Impacts on Flood Risk from Land Use Strategies for Coping with Climate Change

– An Assessment using the Time-Area Method

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Abstract

Climate change places pressure on rural land in terms of carbon sequestration, biomass for substitution and adaptation of crops. Land use can both positively and negatively influence the runoff regime, therefor a catchment perspective is important when developing climate strategies. This is also important with respect to flood-risk that will increase with climate change. Here I investigate if there is the potential to improve the representation of impact from rural land use during conventional hydrological modeling using the simple Time-Area Method, an advantage over other expensive and time consuming models. Using this method I have further assessed the impact on flood risk due to external effects from climate strategies in the rural sector.

I have further developed the rural component of an existing MIKE URBAN model over a small village, Eneryda, Sweden. The focus has been on constructing more detailed runoff coefficients (φ) for rural areas. Through a literature search and results from an integrated land use model, Dyna-CLUE, I constructed four rural climate strategy scenarios for year 2050: *A2, B2, Substitution* and *Carbon storage.* The impact from the different climate strategies on the flood risk was then analyzed in MIKE URBAN and MIKE FLOOD.

My results show that there is a potential to present the general impact from rural land use through the Time-Area Method. The influence from rural land is of importance for flood risk in Eneryda, prolonging the duration of over pressure in the sewer system. The total sum from the applied φ is valid for both the west and east catchments in Eneryda during the validation of a ~10 year rain event (r^2 0.9633 and 0.8691). The individual φ are higher then what is conventionally applied in Sweden, but the values used are supported for conditions with high soil moisture in other countries. Results from a MIKE SHE model also supports the proportional difference in my φ values for mixed forest, agriculture and clear-cut. The substantial disadvantage with my model is the inability to distinguish the effect of different runoff processes on how they contribute to the resulting hydrograph.

Rural climate strategies can have external effects on flood risk in Eneryda. A substitution strategy for example, including intensive forestry, is projected to increase the flood risk compared to a climate strategy favoring carbon storage. When both are exposed to a 100-year (24 hour) rain event, the substitution strategy increases the water volume by 22%, giving a 1 hour longer and 2.5% larger flooded area, and increasing the severity of flood depth by a few centimeters. This shows that local adaptation of strategies and the use of best forestry and agricultural practices are needed to not increase the risk of flooding.

The impact from rural land use also highlights the importance of working with flood measures using a wider perspective than considering only grey infrastructure as land use change over time. Land use and the runoff regime can also change quickly due to direct effects from weather events. Recently, substantial storm damage of the forest in the area has made the current land use the worst case scenario for floods in this thesis. My results therefore stress the importance of adaptation strategies in the forest sector.

Keywords: environmental science, physical geography, climate strategies, land use, hydrological modeling, flooding

Contents

1. Introduction

River floods cause threat and damage in Sweden every year and the problem is expected to increase due to a change in the precipitation pattern with climate change (SOU 2007:60). Measures to mitigate[1] and adapt[2] to climate change include land use strategies (Le Quéré et al. 2009) which also can influence the runoff regime in both a positive and negative manner (Kundzewicz et al. 2012). A multifunctional approach to the landscape is therefore vital when it comes to humankind and land use planning (European Commission, 2009). This is clearly visualized with a catchment perspective so that a measure implemented up-stream to reach one aim does not create another problem down-stream (European Commission, 2011). When *"developing policies referring to water and land use….the potential impacts that such policies might have on flood risks and the management of flood risks…should be considered"* (2007/60/EC).

Regulating ecosystem services[3] has gained increasing interest in recent years since natural ways of flood prevention can be more efficient than simply focusing on physical infrastructure, as positive externalities are gained (European Commission, 2011, Ds 2013:1). Essential for the development of strategies is the assessment of the impact and consequences. This requires scientific knowledge of the complexity of hydrological processes in landscapes. Equally important is to make this knowledge available to policymakers and stakeholders for implementation.

The Time-Area Method is conventionally used in hydrological models to calculate runoff and therefore often is what policymakers on a local level base their decisions upon (Dunne and Leopold, 1995 p.299, Svenskt Vatten, 2004). As the method is designed for urban areas, and because of its few parameters, there are doubts if it also can be used to reflect the impact from land use in rural areas (Merz et al. 2006). For urban areas, runoff coefficient is shown to be one of the most sensitive flow parameter (Kleidorfer et al. 2009).

