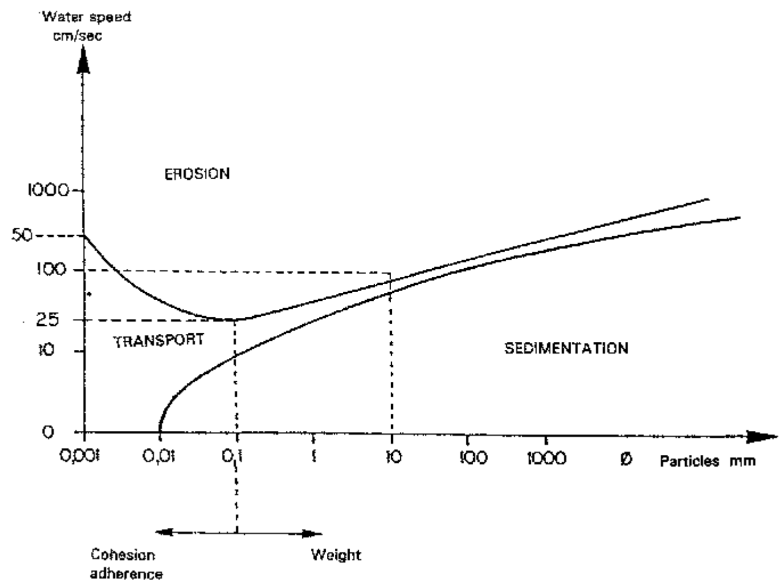

Figure 8 Hjulström's diagram (Roose, 1996)

In this context the tool chosen to quantify the erosion over the catchment of Romdrup Å is the Revised Universal Soil Loss Equation. The model shows the erosive process of detachment, transport and deposition of soil particles (Renard K.G, 1997). Erosion is therefore considered as the function of climate, soil properties, topography, surface conditions and human activities (Renard K.G, 1997).

4.4 Water Quality

It has been found that the leaching of phosphorus from agricultural catchments is derived primarily to the movement of water through soil, as well as erosive process and catchment drainage (Jensen, et al., 2006). When maximum soil saturation b Particulate P is usually the most significant fraction of the overall surface as runoff or within the soil layer as interflow. Phosphorus dissolved in water, will move carried with the generated flow, entering waterways, since it is be flow bound to organic matter and sediments. P is therefore carried through runoff and erosion from neighboring agricultural lands (Randall, et al., 2016).

Dissolved inorganic phosphorus is present in the topsoil through sorption. Little amounts leaching into waterways through surface runoff. If the sorption capacity of the soil is reached with higher DIP concentration leaching occurs. Threshold of phosphorus saturation varies according to soil type, with a higher risk of leaching occurring in soils with high organic matter contents (Jensen, et al., 2006). This occurs since organic matter limits the soil sorption capacity, therefore retaining less dissolved phosphorus compounds (Jensen, et al., 2006).

Different soils have different capacities to retain P. Generally coarser soils will not retain high amounts of P, unlike more finely textured soils which will have a higher capacity to adsorb the element. For this reason, coarser soils will cause higher amounts of solute P to travel to neighboring water bodies (Busman, et al., 2009). On the other hand finer textured soils, have a higher erodibility which will result in soil particle uptake by water movement either in the form of runoff, and interflow. This will result in Particulate P travelling to neighboring water bodies, and dissolved once the particles are present in water, and generating alteration of water quality even at minimal increments in concentration (Busman, et al., 2009).

While it is possible to estimate how much P is carried from the catchment to streams, and its established connection to oxygen depletion and eutrophication in surface waters, it is less easy to establish threshold values for the concentration of Total P and Dissolved P in streams (Kronvang, et al., 2015). More specifically, it is difficult to determine how what concentrations a particular waterway can tolerate before eutrophication occurs. Rivers and streams may have different loading capacity depending on the pressure from the catchment processes as well as the hydrodynamic regime of the specific waterway. According to (Dodds & Smith, 2016) concentrations are Total P (µg/L) < 25 in Oligotrophic streams and Total P (µg/L) > 75 in Eutrophic streams. These values have been investigated through the measurement of stream benthic chlorophyll, nutrients and biomass (Dodds & Smith, 2016). In general Dissolved P represents the most available form, which can create rapid algae growth due to its solute form, while Particulate P represents a pool of potentially available P by becoming soluble over time (Randall, et al., 2016).

4.5 Elements of surface erosion in the RUSLE

The Revised Universal Soil Loss Equation (RUSLE) is a tool developed by the United States Department of Agriculture (USDA), which allows to estimate erosion by accounting for rainfall, soil properties, slope variation and land cover. It represents a developed form of the Universal Soil Loss Equation (USLE), developed by (Wischmeier & Smith, 1978). The equation allows to estimate the amount of soil loss per unit area, mainly from agricultural fields. The model has been extensively used in numerous catchments around the world (Renard, et al., 1997). The RUSLE is presented in the following expression (1) and provides the magnitude of erosion as the product the factors employed in the model.

$$(1) \quad A = R * K * LS * C * P$$

Where:

A	Amount of erosion expressed as mass per unit area	(ton he $^{-1}$ year $^{-1}$)
R	Rainfall erosivity factor	(t-m cm ha^{-1} h^{-1} year^{-1})
K	Soil erodibility	(0<K<1)
LS	Slope-length/steepness factor	(°m^{-1})
C	Crop factor or land cover	(0<C<1)
P	Conservation factor	(constant)

(Rekolainen & Leek, 1996)

The equation (Nielsen & Søe, 2015) yields a potential amount of erosion, obtained through the product of the above mentioned factors, expressed as annual soil loss potential in (tons/hectare/year). Therefore by combining morphological, geological and climatic data it is possible to obtain a potential amount of erosion for the specific catchment. As most of the P entering waterways derives from surface erosion, this model can provide an indication as to what is the potential magnitude of P leaching to the analyzed catchment. The RUSLE aims to estimate soil loss from specific areas through a series of equations and parameters which describe the conditions and pressure on the catchment. The model is the result of the product of different factors hereby listed. As mentioned by (Rekolainen & Leek, 1996) , the RUSLE is not an event-based model but is based on annual rainfall data, therefore providing a cumulative erosion amount for the studied catchment (Rekolainen & Leek, 1996).
The chosen model to analyze the magnitude of soil loss over the catchment relies on theoretical assumptions and description of the individual parameters. Each parameter or product of the equation is the spatial measure of a component responsible for erosion and soil loss. These components will be described and their values referenced for further interpretation of the results.

4.5.1 RUSLE Factors

First term in the equation is the rainfall erosivity factor (R), which described the effect of intense rainfall events on soils, using several years of recorded events to analyze soil vulnerability (Panagosa, et al., 2015). Highest values for rainfall erosivity factor in the European Union are found in the Mediterranean and alpine regions, with average values above 1000 (MJ mm ha^{-1} h^{-1} yr^{-1}), while lowest values are found in the Nordic countries, lower than 500 MJ mm ha^{-1} h^{-1} yr^{-1} (Panagosa, et al., 2015).

Soils characteristics are defined by the K factor, or soil erodibility factor. Average values for the K factor in Europe 0.0246 (t ha h ha−1 MJ−1 mm−1) (Panagos, et al., 2013). Highest K values have been linked to medium to finely textured soils as shown in (Panagos, et al., 2013) in Figure 9.

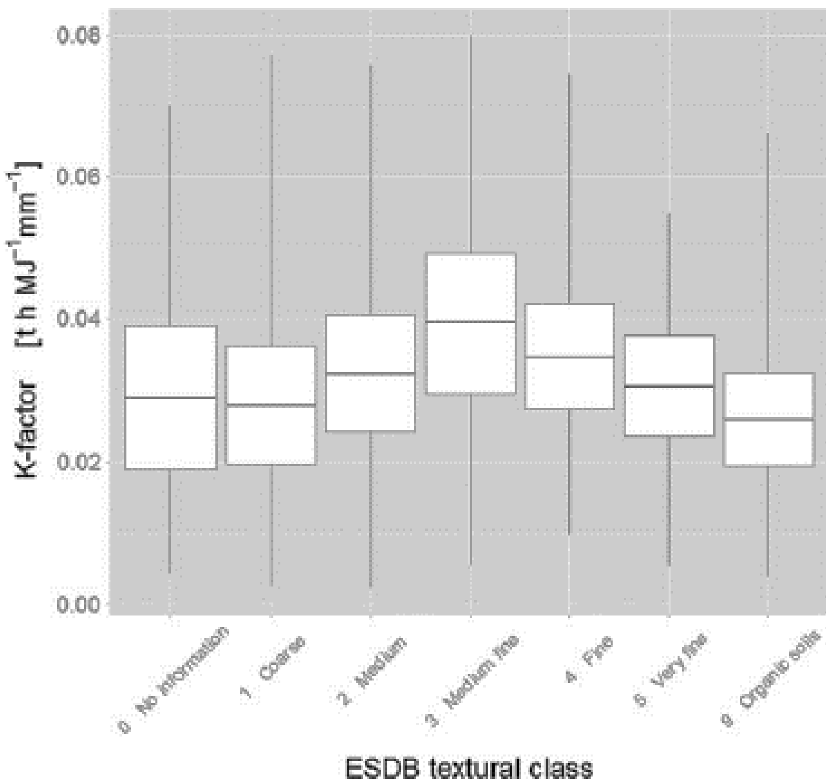

Figure 9: K factor variations for soil texture classes based on LUCAS database (Panagos, et al., 2013)

Effects of topography are described by the slope-length factor (LS). The distribution of the slope gradient is taken into consideration, since slope is not evenly distributed in all parts of the case area (Wischmeier & Smith, 1978). The slope length factor determines the slope of the area between the initial detachment of soil and the subsequent area of deposition. Depending on the number of uniform slope segments, there will be a higher soil loss correlated to a lower number of slope segments. In general, higher levels of soil loss are found where the slope length factor is higher, specifically where the longest distance is found between detachment and deposition.

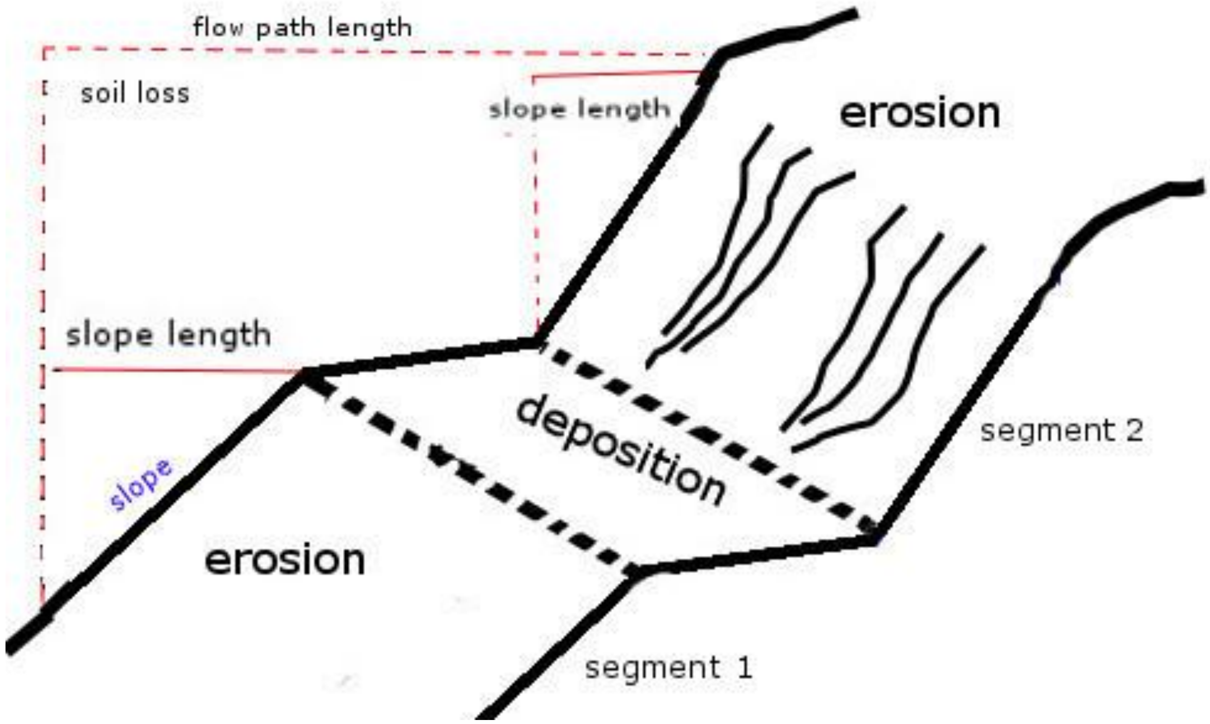

Figure 10 description of the Slope-Length factor

Great importance is given also to the cover management factor (C) in determining erosion risk. Vegetation cover and its variations throughout the year, effects the soil aggregation properties, as well as the exposure to climatic pressure. Generally values for C factor increase with lower vegetation cover, due to higher exposure of soil to weathering (Panagos, et al., 2015). Variables such as seasonal canopy cover and crop rotation periods (Wischmeier & Smith, 1978), as well the bare or tilled state of the soil. The C factor described an index of the cover management practices, applied over a certain agricultural area (Wischmeier & Smith, 1978). Ad hoc calculations of the C factor consider prior land use, canopy cover, canopy height, surface roughness and soil moisture (Panagos, et al., 2015). In Denmark, calculations for the C factor conducted at the European level, show the following values as references according to agricultural practices

Land Use	C Factor (DK)
Pastures	0.0905
Complex cultivation	0.1250
Agriculture and natural areas	0.1152
Forests	0.0012
Grassland	0.0424
Transitional wood and shrub	0.0216
Sparse Vegetation	0.2648

Table 1 Values for C factor for land use classification in Denmark (Panagos, et al., 2015)

The support practice (P) factor takes into consideration the practices taken by farmers under specific regulations, to reduce the risk of erosion from fields and plots of land (Panagos, et al., 2015). For the reference dataset used in this report, the values for P at a European level, were based on rules applied to member states by the Common Agricultural Policy (Panagos, et al., 2015). As stated in (Renard, K.G., et al., 1991) and cited in (Panagos, et al., 2015)"*The P-factor accounts for control practices that reduce the erosion potential of runoff by their: "The influence on drainage patterns, runoff concentration, runoff velocity and hydraulic forces exerted by the runoff on the soil surface".* Examples of support practices can be contour farming, strip cropping, terracing and subsurface drainage. The lower the P factor, the higher measures are taken in a specific area to reduce surface erosion by farmers. (Panagos, et al., 2015).