1.1 Aim

My aim is to investigate if there is the potential to improve the representation of rural impacts during conventional hydrological modeling and assess the impact on flood risk due to external effects from climate change coping strategies in the rural sector. The village of Eneryda, Sweden, has experienced problems with flooding. This leads to the following research questions:

1. *Can the impact on runoff from rural land use be incorporated in the event runoff coefficient and visualized through the Time-Area Method?*
2. *What impact will the effect from climate change coping strategies on rural land use have on flood risks for the village of Eneryda in the year 2050?*

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[1] Mitigation measures focus on decreasing the concentration of greenhouse gases (CO_2, CH_4, N_2O, CFC etc.) including decreasing the emissions on both supply- and demand side but also through capturing and storing of these gases.

[2] Adaptation measures *"is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities"* (IPCC, 2007 p.6).

[3] Regulating ecosystem services can include climate-, disease- and water regulation, erosion control and water purification. Other ecosystem services are supplying services, in case of products, and supporting services, necessary for the production of other ecosystem services and cultural services (Millenium Ecosystem Assessment Board, 2003).

1.2 Overview of the Method

With this approach I am testing the usefulness of a certain method, and will continue to apply this method to answering a second research question rather than testing specific scientific hypotheses.

I have further developed a rural portion of an already existing MIKE URBAN-model constructed for Eneryda by the consulting company Tyréns[4], and also developed it further into a MIKE FLOOD-model. To answer the first research question I conducted a literature study regarding how land use, different management practices and land use changes influence runoff during extreme precipitation, and how this can be included in the parameters used in the Time-Area Method. I conducted an interpolation between soil curve numbers and known runoff coefficients to create detailed runoff coefficients for agricultural land use. The impact on discharge from different forestry management practices was used to create more detailed runoff coefficients for forest land use. I applied these values in MIKE URBAN and MIKE FLOOD, and the model was calibrated and validated against measured discharge. Sensitivity analyses regarding my choice of up-scaling and climate factors were conducted. I further evaluated the hydrological impact from land use change projected by my model by comparison with a physically based model, MIKE SHE.

Through literature review and the results from an integrated land use model, Dyna-CLUE, I studied the influence of climate change and climate change coping strategies on land use. From this I constructed four scenarios for the rural catchments of Eneryda for the year 2050: *A2, B2, Substitution* and *Carbon storage.* The impact from the different climate strategies on the flood risk in Eneryda in the year 2050 was then analyzed in MIKE URBAN and MIKE FLOOD considering volume, peak and duration of discharge and distribution and depth of flooding.

1.3 Limitations

The focus for my thesis is within river flooding during the vegetation season, not including the influence of sea level, nor winter conditions. The impact of land use on time of concentration is outside the scope of this study. My research area does not include lakes or wetlands; therefore their impact on the runoff regime will therefore not be investigated.

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[4] Tyréns is a consulting company in the sector for planning and construction (Tyréns, 2013a).

2. Background

2.1 Climate Change Coping Strategies for Rural Land Use

Land use management and land use change is vital for both mitigation and adaptation measures regarding climate change. Agriculture and forestry are part of the problem, contributing 10% and 12-20%, respectively, of the annual global emissions of greenhouse gases comes from these sectors (FAO, 2013, Le Quèrè et al. 2009). But they are also part of the solution since there is a great potential for carbon sequestration[5] within these sectors (FAO, 2001, Le Quèrè et al. 2009). There are two major strategies concerning land use and climate mitigation (FAO, 2001, SOU 2013:43):

- **The substitution principle**. As carbon is captured through photosynthesis the amount of carbon released from burning biomass can be viewed as carbon neutral (FAO, 2001 and 2012, 2009/28/EC, SOU 2013:43). This view depends on the time perspective, as also the main sources of greenhouse gases such as black carbon, oil and nature gas consist of carbon that have been captured through photosynthesis further back in time (Sathre and O`Connor, 2010). The time it takes to store carbon and the time it takes to emit it needs to be the same to be truly carbon neutral (Sathre and O`Connor, 2010). Transitioning our source of energy from fossil energy to renewable energy sources is also a necessary part in the adaptation of our society to enhance energy security, as fossil energy availability is peaking. The European Union has a target that 20% of total final energy consumption, and 10% of the energy in the transport sector, should come from renewable energy sources by 2020 (2001/77/EC and 2003/30/EC). Biomass is one of the main sources of renewable energy and is expected to play a major role in reaching the long-term target to reduce greenhouse gas emissions by 60–80% by 2050 (Faaij, 2006, IEA, 2010). This substitution principle also applies for material such as plastic and concrete (FAO 2001, Sathre and O`Connnor, 2010). Carbon is then released at a slower rate as it will continue to be stored in the material.

- **Carbon storage.** The terrestrial biosphere sequesters 34% of the annual global emissions of greenhouse gases[6] (House et al. 2002). Another strategy is therefore to favor and maintain this sequestration so that carbon from the atmosphere continues to be captured and stored in vegetation and soil (FAO, 2001, SOU 2013:43).

2.1.1 Forestry

Boreal forests are important both for carbon sequestration and for the large amount of stored carbon in vegetation and soil (Hari and Kumula, 2008, WWF, 2011). The storage rate is high for a young forest and then decreases as the forest reach maturity (Ågren et al. 2008). Even several hundred years old boreal forests continue to accumulate carbon and therefore contain large amounts of it (Luyssaert et al. 2008).

Climate change is projected to increase the growth in Swedish forests (Hari and Kumula, 2008, Skogsstyrelsen, 2007). Mitigation measures within the forestry sector can be divided into strategies that rely on the substitution principle, and those that use carbon storage (WWF, 2011). For increasing substitution, there are arguments for a more intense forestry with increased harvesting,

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[5] Atmospheric carbon is being captured in vegetation through photosynthesis.

[6] Calculated as the remaining fraction from the oceanic uptake and the increase in atmospheric concentration.

including the harvesting of branches, tree tops and stumps, fast rotation and nitrogen fertilization (Skogsstyrelsen, 2013b). To increase carbon storage a decrease in timber harvesting and less soil disturbance, as well as maintaining and preserving forests need to be achieved (FAO, 2001). Reforestation after timber logging is important for both strategies. Afforestation also comes into consideration (FAO, 2001).

At the same time as the productivity of forests increases with climate change the risk for damage due to storm felling and pests, like insects and fungus, also is expected to increase (Skogsstyrelsen, 2007 and 2013a). The successful achievement of the above-mentioned strategies is therefore dependent on the vulnerability[7] and resilience[8] of the forest. Adaptation of forest management is thus important to decrease the economic loss for forest owners. Current conventional forestry in Sweden includes clear-felling and a homogenous forest in age and species (Skogsstyrelsen, 2007). Adaptation strategies to decrease storm felling is to decrease the amount of stand borders through eliminating clear-felling, using continuous forestry and preserving forests. Avoiding monocultures and therefore increasing the diversity of tree species and ages can also contribute to mitigating storm felling, as well as mitigate the success of pests (Skogsstyrelsen, 2009). Today, Norway spruce (*Picea abies*) is extensively planted southern of its natural northern range, making them more vulnerable to storm felling and pests (Skogsstyrelsen, 2007). Adaptation of tree species, example through conversion back to species naturally found at a given location, and through facilitating a shift in distribution ranges needed to adapt to climate change, could decrease this vulnerability and increase resilience (Skogsstyrelsen, 2007, Jost et al. 2011).

2.1.2 Agriculture

In the agricultural sector, the yield is projected to increase due to climate change with about 5% within the next 25 years (Jordbruksverket, 2007). Crop and livestock management and the location of production is likely to be affected, with opportunities for new crops in Sweden and a transition from spring towards winter cereals (Jordbruksverket, 2007). With climate change, the risk for crop failure increases with the severity of extreme weather, both in the form of drought and floods (Jordbruksverket, 2007, European Commission, 2009). Also here, the risk for disease and pest increases (Jordbruksverket, 2007). The potential in using biochar[9] is discussed as a way to increase the carbon sequestration, maintain water and at the same time increase the yields in agriculture (Nordic Association of Agricultural Scientists, 2013). Further research is needed before implementation.

The production of livestock accounts for a large proportion of the greenhouse gas emissions from the agricultural sector; this is why a change in consumption is one of the main focuses for climate change mitigation. Livestock production is also a question of whether or not it is an efficient way of land use at that specific location and region.

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[7] *"Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity." (IPCC, 2007 p.6)*

[8] Resilience is *"the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change."(IPCC, 2007 p. 880)*

[9] Charcoal used for soil amendment.

Another external force on agriculture land is the substitution of biomass into fuels. The second generation biofuels, produced from cellulose, is projected to increase (SOU 2007:036). With that, it is likely that the planting of short-rotation energy-forests such as *Salix sp*. will also increase (Jordbruksverket, 2007). Technological developments in agriculture, as well as reforms to reduce agricultural overproduction, are likely to lead to forest expansion on former arable lands (Robinson et al. 2003). Constructed in the right way, the Common Agricultural Policy[10] within EU could play a central role in assisting in climate mitigation and adaptation, including increasing the resilience of the landscape (European Commission, 2009).