5 Methodology

In this section the methodology and approach used to determine P pathways through erosion, as well as the filed measurements conducted will be described.

5.1 General Approach

In order to solve the question presented in the problem statement on Page 6, a combination of erosion modelling and rainfall-runoff modelling will be used. The models will be applied to the designated catchment area. The general approach is represented in the following schematic.

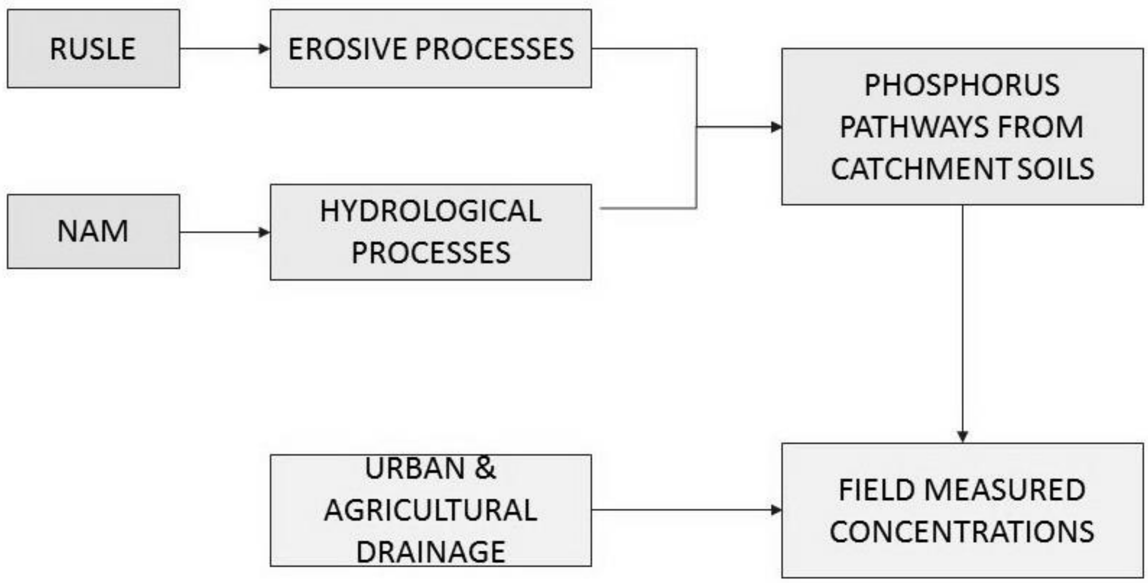

Figure 11 schematic of the methodology approach

Phosphorus usually bound to soil particles from non-point sources is this case is estimated through erosion potential in the catchment. Therefore the major sources of phosphorus loading to surface waterways is represented by erosion and runoff (Perlman, 2016).Erosion from Romdrup Å catchment area will be analyzed with the Revised Universal Soil Loss Equation (RUSLE), to analyze the amount of soil loss over the entire basin. The factors will be calculated based upon available data, and obtained from literature, where data is not sufficient.

In order to identifying amount of surface runoff which is commonly generate and how the catchment responds to rainfall intensity the NAM model is used with the purpose of isolating the highlighting the magnitude of the interflow and surface runoff in the catchment. These represent the primary process though with Phosphorus is delivered from the catchment to the streams. The combination of the two different models along with the hydrological and soil characterization of the catchment areas, can provide an estimate of the pathways and magnitudes of P losses entering the stream. In the final part field analysis is carried out through collection and analysis of water samples, tested for total P and dissolved P, as well as suspended solids.

Most waterways can be effect by a variety of stressors, and run though different types of environments and land use, it can be useful to combine the different evaluated inputs, into a dynamic system able to take into account various factors and channels of nutrient leaching, through which the specific water channel is affected. Specifically the project focusses on surface erosion, agricultural drainage, and sewage input. These elements are considered to be differentiated sources for the P measured within the stream.

The results of the phosphorus concentration in the water, based on field sampling occurring in mid-April and late May, are used to indicate general content in P, and attempt to highlight the variation in dissolved and total phosphorus occurring downstream of drainage outlets. In this way it can be evidenced how the drainage channels to the stream, may be the cause of phosphorus loading in the water, in addition to erosion and surface transport from overland flow. The phosphorus sourced from the soil in the catchment is estimated though the analysis of soil texture type and land use. Therefore the effective concentration of P in the soils, is not directly measured, but estimated to pre-existing data.

5.2 Basin Analysis

The processes through which the watershed is delineated will be briefly described in this section. Starting from the 10m grid Digital Elevation Model (DEM) of Denmark (Effektivisering, 2016), the area of Romdrup Å is selected. Due to the high resolution of the DEM, it is necessary to reduce the resolution in order to proceed with the other steps of the watershed delineation. The resolution can be transformed by use of the tool *AGGREGATE* in ArcMap 10.3. The *AGGREGATE* tool, allows to merge several pixel values of the DEM into a chosen number of larger pixels, by accounting for the SUM, MEAN, MEADIAN or the cell values required to form the new larger cell value. In this project it is chosen to aggregate the DEM with the MEAN value of each grid cell, and a resolution of 30x30m. The results is shown in Figure 1.1.

Next the tool FILL is used, in order to replace any hollow values through which water could flow, making it possible to see how the water would flow in a natural setting. The *FLOW DIRECTION* tool is used to calculate the angular inclination of the surface over which water would flow in a specific direction. The result can be seen in Figure 1.2. The layer file generated with the FLOW DIRECTION tool is necessary for the calculation of the flow accumulation. With use of the *FLOW ACCUMULATION* tool, it is possible to delineate the major stream, result from the accumulation of two or more adjacent or consequential cells of flow direction. The result of the flow ambulation output is shown in Figure 1.3.

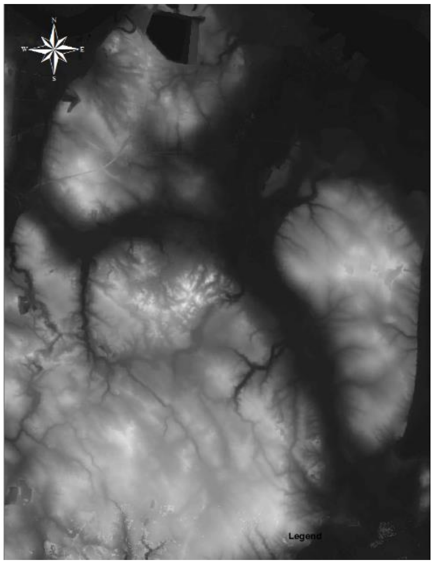

Figure 1.1: Digital Elevation Model (30x30m cell size))

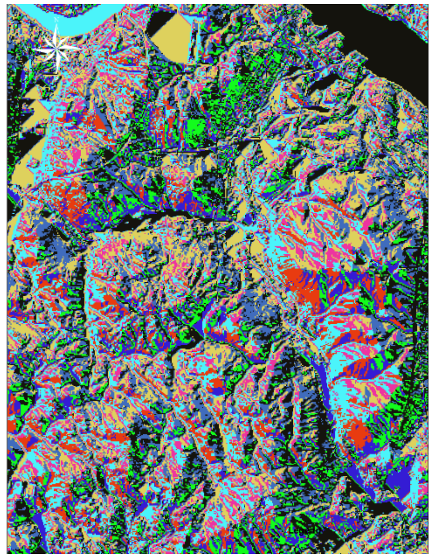

Figure 1.2: Flow direction

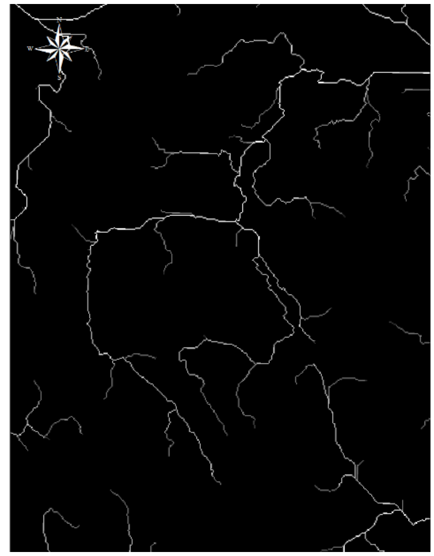

Figure 1.3: Flow accumulation

The resulting layers are necessary both for the watershed delineation and the calculation fo the Slope-Length factor in the RUSLE erosion model presented later in the project. The watershed is calculated as the sum of all accmulation occuring upstream of a chosen point, ususally the outflow point, or the point of merge between streams of different order. The basin is calculated using the tool *BASIN* in ArcMap10.3.The output results is presented on Figure 1.4.

Figure 1.4: Basin delineation

Finally the watershed is calculated using the tool *WATERSHED*, which allows to calulate the overall area of flow accumulation upstream of a determined point. The point is chosen at the outflow of the stream, but it can also be chosen at points of merge bewtween primariy and secondary stream branches, depending on the characteristics of the hydrographic network. For the purpose of this project, it is important to determine the overall area of accumulation for he stream, as it is the area from which the erosion, runoff and phophorus transport pathways ought to be analyzed. It is therefore necessary to consider the basin as a unique area and not a series af interdependant watersheds.

5.3 Erosion Model

In this section the methodology chosen for the calculation of the RUSLE factors will be described. The factors have been calculated and implemented in ArcMap 10.3 as raster layers, in which each pixel value represents a unit measure of the relative parameter. This allows for the product calculation to be applied to the entire basin, with each factor having an equal spatial resolution (10x10m) (DHM-2007, Datastruktur & Styrelsen for Dataforsyning og Effektivisering, 2007).

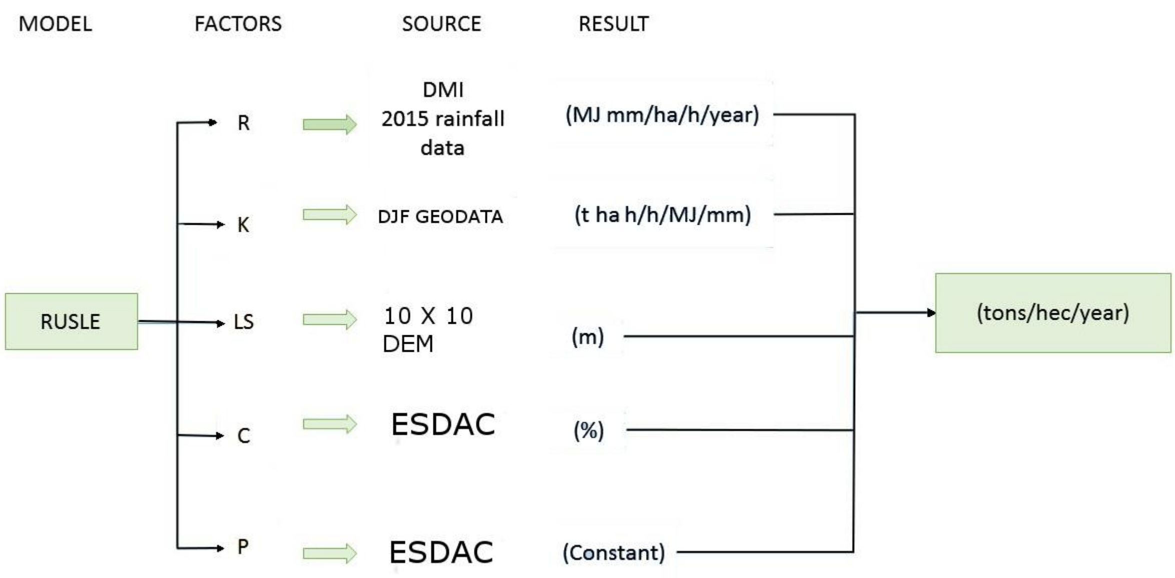

Figure 12 Schematic of data sources employed in the methodology

5.3.1 R/Rainfall Erosivity Factor

The R factor represents the erosive power of rainfall on the soil substrate. It is usually calculated with different methods according to the type and accuracy of the rainfall data available. This parameter is calculated using the modified Fournier Index (F) developed by (Arnoldus, 1980). This parameter takes into account the square sum of the average precipitation for the rainiest month and the average annual precipitation. Due to the availability of higher spatial variability but lower temporal resolution, the value has been calculated for several measuring stations taking the monthly precipitations for 1 year, for each station. Monthly precipitation data provided by DMI (Thomsen, , 2016) has been used. A description of the measuring stations, and calculated values is presented in Table 1 on page 24.