2.1.3 Integrated Land Use Model

To be able to investigate the hydrologic effect from climate change coping strategies, projections of future land use and land use change are needed. Several different market and policy forces and interactions will affect the development of the landscape, in combination with vegetation processes (Verburg and Overmars, 2009). Land use models that can integrate these can be used as a tool to aid in the creation of future scenarios (Verburg and Overmars, 2009). The integrated land use model Dyna-CLUE version 2.0 (Dynamic Conversion of Land Use and its Effects) is, for example, used by the European Commission. It has been used to investigate the impact on land use based on the climate storylines from the IPCC (Intergovernmental Panel on Climate Change) (IPCC, 2007 p.22). The four storylines from the IPCC for long-term greenhouse gas emissions are developed to represent the range of driving forces and emissions based on scenario research (IPCC, 2007 p.22). The Dyna-CLUE model combines the large-scale dynamics of land use change from a top-down approach with local processes of vegetation dynamics represented through bottom-up dynamics. For the agriculture sector, where the demand is largely determined by the global food, animal feed and energy markets a top-down approach is appropriate (Verburg and Overmars, 2009). Forces that act upon (semi-) natural land are wood demand or policies, but also indirectly through demand of land for agriculture and urban areas, as well as vegetation succession. Simulation of land use conversion due to, for example, abandonment of agricultural land is then better explained by bottom-up processes (Verburg and Overmars, 2009). In Dyna-CLUE conversion rules indicate which conversions are possible for each land use type, over specific time-scales.

2.2 Increased Risk for Flooding in Sweden

Conditions that can influence flooding include climatologic, terrestrial and socio-economic factors (Kundzewicz et al. 2012). In risk management, the risk can be explained as the probability of a hazard to occur, the nature of the hazardous event, i.e. the threat and its severity, and the vulnerability, i.e. the exposure and sensitivity; see Equation 1 (Wamsler, 2014 p. 19 and 31, IPCC, 2014):

$$\text{Risk} = \text{probability} * \text{hazard} * \text{vulnerability} \qquad \text{Eq. 1}$$

The flood risk is expected to increase as the amount of precipitation as well as the rate of extreme weather events is projected to increase in Sweden due to climate change (Rummukainen, 2010, Olsson and Foster, 2013). The global trend of urbanization and land use change also increases the severity of flood events. Along with increasing pressure on flood prone areas for development and placement of settlements and infrastructure this affect the exposure to floods (Kundzewicz et al. 2012).

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[10] A system of agricultural subsidies and other programs. See example http://ec.europa.eu/agriculture/cap-overview/2012_en.pdf

The relationship between flooding and climate vulnerability, and the impact on the Swedish society, has been investigated by “The assessment of Climate and Vulnerability” (Klimat- och Sårbarhetsutredningen) (SOU 2007:60). It gives a summary of the extended impact from floods that can affect important public services and in doing so threaten our protection and safety. Surface and subsurface flow could lead to damage to settlements and infrastructure such as transportation, electricity, telecommunication, surface water, drinking water and wastewater; erosion, landslides and mudflow may contribute to damage as well. Spreading of toxins from agriculture and contaminated soils can result in increased ecological- and health risks (SOU 2007:60, ch. 4). Subsurface flow and increased ground water levels could lead to damage through penetration of foundation walls. Groundwater can also penetrate drainage pipes connected to the sewage system creating a higher pressure on these pipes (Svenskt Vatten, 2007). The sewer network can due to intense and/or prolonged precipitation be overloaded. A combined system[11] could in that case lead to backflows and flooding in basements with untreated waste water as a result while a separate system[12] could lead to overpressure in the surface water drainage system creating unexpected overland flow (Svenskt Vatten, 2007). Increased discharge and/or in combination with under-dimensioned wastewater treatment plants could lead to contamination of water supplies. Overflowing of untreated sewage water is then released to the receiving water, resulting in increased health risks (SOU 2007:60 ch. 4).

2.3 Flood Prevention

2.3.1 Regulating Ecosystem Services

Traditionally flood prevention has been accomplished through physical infrastructural measures, such as extended flood barriers and larger dimensioning of dikes and pipes (Svenskt Vatten, 2007). That tendency is about to change towards more natural flood management based on water regulating ecosystem services that work with hydrological processes across the whole catchment to regulate the flow (European Commission, 2011). Practical examples are the re-connection of rivers with their floodplain, restoration of wetlands, sustainable forestry and agriculture practices and green infrastructure in urban areas (European Commission, 2011).