The R factor is therefore calculate with the modified Fournier index (Arnoldus, 1980) (Renard & Freimund, 1994), expressed through equation (1.1):

$$(1.1) \qquad F_M = \sum_{i=1}^{12} \frac{{P_i}^2}{P}$$

Where:

P_i	Monthly average amount of precipitation of wettest month	$[mm]$
P	Average annual quantity of precipitation	$[mm]$

(Renard & Freimund, 1994)

The R factor is estimated through the relation (1.2) yields an R factor expressed in units of (MJ/mm/ha/h/year). As stated in Freimund 1994, this relationship used to calculate the R factor from modified Fournier index values, has been found suitable for locations in which the Fm factors exceed 55mm/month (Renard & Freimund, 1994). The equation used to calculate the R factor based on the modified Fournier index (Arnoldus, 1980) are the following two relationships, found to be fitting in the relation with the R factor (Renard & Freimund, 1994). Equation (1.2) returns value measured in (MJ mm ha^{-1} h^{-1} year^{-1}) and equation (1.3) returns R values in (t-m cm ha^{-1} h^{-1} year^{-1})

$$R\ Factor = 95.77 - 6.081F + 0.4770Fm^2 \quad (1.2)$$

$$R\ factor = 0.264F^{1.50} \quad (1.3)$$

The map layer for the R factor is generated through interpolation of the R factor, calculated by means of the above mentioned equations, for 19 weather stations, located in Nordjylland and Midtjylland respectively. The chosen interpolation method is KRIGING in ArcMap 10.3.The table below indicated the name and code for the weather stations used to calculate the R factor, and obtained through *DMI Report 16-03 Drift af Spildevandskomitéens Regnmålersystem Årsnotat 2015* (Thomsen, , 2016). To obtain values for R factor for the areas between the different measuring stations, an interpolation through KRIGING (ArcMap 10.3) has been applied, which allowed to generate R values for the region. The calculated R value is expressed as a range of values or an averaged value for the entire watershed expressed in (MJ mm/ha/h/year).

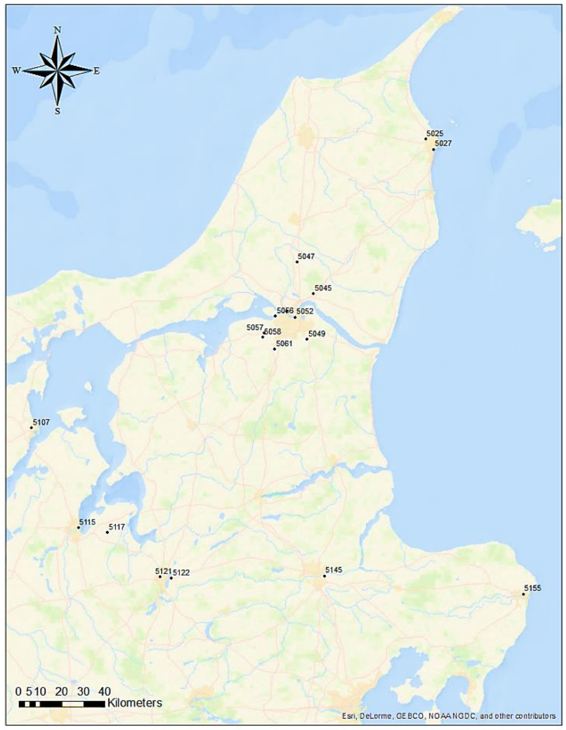

Figure 13: Rainfall Measuring Stations in Northern Jutland (Thomsen, , 2016)

Station	UTM zone 32, datum WGS84	N	E
5025	Frederikshavn Materielgård	6368352	589564
5027	Frederikshavn Centralrenseanlæg	6365840	591625
5045	Vodskov	6328973	562047
5047	Sulsted	6336906	557766
5049	Gistrup	6317424	560707
5052	Ålborg Østerport Pumpest.	6322923	557584
5054	Nørresundby Søvangen Pumpest.	6324522	555264
5056	Ålborg Renseanlæg Vest	6323092	552479
5057	Frejlev Nord Verdisvej	6318783	549809
5058	Frejlev Syd Lannerparken	6317777	549416
5061	Svenstrup J.	6314738	552419
5107	Nykøbing M. Vandværk	6294432	490677
5115	Skive Renseanlæg	6268933	502699
5117	Skive Lufthavn	6267743	510142
5121	Viborg Materielgård	6256349	523717
5122	Viborg Hedeselskabet	6256012	526645
5145	Randers Centralrenseanlæg	6257092	565937
5155	Grenå Ådalen P40	6253558	617298

Table 2: rainfall measuring stations in Northern Denmark, obtained by DMI (Thomsen, 2016)

5.3.2 K Factor

The K factor in the RUSLE represents the soils vulnerability to rainfall erosion. The effect of erosion occurs through raindrop impact on the soil surface and consequent detachment of soil particles (Renard, et al., 2010). The K factor is measured in$[t\ ha\ h\ h^{-1}MJ^{-1}mm^{-1}]$. In optimal conditions the parameter is best determined through direct observation of runoff (Renard, et al., 1997). In the specific case of the data available in Denmark, a database of (1987-89) is used, due to its extensive description of soil composition throughout the country. The methodology uses the geometric mean particle diameter $[D_g]$to and is calculated based on the primary particle size fraction in percentage (Renard, et al., 1997) in equation (2.2).

$$(2.2) \quad D_g = exp^{(0.01\sum f_i \ln m_i)}$$

Where:

D_g	Geometric mean particle diameter	$[mm]$
f_i	Primary particle size fraction	$[\%]$
m_i	Arithmetic mean of the particle size limit of that size	

(Renard, et al., 1997)

The expression through which the K factor is calculated using the texture point values present within the watershed is the following equation (2.3) (Renard, et al., 1997).

$$(2.3) \quad K = 7.594\left\{0.0034 + 0.040exp\left[-\frac{1}{2}\left(\frac{log(D_g) + 1.659}{0.7101}\right)\right]\right\}$$

The arithmetic mean of the particle size limit has been calculated based on the size ranges of the single particle fractions, as presented in Table 3: Particle size fractions for texture points in the Romdrup Å catchment, obtained from . Resulting values in the K factor with the above mentioned methodology are expressed in$[ton\ ha\ h\ ha^{-1}MJ^{-1}mm^{-1}]$ (Renard, et al., 1997).

Particle sizes	MIN (mm)	MAX (mm)	ARITHMETIC MEAN
clay	0	0.002	0.001
silt	0.05	0.002	0.026
very fine sand	0.1	0.05	0.075
fine sand	0.25	0.1	0.175
medium sand	0.5	0.25	0.375
coarse sand	1	0.5	0.75
very coarse sand	2	1	1.5
CaCO3	0.003	0.004	0.0035
organic matter	0	0.005	0.0025

Table 3: Particle size fractions for texture points in the Romdrup Å catchment, obtained from (Miljø & Fakultet, 1987-89) .

5.3.3 LS Factor

The Slope-Length factor highlights the effect generate on erosion by the shape of the landscape, as in slope steepness, slope gradient in relation to distance. This parameter is obtained from the Digital Elevation Model and the flow accumulation raster dataset previously determined for the watershed delineation. In ArcMap the SLOPE tool is used to calculate the maximum rate of change in value from a cell to its neighboring cells. The slope is calculated through the conceptual equations (3.1) and (3.2) applied to the DEM (Burroght & McDonell, 1998).

$$(3.1) \quad Percent\ of\ slope = \frac{rise}{run} * 100$$

$$(3.2) \quad degree\ of\ slope\ (\theta) = \frac{rise}{run}$$

The highest rate of change between the cell distances, identifies the steepest slope. To calculate the LS factor in ArcMap the following expression has been used, derived from the methodology of (Pelton, et al., 2016).The output result can be expressed in degrees or in percentage. Once the slope (degrees) raster is generated, the tool RASTER CALCULATOR is used to determine the LS Factor.

Raster calculator

$$LS = Power\ \left[(flow\ accumulation) * \frac{(DEM\ resolution)}{22.13{,}0.4}\right] * Power\ \left[\frac{[\sin(\text{slope degrees}*0.0175)]}{0.09{,}1.4}\right] * 1.4$$

(Pelton, et al., 2016)

5.3.4 C Factor

The C factor represents a value between 0 and 1, in which 0 expresses the minimum due to maximum vegetation cover and 1 the maximum with minimum vegetation cover. As this factor is strongly dependent on seasonality, as well as on availability of yearly variable satellite imaginary. In this report the C factor is obtained through literature, due to time and technical limitations. The data used is obtained from the European Soil Data Center (Join Research Center European Soil Data Center (ESDAC), u.d.), where the C factor is provided as a raster dataset for the EU with a 100x100 meter resolution (Panagos, et al., 2015).

5.3.5 P Factor

The derived P factor values from (Panagos, et al., 2015) show a value of 1 over the entire catchment area of the chosen location, in which the value is attributed to contouring practices. This value is included in the soil loss calculation.

5.3.6 Soil Loss Calculation

The RUSLE factors (R, K, LS, C, and P) are computer directly in ArcMap, through the tool *RASTER CALCULATOR*. Each dataset is represented as a FLOAT type raster map, of the same resolution as the DEM (10x10m). The soil loss is calculated through the following expression:

$$A(Soilloss) = (Rfactor) * (Kfactor) * (LSfactor) * (Cfactor) * (Pfactor)$$

The resulting values give a cell value expressed as (tons/ha/year).

5.4 Rainfall-Runoff model NAM

The NAM (Nedbør-Afstrømnings-Model) developed by the department of Hydrodynamics and Water resources of the Technical University of Denmark (DHI, 2012), is a lumped conceptual model, able to analyze the hydrological processes occurring as rainfall-runoff over a catchment by estimating the water content in four main storages. The input data required to run the NAM model is precipitation (mm/day), evapotranspiration (mm/day), temperature (°C) and observed discharge (m^3/day). The model works by accounting for the moisture content in the surface storage (U), root zone storage (L) and groundwater storage (G). When maximum capacity is reached in each storage, based on the characteristics of the catchment the other storages compensate the capacity. In the case of maximum capacity reached in the surface storage (U), the access water will generate surface runoff. After a specified time interval the water contained in the surface storage will infiltrate to the root zone storage (L), where interflow is generated in case maximum capacity is reached.

In this report it is used primarily to investigate the main pathways of water over the catchment and to depict which of the water storages is predominant. It therefore allows to determine the proportion of surface runoff, infiltration and interflow generated from large precipitation

Records, or single intense events, it is possible to estimate how soil particles are mobilized at the catchment level, and through which hydrological process predominantly. The input data for the model are 18 year time series for rainfall (mm), temperature (ºC), and evapotranspiration and discharge (m^3/s). Based on the topsoil characteristics and the infiltration capacity over the catchment, it is possible to point out the amount surface runoff generated. With the use of rainfall data for area for region including Romdrup Å, erosion intensity and pathways are investigated.

Model Parameters		
Surface-Root zone		Range
U_{max}	Maximum water content in surface storage (root zone)	1.0-50.0 (mm)
L_{max}	Maximum water content in root zone storage	20.0-500.0 (mm)
CQOF	Overland flow runoff coefficient	0.01-1.0
CKIF	Time constant for interflow	500-1000
CK 1.2	Time constant for routing overland flow	3-48
TIF	Root zone Threshold value for interflow	0.0-0.7
TOF	Root zone Threshold value for overland flow	0.0-0.7
Groundwater Parameters		
CKBF	Time constant for routing baseflow	500-5000
Tg	Root zone threshold value for groundwater recharge	0.0-0.7

Table 4 NAM model parameters regulating water content and distribution in the main storages (DHI, 2012).

In combination, the NAM model provides an overview of the pathways of water for the specific catchment, showing the proportion of water entering the stream through overland flow, and later response interflow. The catchment is analyzed in terms of soil properties, allowing to calculate how the potential amount of Phosphorus losses from soils, both in the top layers and in the upper soil horizon. Soil samples along the stream used to determine K factor (tons/hectare) will be collected along buffer zone, present along the stream.

The main water storages taken into consideration in the model will be briefly described in the following paragraphs.

5.4.1 Evapotranspiration

Evapotranspiration, represents the potential moisture available to the root zone vegetation, and occurs when the moisture content in the root zone results lower than the potential evapotranspiration. When the difference between surface storage moisture content and potential evapotranspiration is positive, effective evapotranspiration can be generated, and is directly proportional to the soil moisture content in the root zone (DHI, 2012) is calculated in the model through equation 4.1.

$$(4.1) \quad E_a = \left(E_p - U\right)\frac{L}{L_{max}}$$

Where:

E_a	evapotranspiration
E_p	Potential evapotranspiration
U	Moisture content in surface storage
L/L_{max}	Soil moisture content in surface storage

(DHI, 2012)

5.4.2 Overland Flow

Overland flow is determined thought the NAM model, indicating the portion of rainfall not infiltrating into the soil during and after a rainfall event. It is largely dependent on the intensity and duration of the single rainfall events, and thus how the precipitation is distributed over time (DHI, 2012). This parameter can show what is the potential of surface erosion, and is based on vegetation cover, seasonality, and texture of the topsoil. Due to the presence of mainly agricultural land in the Romdup A basin, the organic matter in the topsoil can be estimated via an analysis of the type and pattern of present crops.

$$(4.2) \quad QOF = \begin{cases} CQOF\,\dfrac{\frac{L}{L_{max}} - TOF}{1 - TOF}\,P_N & for\ L/L_{max} > TOF \\ 0 & foR\ L/L_{max} \leq TOF \end{cases}$$

Where:

$CQOF$	Overland flow coefficient	$0 \leq CQOF \leq 1$
TOF	Threshold value for overland flow	$0 \leq TOF \leq 1$

(DHI, 2012)

5.4.3 Interflow

The interflow represent lateral movement of water within the soil column. Phosphorus sorption in the soil can be picked up by moving water with subsequent leaching into surface water. Based on a visual model of the interflow volume and velocity, and the soil properties and sorption capacity, and estimate of Phosphorus load in the interflow can be made (DHI, 2012). This estimate will serve as a contribution to the overall source budge and as one of the pathways of P leaching to the stream.

$$(4.3) \quad QIF = \begin{cases} (CKIF)^{-1} \frac{\frac{L}{Lmax} - TIF}{1 - TIF} U & for\ L/L_{max} > TIF \\ 0 & for\ L/L_{max} \leq TIF \end{cases}$$

Where:

$CKIF$	Time constant for interflow
TIF	Root zone threshold value for interflow

(DHI, 2012)

5.4.4 Groundwater Recharge

Growndwater recharge is the amount of water added to the growndwater storage component, based on the moisture content in the root zone (DHI, 2012).It is calculated with the following expression:

$$(4.5) \quad G = \begin{cases} (P_N - QOF) \frac{\frac{L}{Lmax} - TG}{1 - TG} & for \frac{L}{Lmax} > TG \\ 0 & for \frac{L}{Lmax} \leq TG \end{cases}$$

Where

TG	Root zone threshold value for groundwater recharge	$0 \leq TG \leq 1$

(DHI, 2012)

The above mentioned equations have not been directly calculated but represent the defining expressions implemented in the NAM model.

5.4.5 Model Calibration

The NAM model is a lumped model in which the single parameters cannot be determined based on the characteristics of the catchment. Due to the fact that the values represent an average for the entire catchment, calibration is necessary to determine the values of the parameters (DHI, 2012). Calibration of the model is done by attempting to find the best possible fit between simulated runoff (Qsim) and observed discharge (Qobs) values. The model calibration is complete when there is agreement between the shape of the hydrographs of Qsim and Qobs, peak flows and low flows (DHI, 2012).Generally it is difficult to achieve optimal correlation in each of the mentioned results, therefore it is chosen to calibrate based on the aspects which are most relevant to the purpose. A good agreement amongst the different variables, is the result of the overall water balance error WBF (%). When the WBF has a value of 0 or sufficiently close, the calibration process can be considered complete. After a series of trial simulations, in which the model parameters are adjusted for each trial, calibration is completed when the best correlation in the results is reached.

5.5 Field Measurements

Water samples have been collected along Romdup Å, to test the concentration of dissolved reactive phosphorus and total phosphorus in the water. Suspended Solids in the water have also been measured, to investigate the amount of sediment carried in suspension along the stream, responsible for part of the phosphorus present, and derived from the erosive processes investigate over the catchment. Testing for phosphorus has been done through direct water sampling, with particular regard at chosen points where the outflow from agricultural drains and pipelines was identified. The phosphorus concentrations have been determined using the approach described by (Nielsen, 2007) in "*Determination of total phosphorus and dissolved reactive phosphorus".* The article is an adaptation of the Danish Standard 292 and Standard Methods 2500-P (Pedersen M.K, 2015).

Test	Description	Unit
Total Phosphorus (TP)	Combination of dissolved and particulate P	(µg/L)
Orthophosphate (DP)	Soluble inorganic P able to be taken up by plants	(µg/L)
Suspended Solids	Sediment load in water	(mg/L)

Table 5: Description of field measured values

5.5.1 Total Phosphorus

Total phosphorus concentrations are measured after a 25ml portion of sample has been combined with peroxydisulfate, through a process known as persulfate digestion. The sample is combined with 0.25g of Potassium Peroxydisulfate ($K_2S_2O_8$), and heated in an autoclave for 30 minutes, at 120°C. The inorganic phosphorus and organic phosphorus are released as orthophosphate. The orthophosphate is then measured by ascorbic acid method (Nielsen, 2007), described in the following paragraph.

5.5.2 Dissolved reactive phosphorus

Dissolved phosphorus or dissolved reactive phosphorus is measured through the ascorbic acid method and direct colorimetry analysis (Nielsen, 2007). The ascorbic acid method consists of the combined reaction of ammonium molybdate and potassium antimonyl tartrate with orthophostate in acid medium. The heteropoly acid is formed as a product of this reaction and is then reduced to molybdenum which presents itself as intense blue colored.

5.5.3 Suspended Solids.

The suspended solids have been measure through water samples at nodal points between drainage outflows and stream segments. A total of 8 samples have been collected. Water samples has been filtered through a 2µm filter in order to allow to retain any particulate matter in the sampled water. The sample is poured onto the filter, until saturation is reached, when water passage through the filter is sufficiently slow. Filters are dried in desiccator overnight to allow any moisture to evaporate. The fraction of suspended solids, is calculated by weight measurement of the filter, minus the weight of the filter.

5.6 Data Analysis

5.6.1 Drainage contribution

In order to analyze the data and establish a more precise contribution of the drainage channels, an interpolation has been made to be able to estimate additional sample concentrations, which allow for estimation of the variation in DP and TP along the stream. Tested concentrations are given a spatial attribution as measurements accounting for the accumulated input of several drainage pipes along the stream channel. In order to estimate the relevant contribution of individual drainage channels along the stream, interpolated values are calculated. Allowing for an estimation of the relevant percentage of influence of individual drainage features along the stream.

$$X_{NEW} = \frac{X_1 + (X_{n+1} - X_1)}{N}$$

X_{NEW}	Calculated concentration for drain XX
X_1	Field measured concentrations downstream
X_{n+1}	Field measured concentration upstream
N	Number of drains between X_{NEW} and the following measurement

(Meijering, 2002)

5.6.2 Correlation and Significant difference

The datasets are also tested for significant difference between the values of the two measurements days through correlation coefficient and the independent sample t-test.

6 Results

In this section the results from the Revised Universal Soil Loss Equation, the NAM model, and the field measurements will be presented, along with the statistical analysis used to validate the obtained data.

6.1 RUSLE factors

The single factors of the RUSLE will be presented. The values are calculated for each individual cell or the Romdrup Å watershed. Each factor is therefore presented through the pixel value associated with the raster output of the calculation.

6.1.1 R factor.

Firstly based on the chosen methodology are the results of the calculated Fournier index values (*Fm*) for each weather station. The calculated values can be found in Table 6.

station	UTM zone 32, datum (WGS84)	Fm (mm)	R
5025	Frederikshavn Materielgård	90.28894	226.4935
5027	Frederikshavn Centralrenseanlæg	82.58245	198.1233
5045	Vodskov	85.34356	208.1422
5047	Sulsted	93.65798	239.2881
5049	Gistrup	92.72062	235.7048
5052	Ålborg Østerport Pumpest.	88.30123	219.0555
5054	Nørresundby Søvangen Pumpest.	77.42186	179.8454
5056	Ålborg Renseanlæg Vest	93.46997	238.5679
5057	Frejlev Nord Verdisvej	111.3815	310.3298
5058	Frejlev Syd Lannerparken	96.90116	251.8241
5061	Svenstrup J.	100.6241	266.4753
5107	Nykøbing M. Vandværk	105.5381	286.2319
5115	Skive Renseanlæg	98.85481	259.478
5117	Skive Lufthavn	100.7318	266.9032
5121	Viborg Materielgård	103.398	277.5696
5122	Viborg Hedeselskabet	108.0425	296.4804
5145	Randers Centralrenseanlæg	80.73638	191.5172
5155	Grenå Ådalen P40	81.95556	195.8716

Table 6: Fournier index and R factor calculated for 18 weather stations

The rainfall erosivity factor calculated through interpolation of R values for 18 weather station in Nordjylland and Midtjylland result in values in a range between 219.9132 and 244.1150 (t-m cm ha^{-1} h^{-1} year^{-1}). As observed in Figure 13, the highest values for the R factor are found in the western area of the catchment.

6.1.2 K factor.

The erosivity factor, calculated with reference to the Danish Soil texture class database (Miljø & Fakultet, 1987-89), yields values between 0.05139 (ton/ha/ha^{-1}/MJ^{-1}/mm^{-1}) and 0.11125 (ton/ha/ha^{-1}/MJ^{-1}/mm^{-1}). The values are typical of coarse textured sandy soils, and highest values can be found in the eastern and southern portions of the catchment area.

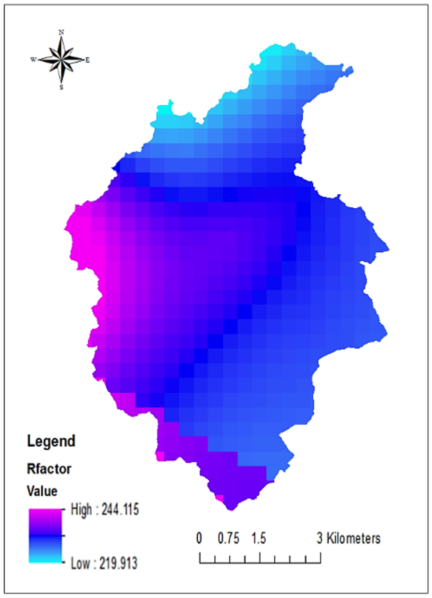

Figure 14: K factor values to the catchment area

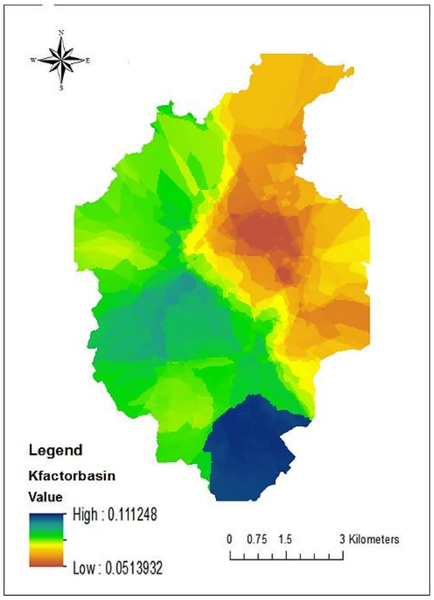

Figure 15: R factor values for the catchment area.

6.1.3 Slope and LS factor.

The slope length factor which described the angular slope in relation to the horizontal distance for each unit area results in values between 0 and 48.078 meters. Catchment values for the LS factor are shown in Figure 15, and values for the slope gradient in Figure 16.

6.1.4 C and P factors.

The cover management factor, based on the ESDAC European dataset shows values between 0.059% and 22.6% as shown in Figure 17. The support practice factor (P) also obtained through the ESDAC dataset (Panagos, et al., 2015), presents a constant value of 1 (Figure 18).

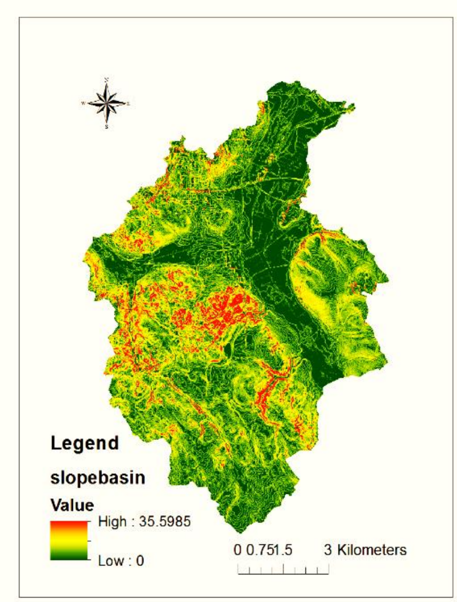

Figure 16:LS factor (degrees-m)

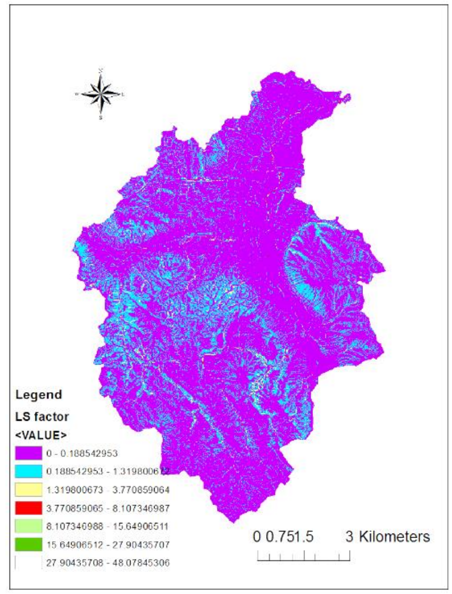

Figure 17: Classified values for LS factor

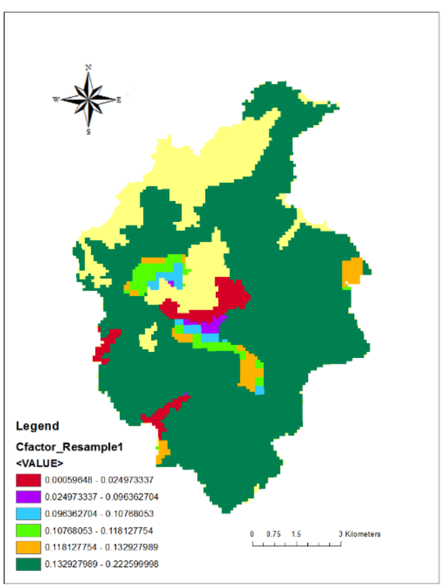

Figure 18: Cover management factor (C)

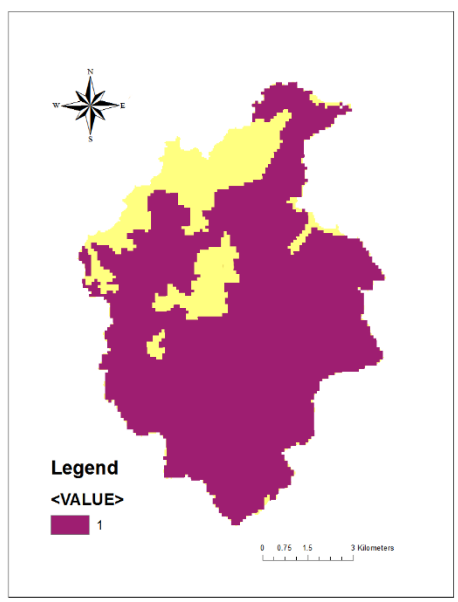

Figure 19: Support practice factor (P)

6.2 Soil Loss over the catchment

The product of the single factors, computed using raster calculator in ArcMap 10.3, is an output raster dataset with equal spatial resolution to the factor datasets, in which each pixel value refers to the mathematical product of the equation factors. The output result of the soil loss calculation yields values between 0 and 240.614 (t/he/year). The mean value over the catchment is 0.5503 (t/he/year) and the standard deviation of the result distribution is 2.1059. Zonal statics results show that the highest variation in values in the R factor, with a standard deviation of 3.5514.