For policymakers and planners the socioeconomic cost and benefits needs to be analysed regarding both flood risk reduction and climate change coping strategies. As measures in infrastructure can be very costly, the interest in more natural water management approaches lies in the potential to lead to more efficient flood reduction, but also in the positive externalities that such an approach may produce (European Commission, 2011, Svenskt Vatten, 2007). For measurements concerning land use the concept of water regulating ecosystem services can be interpret as a tool for this kind of valuation. This highlight the value that is provided by nature, and that damages of nature also must come with a proportional cost, but not necessarily a well-defined monetary value (Millenium Ecosystem Assessment, 2005, Ds 2013:1).

The political will within this area can be seen in the *White Paper on adapting to climate change* (European Commission, 2009) and the information package "*Towards Better Environmental Options in Flood Risk Management*" (European Commission, 2011) among others. On a national level, for example, SOU 2013:43 highlights the need for the substitution of fossil fuels by biomass and carbon

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[11] waste-, storm- and drainage water in the same pipe.

[12] only waste water or sometimes in combination with drainage water in the same pipe.

sequestration in forest and wetlands in combination with increasing the water-regulating ecosystem services provided by forests and wetlands.

The Floods Directive (2007/60/EC)[13] is, together with the Water Framework Directive (2000/60/EC)[14], the key legislation within this area. The catchment perspective is integrated as an important part as the unit of management. This integrated management approach demands cooperation between up-stream and down-stream communities, and between rural and urban areas both to secure water quality and for flood prevention (European Commission, 2011). Also, the legislation surrounding Environmental Impact Assessment (2011/92/EU) and Strategic Environmental Assessment (2001/42/EC) applies to flood risk management measures[15]. These documents, in accordance with the plan-monopoly (2010:900 1 ch. 2§) and the responsibility that the Swedish municipalities have in order to prevent flooding (2010:900 2 ch. 5§), drives the development within land and water use in public plans and programs like the Comprehensive plan and the Detailed plan[16]. One interim target until 2018 for the environmental goals in Sweden is the integration of ecosystem services in relevant public decision making, such as environmental impact assessments (Miljömålen, 2014, SOU 2013:68)

2.3.2 Hydrological Models

Models can work as a supporting tool for policymaking assisting with a catchment perspective (Bellocchini et al. 2009). Hydrological models simulate the rainfall-runoff from the catchment while hydraulic models simulate the hydraulic processes in infrastructure systems (Svenskt Vatten, 2004). A combination of a hydrological and hydraulic model can help to determine if floods exceed the designed dimension capacity of channels, culverts and sewer system downstream (Svenskt Vatten, 2004).

An empirical model run based on statistical correlations, such as coefficients, while a process model runs based on mathematic equations for the included processes, and the interaction between the processes. A physically based hydrological model can describe processes such as interception, infiltration and subsurface runoff to a different extent (Mays 2011, p.262-363). An event-based model simulate individual rain events, without describing hydrological balance between storms such as evapotranspiration and soil water movement, while a continuous model include these processes (Mays 2011, p.262-363, DHI, 2012a p.72).

MIKE URBAN developed by Dansk Hydraulisk Institute (DHI) is one of the commonly used hydrodynamic models for modeling floods (DHI, 2012a). Different methods can here be selected for the hydrological model; one empirical surface runoff model is the *Time-Area Method* (described below). The hydraulic model can use the engine MOUSE (Model of Urban Sewers) or SWMM5 (Storm Water Management Model) to calculate pipe flow simulations for distribution and wastewater collection systems. For further information see DHI (2012a). Such a surface model is suitable to use in urbanized areas for a single rain event where most of the runoff is generated from impervious surfaces (DHI, 2012a). MIKE FLOOD is further a connection between the 1D pipe flow in MIKE URBAN and the 2D overland flow model MIKE 21 that simulate distribution, depth and velocities of flooding (DHI, 2012a, DHI, 2007). To analyse the effect from land use and land use change in rural areas where

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[13] Implemented in Swedish legislation through *Förordning (2009:956) om översvämningsrisker.*

[14] Implemented in Swedish legislation through *Förordning (2004:660) om förvaltning av kvaliteten på vattenmiljön"*

[15] Implemented in Swedish legislation *Miljöbalken* (1998:808 ch. 6).

[16] Mandatory documents for municipalities in Sweden.

runoff is dependent on historical precipitation and subsurface runoff, a process based continuous model is preferred (DHI, 2012b). One example of such a model is MIKE SHE; for further details, see DHI (2012b).

The accuracy of the model depends on its construction but also on the quality of the in-put data, and on the calibration process. For hydrological modeling there is a need for data in regards to precipitation, elevation and biogeochemical and biogeophysical processes to differing extents depending on the choice of model. Some data can be difficult, time-consuming and costly to obtain and format. The purpose of the simulation but also data availability, time available and budget all factor into the decision of model choice.