RUSLE factors	MIN	MAX	MEAN	STD
R	219.9132	244.1150	230.9291	3.5514
K	0.0514	0.1112	0.0813	0.0134
LS	0	48.0785	0.1511	0.5106
C	0.0006	0.2226	0.2047	0.0512
P	1.0000	1.0000	1.0000	0.0000
Soil Loss	MIN	MAX	MEAN	STD
A	0.0000	383.0754	0.9239	3.5325

Table 7 Parameter distribution values for each layer

6.3 NAM Calibration

The results of the NAM calibration have resulted in the following values for the model coefficients, obtained during the calibration process. Calibration was ultimate with an R2 coefficient of 0.56 and an overall water balance error of 0.0% where the observed discharge yields 215 mm/y and the simulated runoff 214 mm/y.

Calibration Coefficients	Value
U_{max}	19.8
L_{max}	150
CQOF	0.2
CKIF	525
CK1.2	18
TOF	0.4
TIF	0
TG	0.024
CKBF	3093

Table 8 Resulting parameter values from NAM calibration

The resulting graph exported from the Mike11 RR file, shows the goodness to fit between observed discharge and simulated runoff. The two series show a high level of correlation.

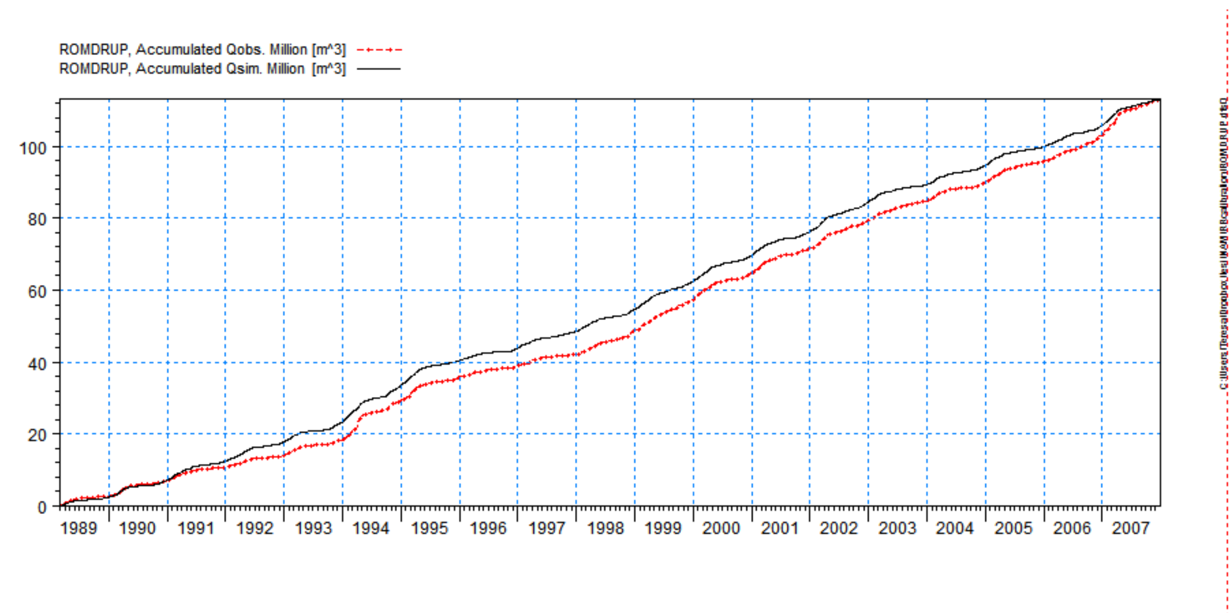

Table 9 Graph of simulated and observed discharge over 18 year time series

6.4 Field Measurements

In the following pages the results of the field measured concentrations of Total Phosphorus and Dissolved Phosphorus (orthophosphate) will be presented. Values will be listed based on the measurement type in the two samples collected approximately one month apart.

6.4.1 Total Phosphorus

Total phosphorus measurement values for the 14th April show a maximum of 11.58349 (µg/L) and a minimum value of 11.492 (µg/L). The mean value for the measured samples is 11.509 (µg/L). Values are shown in figure 5

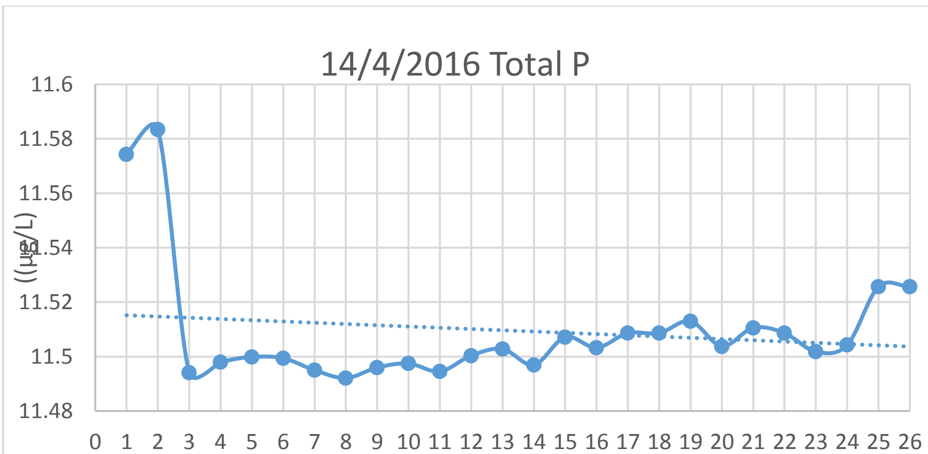

Figure 20: Total phosphorus measured values along Romdrup Å for mid-April.

Values for the 31st May show a maximum of 46.106 (µg/L) and a minimum value of 45.736 (µg/L). The mean value for the sample dataset is 45.821 (µg/L). Values for all samples are presented on figure 6.

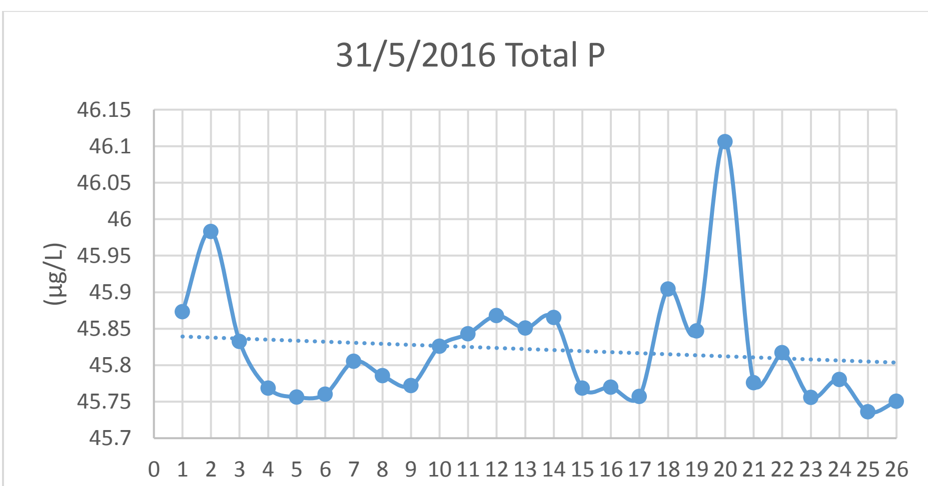

Figure 21: Total phosphorus measured values along Romdrup Å for late May.

6.4.2 Dissolved Phosphorus

Dissolved P measure in mid-April show a range of measured concentration between 11.519 (µg/L) and a maximum of 11.572(µg/L). The mean value for mid-April is 5.299 (µg/L).

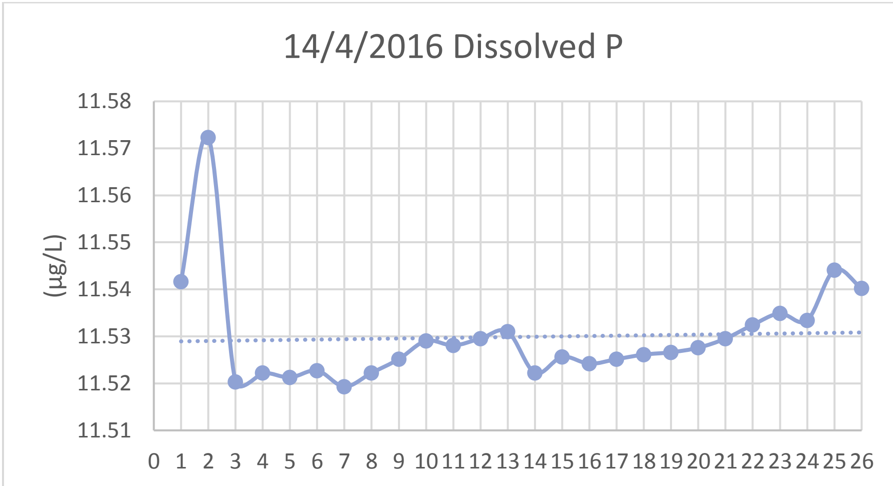

Figure 22 Dissolved reactive phosphorus concentration along Romdrup Å for mid-April

For the measurements conducted in late May, the values ranges from 45.75 (µg/L) to 45.852 (µg/L), with a mean value of 45.769 (µg/L).

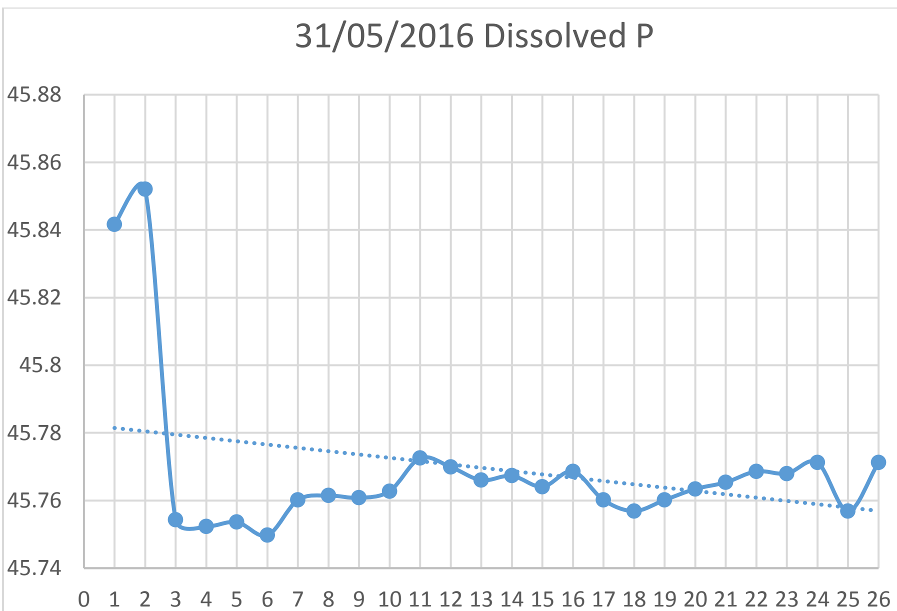

Figure 23 Dissolved reactive phosphorus concentration along Romdrup Å for late May.

Measurements of dissolved phosphorus show the highest concentrations been recorded in the first two sampling locations, denoting higher concentrations in proximity of the stream outlet. Values show a significant regression upstream, with a variable pattern, generally increasing as the distance from the outlet increases.

6.4.3 Suspended Solids

The measurement for suspended solids return values ranging from 1.240 (mg/L) to 1.316 (mg/L). Values for suspended solids increase from the lowest to the upper sections of the stream, from sample 1 located close to the outlet, and sample 8 at the highest point upstream of the reach.

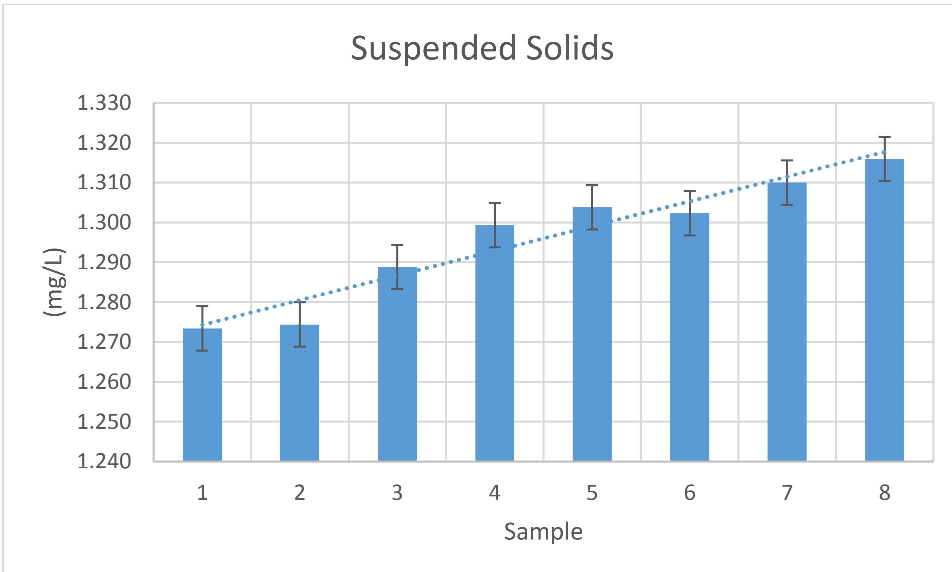

Figure 24 Suspended solids measured along the Romdrup Å channel.