2.3.2.1 Time-Area Method

The Time-Area Method is commonly used in event hydrological models for urban areas to calculate runoff, as it is a relatively easy and cheap method, with a minimum of data requirements, using only a few parameters (DHI, 2012a). It is a widely accepted method for surface runoff projections and is used for the design of storm sewers among engineers (example Dunne and Leopold, 1995 p.299, Vägverket, 2008, Svenskt Vatten, 2004, Merz et al. 2006, Mays, 2011 p.444). Using this method, the amount of runoff can be calculated through Equation 2:

$$Q = P * \text{area} * \varphi \qquad \text{Eq. 2}$$

The volume of discharge (Q) can be calculated based on the amount of precipitation (P) that falls on a certain area times the runoff coefficient (φ) for that specific area. The runoff coefficient (φ) is the proportion of the precipitation that will become runoff.

Understanding of timing is also vital to mitigating and adapting to flooding, in deciding whether the volume of runoff produced at a certain time will be manageable or not. The time aspect for the runoff is calculated in the Time-Area Method using the parameters of time of concentration (t_c) and the Time-Area curve. The maximum amount of time that it takes for the precipitation that falls within a catchment to run off/concentrate to the point of interest determines if a subcatchment contributes to the discharge from a rain event within a specific duration. The Time-Area curve shows how the contributing area increases with prolonged duration of precipitation. It represents, and is a function of, the shape of the catchment, the roughness and slope of the surface, and the movement of the rain cloud (Mays, 2011p. 327-346, DHI, 2012a p.78 and 139).

As the Time-Area Method only contains a few parameters, it will also try to mimic reality with less parameters than a physically based model would use. For the choice of model, it is therefore important to understand which processes are vital for runoff from rural areas, and if these processes can be involved in the few parameters of the Time-Area Method. During sensitivity analyses in earlier studies the φ value has shown to be one of the most sensitive parameters (Kleidorfer et al. 2009).

2.3.2.2 Processes Deciding the Value of the Runoff Coefficient

Looking at the well-known hydrologic cycle can help in understanding the processes behind the amount of runoff produced (Figure 1). Precipitation that falls on a typical Swedish rural landscape will either evaporate from the surface, be intercepted by the vegetation and litter (for later evaporation) or will infiltrate into the ground where it can be stored and/or later transpired by the vegetation. The remainder of the water will create surface and/or subsurface runoff or percolate down to the groundwater.

Interception varies with vegetation depending on species, size, density and previous canopy wetness (Armson et al. 2013, Dunne and Leopold, 1995 p.87). Different soils, land use and vegetation impact the infiltration rate (further information see example Dunne and Leopold, 1995 p.172). Direct runoff on the surface occurs seldom in Sweden but could happen in the case of saturated surfaces, impervious surfaces (including frozen surfaces) or due to extreme rainfall intensity (Grip and Rodhe, 2003). Rural area´s impacts on storm flow volume is a matter of the storage capacity of the entire basin, while peaks are due to the influence of runoff processes, rainfall intensity and design of the ditch/channel (Hawlett, 1970).

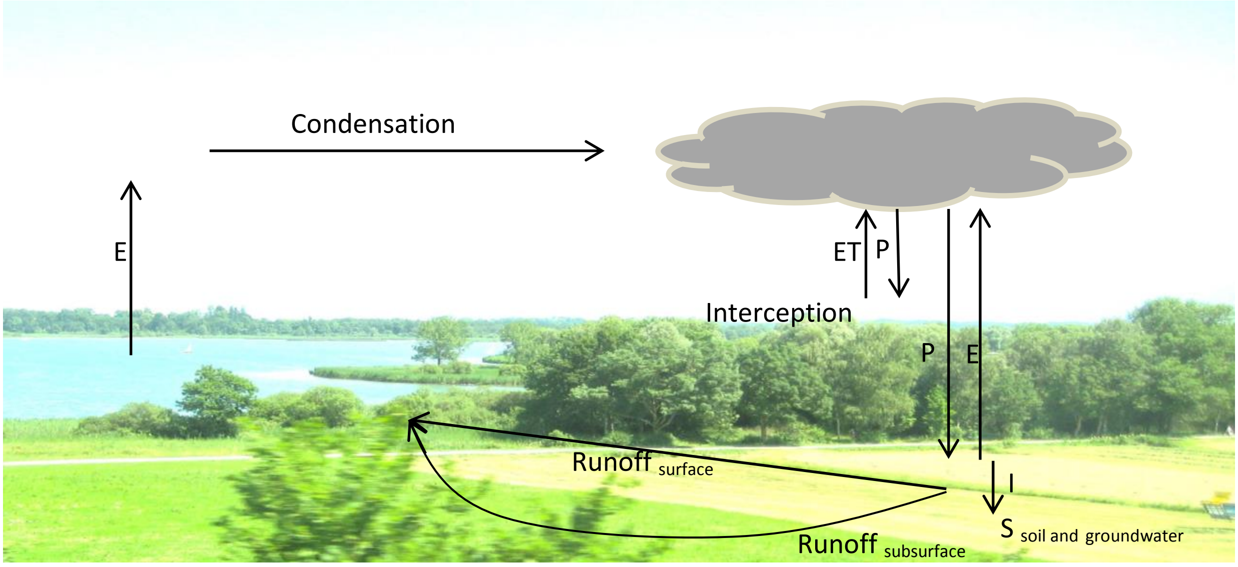

Figure 1: In the hydrological cycle precipitation (P) will be intercepted, evaporated (E) and transpired (T) from the ground and vegetation. Excess water will become surface runoff, or will be infiltrated (I) to be stored (S) in soil and groundwater, or will create subsurface runoff. After evaporation, the condensation process leads to new precipitation.

To be able to compare runoff generation in different catchments, efforts have been made to generalize runoff processes into one single value. The φ represents the part of the precipitation that creates runoff during a single rain event (Merz et al. 2006, Dunne and Leopold, 1995 p. 298-304). It has a value between 0-1 and is almost never 1, since this requires no losses. I interpret that φ also includes subsurface storm runoff according to Hawlett (1970). He writes that "*transmissivity makes the discharge be lagged somewhat in time but not enough to prevent its classification as quick flow*". Field investigations have shown a substantial contribution of subsurface storm flow due to the transmissivity feedback[17] (Grip and Rodhe, 2003, Vikberg, 2010). The φ value can be explained as the ratio between the discharge and the precipitation (Equation 3)(example *Dunne and Leopold 1978 p.303-304*):

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[17] Pressure from added rain water propagates through the ground making the groundwater surface to increase more rapidly than the water particles are moving. As the porosity and hydraulic conductivity decrease with depth in moraine an increase in ground water level closer to the surface creates a larger increase in flow compared to a rise at a lower depth. An increase of the level of groundwater surface and an increase of its slope increase the outflow in outlet areas (Grip and Rodhe, 1994 p. 31, 40-43 and 56).

$\varphi = Q/P$ Eq. 3

In this way it can also be explained by the processes in the water balance that create runoff (Equation 4) (Mays, 2011 p.280-281):

$Q = P - (ET + \Delta S)$ Eq. 4

where the volume of discharge depends on the amount of precipitation (P) and the processes of evapotranspiration (ET) (evaporation and transpiration) including interception and soil storage (ΔS). φ reflects the way vegetation, land use, soil type and topography perform hydrologically (Dunne and Leopold, 1995 p. 299). For urban areas the φ value can also be interpreted as a function of the proportion of the surface that is impermeable (Svenskt Vatten, 2004).

The φ value decreases with an increasing size of area (Svenskt Vatten, 2004). With a larger catchment the time between the precipitation and the peak is postponed and prolonged as runoff from different areas reaches the measuring point at different times (Grip and Rodhe, 2003 p.85). The peak-value per area thus decreases with increasing area. Lakes, wetlands or similar locations for storage also decrease the peak and makes it more prolonged (Grip and Rodhe, 2003 p.85). The storage capacity of the landscape decreases with steeper slopes, this instead increases the surface runoff (Grip and Rodhe, 2003 p.56).

2.3.2.3 Measuring the Runoff Coefficient

Theoretically φ could be estimated by field measurements of the amount of precipitation over a known area and the corresponding discharge produced, but as many parameters are both time and site-specific, such values are not representative of other rain events nor other locations. By using *paired catchment experiments*[18], it is possible to investigate the response of a specific land use treatment and decrease the impact and uncertainties from other circumstances (Brown et al. 2005). On a smaller plot-scale, *s*prinkling experiments can be conducted to allow investigating runoff processes under comparable precipitation conditions. Here also, imitation of more extreme precipitation can be analysed (Hümann et al. 2011). Up-scaling these results to a catchment scale should though be done with great caution (Cerdan et al. 2004).