6.4.4 Data Analysis

The independent sample t-test has shown a P value of 0.0001 (<0.05) for the Total Phosphorus results, and a P value of 0.003 between the Dissolved P values of April and May. Therefore it is shown that there is a significant difference between the two sampling periods, and due to since the null hypothesis is rejected, it is likely that the level of difference is imputable o an external variable and not a casual occurrence. Linear correlation values show a correlation coefficient of 0.30 for Total P sample for both dates, showing a positive yet weak correlation. Dissolved P samples for both dates have a correlation coefficient of 0.8 showing a positive correlation. Dissolved P measurement of April and May are more strongly correlated than Total P measurements for the two dates.

7 Discussion

In this section the possible causes and implications to the results will be looked upon. In addition the outcomes and analysis of the chosen methods, for the purpose of answering the problem statement will be outlined.

7.1 RUSLE factors

R factor. The resulting values for the R factor indicate detailed spatial variation, which allows for better investigation of spatial variations in the soil loss potential over the catchment area. The data has been calculated with a low temporal resolution of 1 year monthly rainfall data for 2015, which is likely to influence negatively the significance of the value. It is instead possible to visualize spatial variation over the basin, which allows for a more fitting spatial calculation of the overall soil loss equation.

K factor: The soil erodibility factor may be considered to be the most accurate in representing the catchment characteristics, since the values have been calculated through direct interpolation for 124 texture points from the (Miljø & Fakultet, 1987-89). The average value for the K factor over the catchment is 0.079 (t/ha/year) with predominance of fine loamy soils. It can also be observed from the comparison of the erosion output map and the land use map, that high levels of erosion are found to be in correspondence with an area dominated by fine sandy soils, which relating to 14are more easily eroded.

LS factor. Slope length factor is calculated directly upon the digital elevation model, therefore not allowing for variability and uncertainties in the calculation. It is likely that this factor contributes significantly to the yearly soil loss results, for it represents the topographical features of the catchment. As surface erosion and soil loss are strongly correlated to steeper terrain variation on page 14), it may be due to the low degree of spatial slope variation that the soil loss results fall into a particular class.

C factor: The cover management factor derived from the ESDAC geodatabase (Panagos, et al., 2015), does not show a significant contribution to the soil loss estimation. Due to the averaged value obtained from literature, and the lacking of directly measured vegetation indexes, it is not possible to fully highlight the contribution of seasonal variations in land cover in the soil loss calculation.

P factor: the P factor also obtained from the ESDAC geodatabase (Panagos, et al., 2015), does not influence particularly the outcomes of the soil loss estimation, due to its constant value throughout the catchment. The relative importance of this factor, can be highlighted in the case of a smaller case area, in which individual values can be investigated directly.

7.2 Soil Loss for Romdrup Å area

Due to the high level of variation in land use the resulting values for the soil loss, show a high spread in the variability. It is therefore difficult to establish any particular areas, which may be prone to high soil loss and therefore contribute significantly to the transport of P to the stream. Through visual observation highest amounts of soil loss values can be observed in the eastern part of the catchment, and in relation to areas where the LS factor is more significant. Therefore allowing to interpret the slope factor as predominant.

The correlation between the calculated soil losses with the RUSLE parameters. A strong correlation is found between erodibility factors (K) and slope-length factor (LS), while a negative correlation is found between LS factor and C factor. The C factor is also negatively correlated to R and K factors. It is deduced from Table 1 that the most influencing parameters in the soil loss determination are represented by the rainfall erosivity (LS) and the erodibility factor (K), showing the highest value in correlation.

factors	R	K	LS	C	P
R	1.000000e+000	1.902322e-001	1.455238e-001	-1.598425e-001	0.000000e+000
K	1.902322e-001	1.000000e+000	6.032173e-002	-1.102184e-001	0.000000e+000
LS	1.455238e-001	6.032173e-002	1.000000e+000	-6.779676e-002	0.000000e+000
C	-1.598425e-001	-1.102184e-001	-6.779676e-002	1.000000e+000	0.000000e+000
P	0.000000e+000	0.000000e+000	0.000000e+000	0.000000e+000	1.000000e+000

Table 10: Correlation matrix for the computed and derived RUSLE factor. Calculation of the correlation matrix has been done in ArcMap 10.3

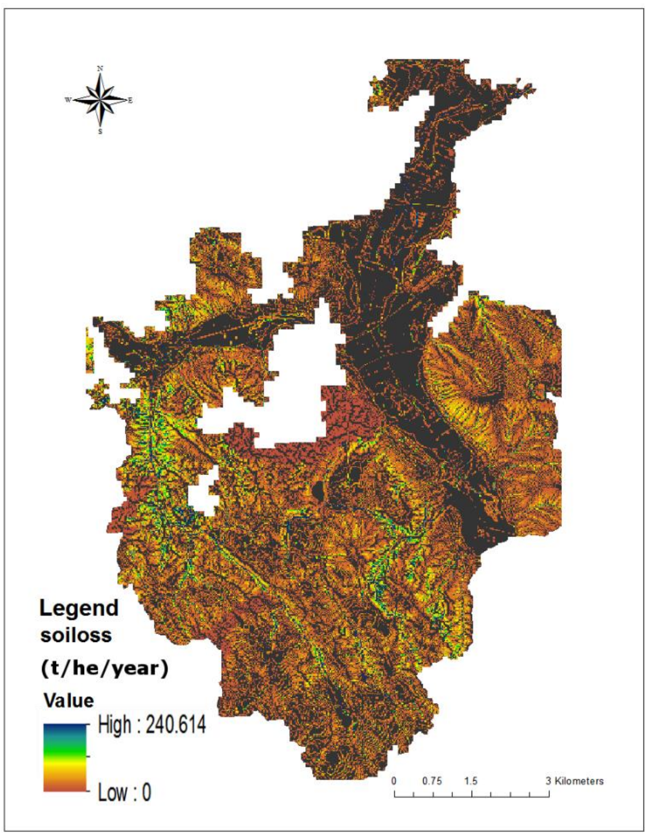

Figure 25: Resulting Soil loss map for calculated values of Å (tons/ha/year)

7.3 NAM calibration results

The results of the NAM model calibration suggest that the catchment allows for significant amounts of moisture in the surface storage (Umax) with a capacity of 19.8, and in the lower zone storage (Lmax) with a capacity of 150, as the values obtained in the calibration results in the higher end of the possible range for these storages. Overland flow is coefficient (CQOF) has a value of 0.2 which indicates a lower occurrence of overland flow and a major portion of infiltration to the root zone from the surface storage. As overland is generated if the moisture content in the lower zone storage exceeds the TOF value, which in this case shows the potential for higher infiltration. Low values for TIF allow for greater interflow, as the threshold value for the relative moisture content in the lower storage is 0, therefore allowing for infiltration to occur as mentioned . Overall the hydrograph shows a good agreement between the simulated runoff (Qsim) and observed discharge (Qobs), although the intensities of the peaks show a clear difference. The simulated hydrograph indicates a lower value in peak discharges that the moisture content in the observed hydrograph can be found in the interflow, with a rapid response. It can be therefore assumed that during rainy periods, the catchment responds with a higher portion of surface runoff than the model calibration has accounted for.

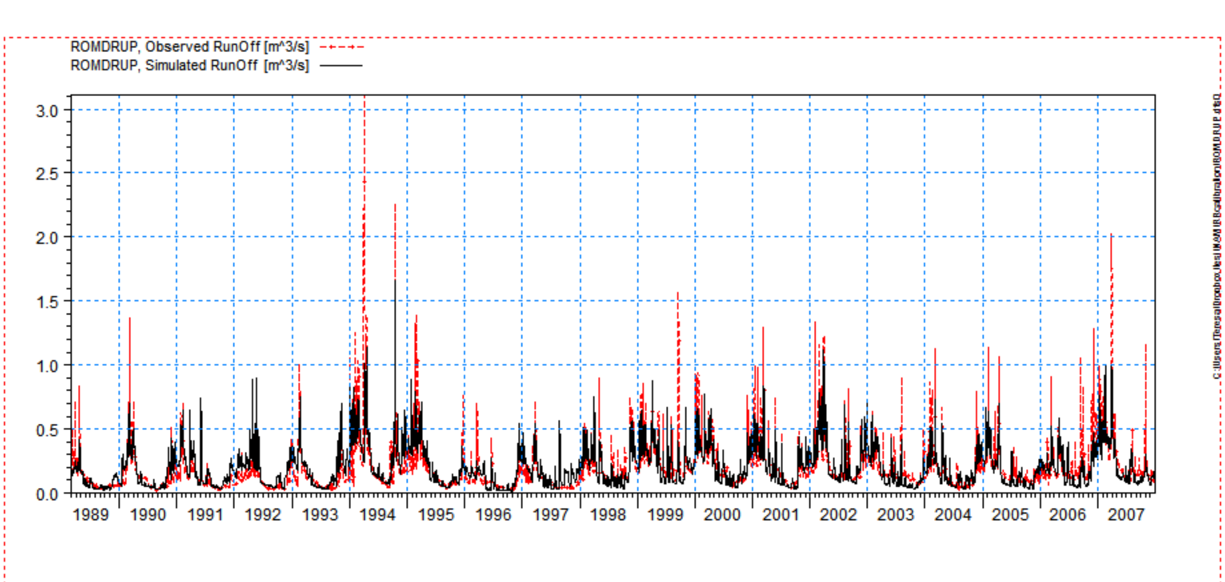

Figure 26: Hydrograph for simulated and observed discharges over an 18 year period (graphic out of NAM RRfile).

It can be argued that the outcomes of the NAM calibration allow to account for what proportions of surface water movement, and flow within the root zone actually occur in the chosen catchment area. There is likely to be a predominance of runoff and overland flow during high intensity rainfall events, due to the limited time for the soil moisture content to enter the groundwater storage.

Uncertainties are numerous, and are mainly related to the generalization that the model parameters take into account. The dynamics of runoff, infiltration, interflow and groundwater recharge are averaged over the entire catchment area. It is not possible to determine specific values attributed to different land uses. The problem may be solved if the chosen area is small, or a single agricultural field, with uniform characteristics is used instead of the entire catchment area. Like for the soil loss factors (RUSLE), the results of the NAM modelling fail to take into account the variability of hydrological processes throughout the catchment area, since the NAM model considers the basin as a uniform entity.

7.4 Total Phosphorus and Dissolve Phosphorus

Resulting from the analysis of the measured phosphorus concentrations in mid-April and late May, the interpolated values attributed to specific drain discharges have been analyzed by means of statistical analysis has been conducted. The values tested for normality of the distribution, are 85 values in total, containing both measured values and interpolated (missing values). It is seen that for all values a confidence interval between 0 and 0.1 is obtained.

The frequency distribution of most commonly occurring concentrations are illustrated in the APPENDIX 4, showing how the some concentrations are highly recurring in areas with several drainage inputs. This signifies that the lowest frequency values are the most significant in determining highly influencing locations, since the measurement is imputable to fewer sources over a certain reach of the stream.

Statistical description	14/4/2016		31/5/2016	
	Dissolved P	Total P	Dissolved P	Total P
DevSQ	0.0113	0.01095	0.01468	0.0612
Kurtosis	-1.5905	34.1120	24.1310	7.1592
Skewness	0.0069	4.9721	4.40618	2.3113
Min-max values	11.5261-11.5625	11.5834-11.4920	45.7497-45.8520	45.7360-46.1062
95% confidence interval	0.0024	0.0023	0.0031	0.0132

Table 11. Summary statistical for combined measurements and calculated missing values

7.5 Suspended Solids

An increment in the sediment is load is found progressing upstream from the out the outlet of Romdrup A. This implies that a higher portion of sediments are found in suspension in the upper reaches of the stream, while lower values in proximity of the outlet are related to deposition. The difference in measurements is not significant, therefore the sediment load may still be attributed to drainage channels transporting sediments from runoff in the lower reaches of the stream channel.

8 Uncertainties

Due to the chosen approach, the catchment area is considered as a uniformly area, in which the calculations for the individual soil loss factors are applied to area of the basin equally. No data on individual fields or agricultural plot areas has been used in the research, therefore limiting the resolution of the individual measurement.

The effect of seasonality has not been directly accounted for, due to limitations in data and instruments. It is therefore assumed that the calculated and literature derived values for the RUSLE factor, take into account the boundaries of the individual values.

It is assumed that the governing factors accounting for the phosphorus concentrations in stream water are imputable to soil erosion from the catchment and sewage, based on the locations of the measured concentration

No soil sorption model has been established due to technical limitations.

It is assumed that the rainfall data used for the NAM and for the calculation of the R factor is representative of the case area.

9 Further Research

In this section, the possible improvements to the chosen methods in order to better attempt to resolve the problem stated in the Research Questions (pg. 6) will be discussed.

In order to derive a more efficient methodology to analyze the state and location of area prone to high soil loss and runoff, responsible for the delivery of nutrients to waterways, a more detailed resolution of specific soil profiling and water movement should be conducted. More specifically, a detailed investigation of the infiltration capacity over cultivated fields, or well defined land use areas can provide estimates of soil loss, infiltration, and water movement through soils in a defined and uniform unit for a specific location. Specifically regarding the chosen methodology in this report, the catchment average results for soil loss can be useful in a first investigation of a certain risk related to erosion and runoff. Taking the results into consideration, whether they show significant values, further and more localized investigations must be conducted. A process of upscaling the measured phenomena can be beneficial for runoff and soil loss evaluation in critical areas, as well as adjust existing monitoring actions and remediation strategies.

In Denmark significant reductions of chemical fertilizers containing phosphorus has been significantly reduced since the 1980s, yet still significant reduced measures need to be taken, (Faglig rapport fra DMU, et al., 2001). The obligation to establish 5 to 10 meter width buffer zone strips between cultivated fields and neighboring streams and lakes, are able to retain significant amounts of phosphorus from leaching to water systems (Kronvang, et al., 2009). In areas where buffer strips do not retain significant portions of phosphorus, investigation of leaching occurring from drainage or storm water runoff ditches should be taken into consideration. Potential accumulation of phosphorus bound to sediments within buffer strips, should also be investigated for further reduction strategies. Maintenance of established buffer zones represents an important factor for long term retention of phosphorus from runoff and erosion (Kronvang, et al., 2009).

Furthermore, the support practice factor (P) as described by (Panagos, et al., 2015)can allow for improved knowledge on possible erosion reduction measures. Implementation on standards for the support practice factor, if applied at a municipal and regional level, may prove as a useful and dynamic tool to monitor erosion and runoff and plan required measures for phosphorus leaching and transport to streams. Further improvements to monitoring methods are can be for example constant monitoring of water chemistry and hydrological regime along streams. Allowing therefore to provide elaborate data records, useful for consultation and implementation in the planning of reduction measures. Examples could be represented by monitoring of concentrations from scattered drainage, or chemical analysis conducted in critical areas done by research establishments.

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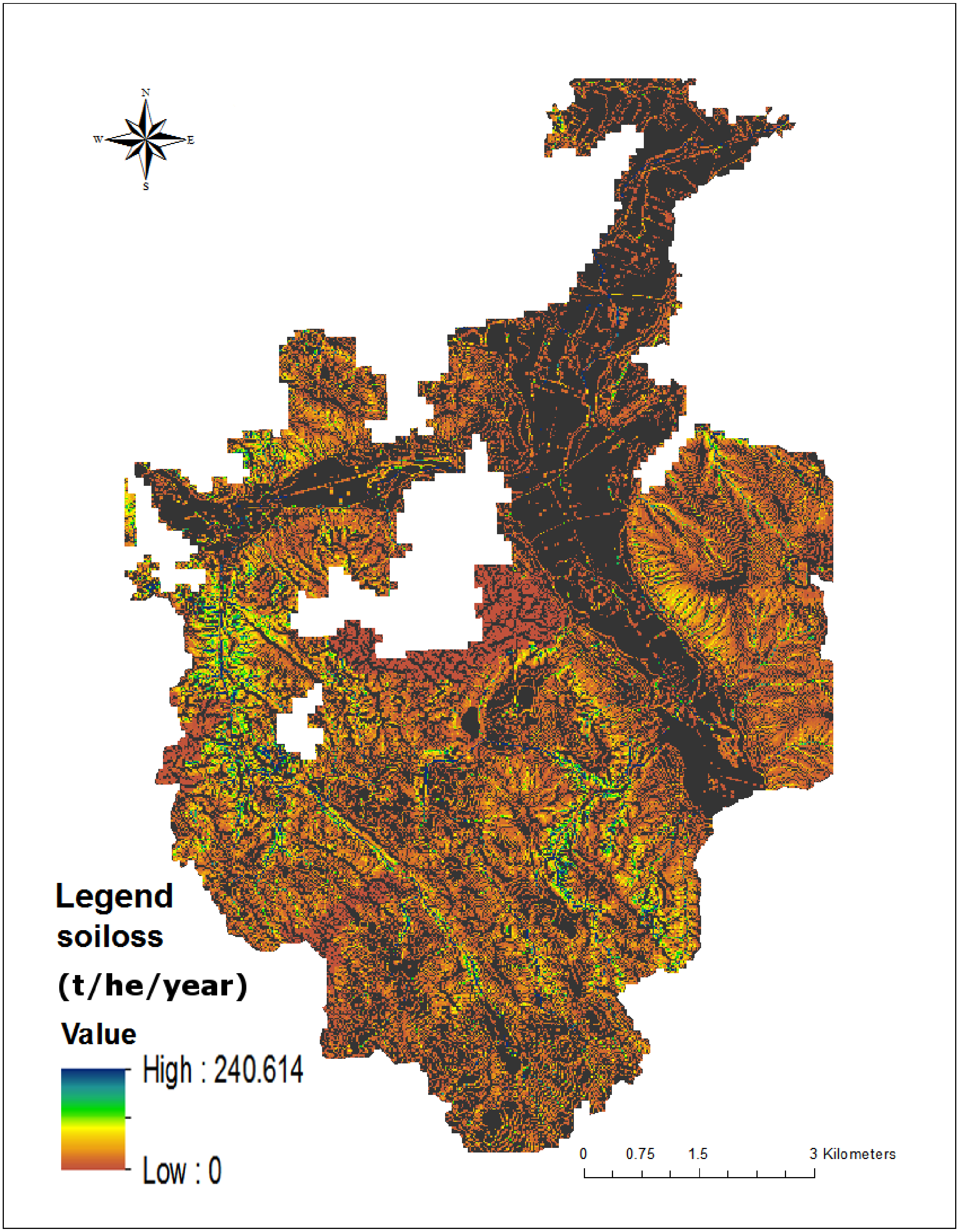
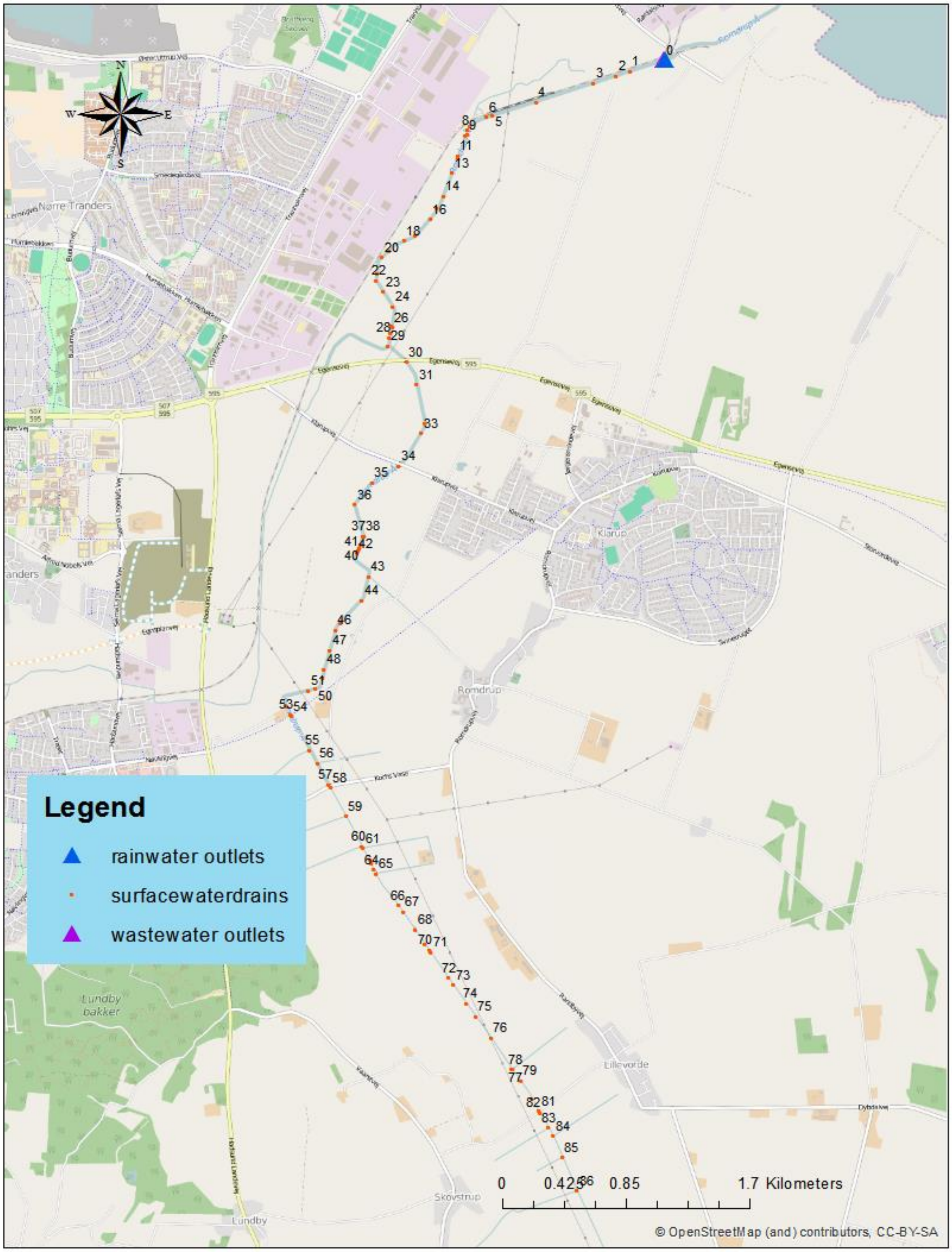
11 APPENDIX 1: Soil Loss Map

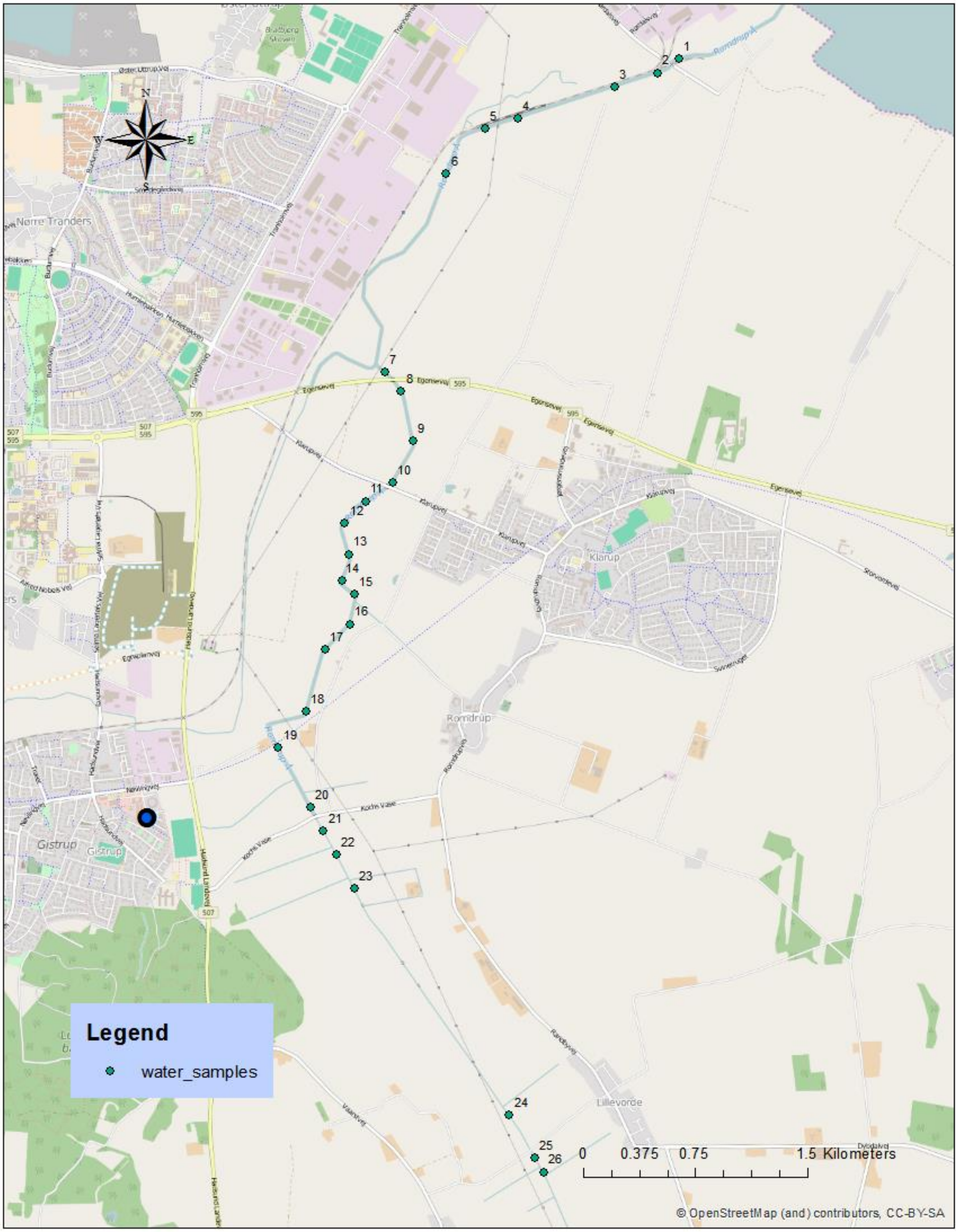


12 APPENDIX 2: DRAINAGE LOCATIONS



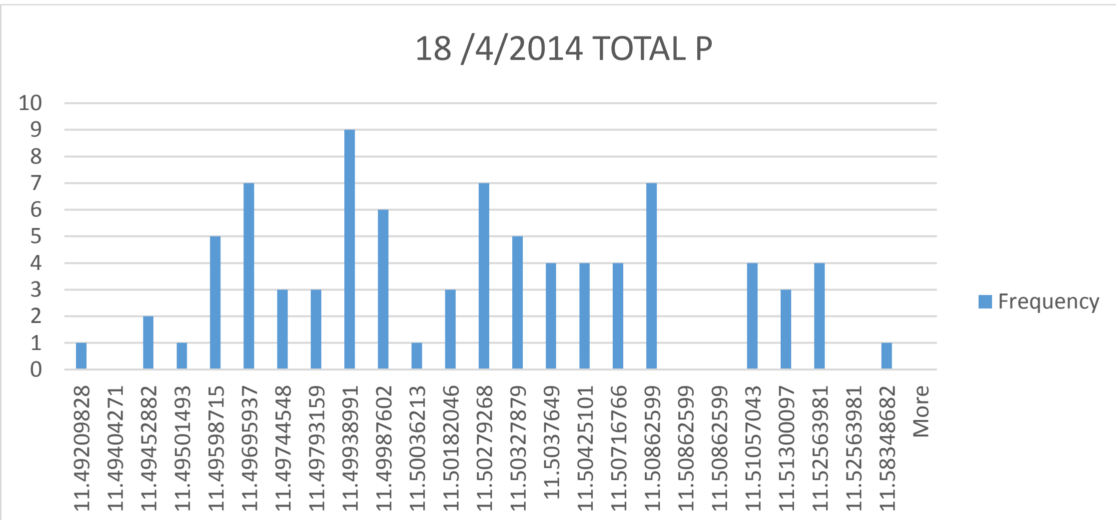
(Aalborg Kommune Miljø- og Energiforvaltning, 2016)

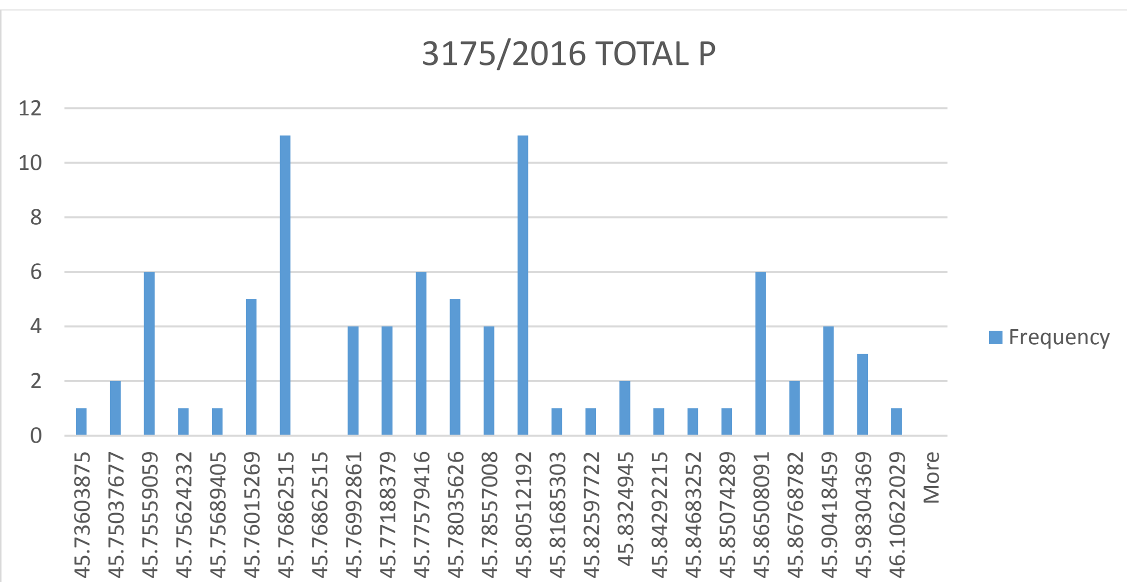
13 APPENDIX 3: SAMPLING LOCATIONS FOR PHOSPHORUS

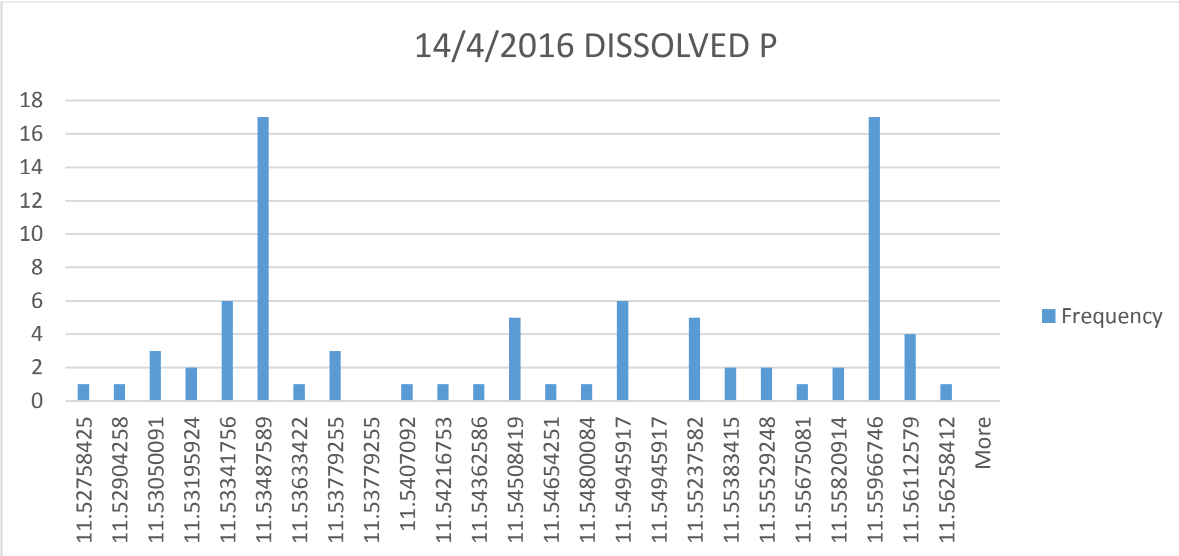


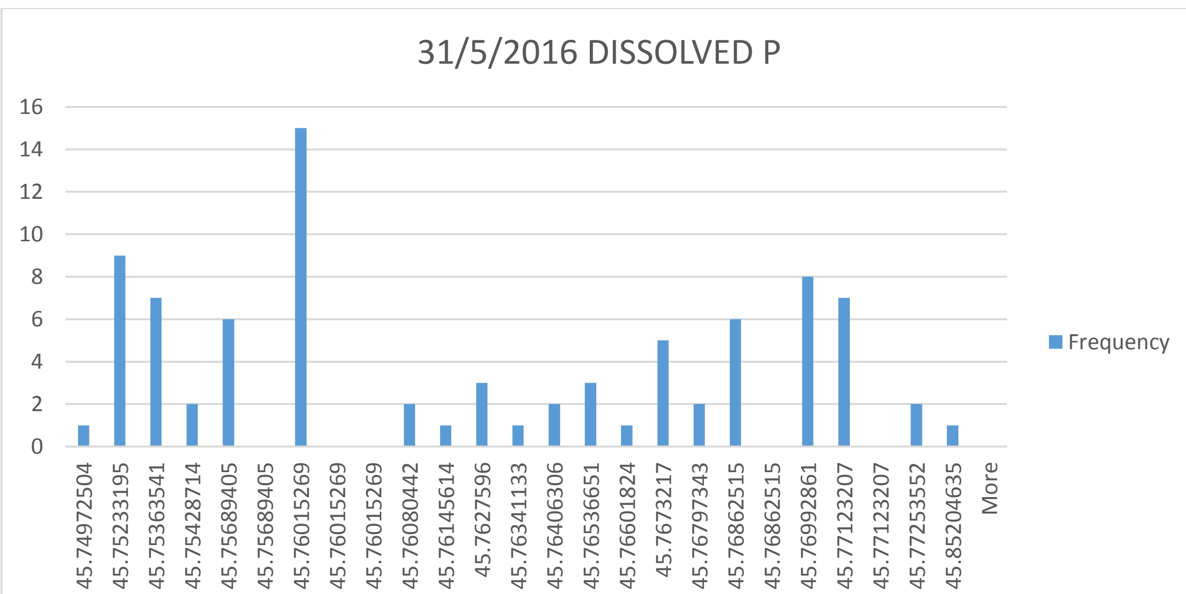
14 APPENDIX 4: PHOSPHORUS FREQUENCY FOR INTERPORALTED VALUES FOR TOTAL AND DISSOLVED PHOSPHORUS IN MID APRIL AND LATE MAY.

In The following tables the frequency for overall concentration values is presented. The total sample size of 85 measurement, are result from the combined distribution of directly measured values and interpolated values for stream locations where drainage is present. It is assumed that the concentration of the nearest measured value accounts for the accumulated input of the number of drains presented between two measurement sites. Therefore the values showing highest frequency are considered proportionally less intense than values with low frequency.

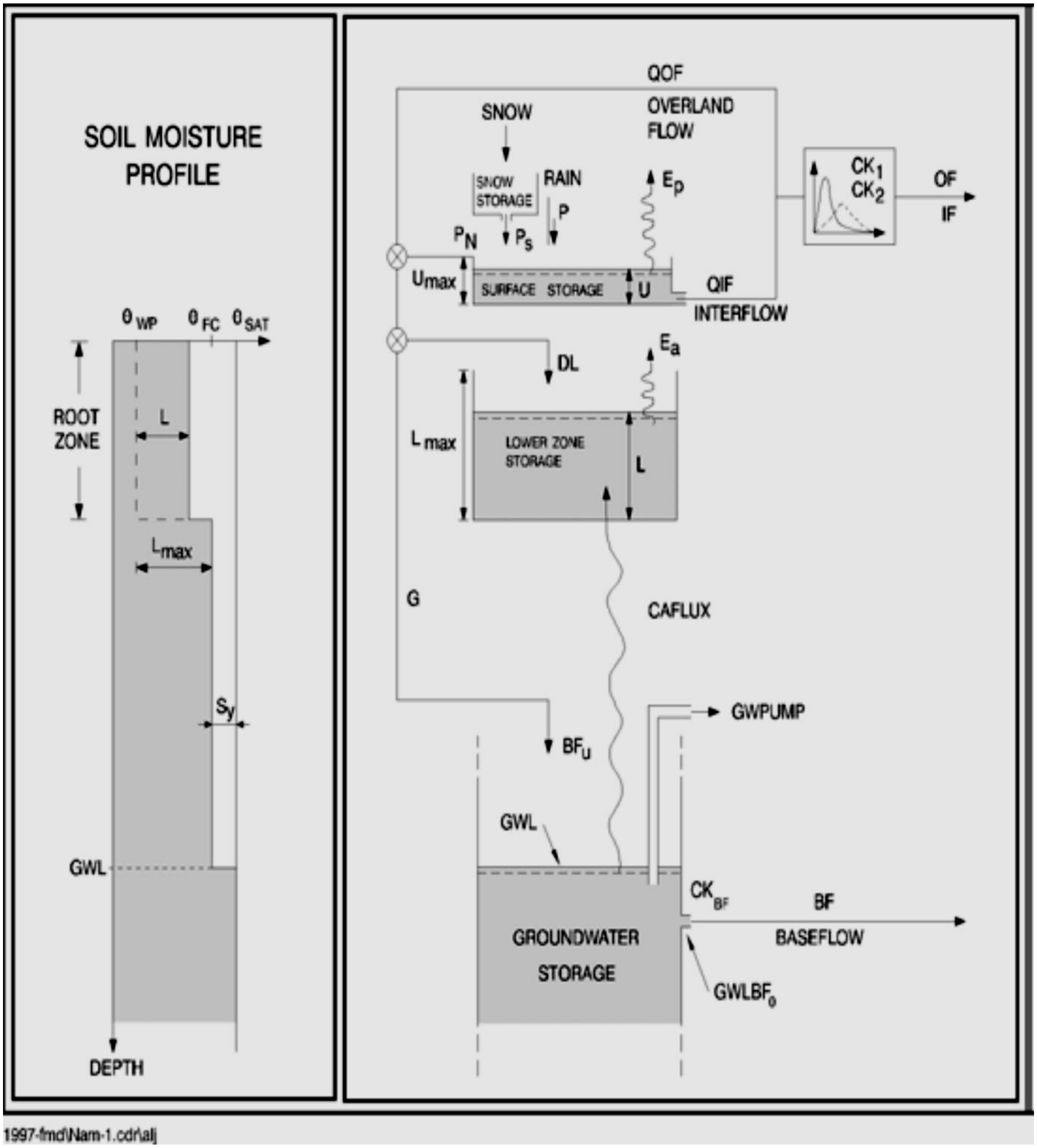





14/4/2016 DISSOLVED P
18
16
14
12
10
8
6
4
2
0
11.52758425
11.52904258
11.53050091
11.53195924
11.53341756
11.53487589
11.53633422
11.53779255
11.53779255
11.5407092
11.54216753
11.54362586
11.54508419
11.54654251
11.54800084
11.54945917
11.54945917
11.55237582
11.55383415
11.55529248
11.55675081
11.55820914
11.55966746
11.56112579
11.56258412
More
Frequency


31/5/2016 DISSOLVED P
16
14
12
10
8
6
4
2
0
45.74972504
45.75233195
45.75363541
45.75428714
45.75689405
45.75689405
45.76015269
45.76015269
45.76015269
45.76080442
45.76145614
45.7627596
45.76341133
45.76406306
45.76536651
45.76601824
45.7673217
45.76797343
45.76862515
45.76862515
45.76992861
45.77123207
45.77123207
45.77253552
45.85204635
More
Frequency

15 APPENDIX 5: SCHEMATIC ILLUSTRATION OF MOISTURE CONTENT IN WATER STORAGES IN THE NAM MODEL



(DHI, 2012)