I have found that the hydrological effect of land use/land cover change in the literature often is presented as a change in peak discharge. However, Hawlett (1970) argues that for flood risk the amount of change in storm flow volume due to land use change is more important than changes in instantaneous peak flow. Thus, as the downstream flood peaks are produced by the summation of the volumes received from the headwaters and not by their individual peaks as there most likely will be a time-difference between them. *The unit hydrograph principle* (USDA, 2000) states that the peak flow rate varies directly with the volume of discharge. It shows that if a certain change in peak flow is measured, this indicates the same change in volume. In the view of the hydrological impact from forest management, the article from Hawlett (1970) hypothesized, that in deep soil where the precipitation becomes subsurface flow, that the influence on peak will be small compared to the influence on the total volume.

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[18] Two locations with similar characteristics in terms of slope, soil, climate, vegetation etc. could be monitored simultaneously, after a calibration period one is treated and the other remains a control making it possible to investigate the response of the treatment (Brown et al. 2005).

2.3.2.4 Soil Curve Number

The US-SCS curve number method is developed by from U.S. Department of Agriculture Soil Conservation Service to calculate the event rainfall-runoff relation for a catchment depending on land use (USDA, 2004). The runoff is calculated using Equation 5:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \qquad \text{Eq. 5}$$

where Q is total storm flow minus base flow, P is total precipitation, I_a is the initial abstraction before ponding for which no runoff occur, and S is the potential maximum retention. The SCS have through empirical studies found that S can be calculated using Equation 6:

$$S = \frac{1000}{CN} - 10 \qquad \text{Eq. 6}$$

where CN is the runoff curve number containing the factors that effect runoff and retention. The CN-values range from 0-100. Data from thousands of infiltrometer tests on the catchment scale from mid-western United States, covering treatments and soil conservation measures, have been used to investigate the rainfall-runoff processes. The I_a is set to be a function of S, making it a one-parameter model (USDA, 2004). A direct translation of CN to φ is not possible but the highest values represent according to both theories the highest amount of runoff (Norbiato et al. 2009). The original method intended for agricultural sites has been extended to other land uses, and are now used throughout the entire United States, as well as in other countries (Ponce and Hawkins, 1996).

2.3.2.5 Processes Deciding the Time of Concentration

As described by the hydrological cycle, runoff can flow both through the hillside, on the surface and subsurface, and in the channel (figure 1). The t_c of a basin is the time required for storm water flow to reach the basin outlet from the hydrologically most distant parts of the catchment (Dunne and Leopold, 1995 p.299). Different processes will, therefore, effect the velocity of the water and with that the t_c (Equation 7):

$$t_c = t_{hillside\ (surface+subsurface)} + t_{channel} \qquad \text{Eq.7}$$

The flow path mainly follows the topography in the Swedish landscape with moraine soil (Grip and Rodhe, 2003 p.40 and 51). The hydrologically most distant point corresponds to the flow path with the longest travel time to the watershed outlet and not necessarily the longest flow distance (USDA 2010). With several subcatchments giving different t_c values the discharge increase as water from more and more distant parts of the catchment reaches the outlet.

For urban areas t_c should be proportional to the duration of the applied precipitation to be able to see the extent of the precipitation without overestimating the effect (Svenskt Vatten, 2004). For rural areas the t_c are typically longer, and the recession time of the hydrograph can be substantial. Depending on the aim of the model a duration of the applied precipitation, covering the main part of the regression curve, can be sufficient for rural areas.

T_c varies also with slope and the character of the watershed. Land use and vegetation will, for both hillside and channel processes, have an impact on concentration time. For hillslopes there are also different types of surface and subsurfaces processes that can occur (for more information see example Grip and Rodhe,1994, Dunne and Leopold, 1995). For calculating the t_c, the processes responsible for the production of runoff at that specific site and situation need to be investigated. The calculation can be made by using estimated velocities, through the velocity method (Equation 8):

$$\mathrm{t} = \mathrm{s}/\mathrm{v} \qquad \text{Eq. 8}$$

where time (t) can be calculated based on the distance (s) and the velocity (v).

3. Methods and Materials

3.1 Research Site and Earlier Investigation

I have carried out the research on Eneryda. It is a small village with 300-400 inhabitants located in the municipality of Älmhult, Kronoberg, Sweden (Figure 2). It is on the southern border of the boreal zone (Hari and Kumula, 2008 p. 124). The catchment mainly contains moraine soil (Appendix 1). As the inhabitants of Eneryda have experienced problems with flooding, the municipality has requested an investigation concerning storm- and wastewater issues and possible measures that could be taken to mitigate floods from Tyréns (Tyréns, 2013b). As part of this investigation discharge measurements were conducted in field and a hydraulic model was built in MIKE URBAN for the urban areas located south of the railway. I have developed the rural part of the initial MIKE URBAN model, i.e. north of the railway, and further developed it with a MIKE FLOOD connection.

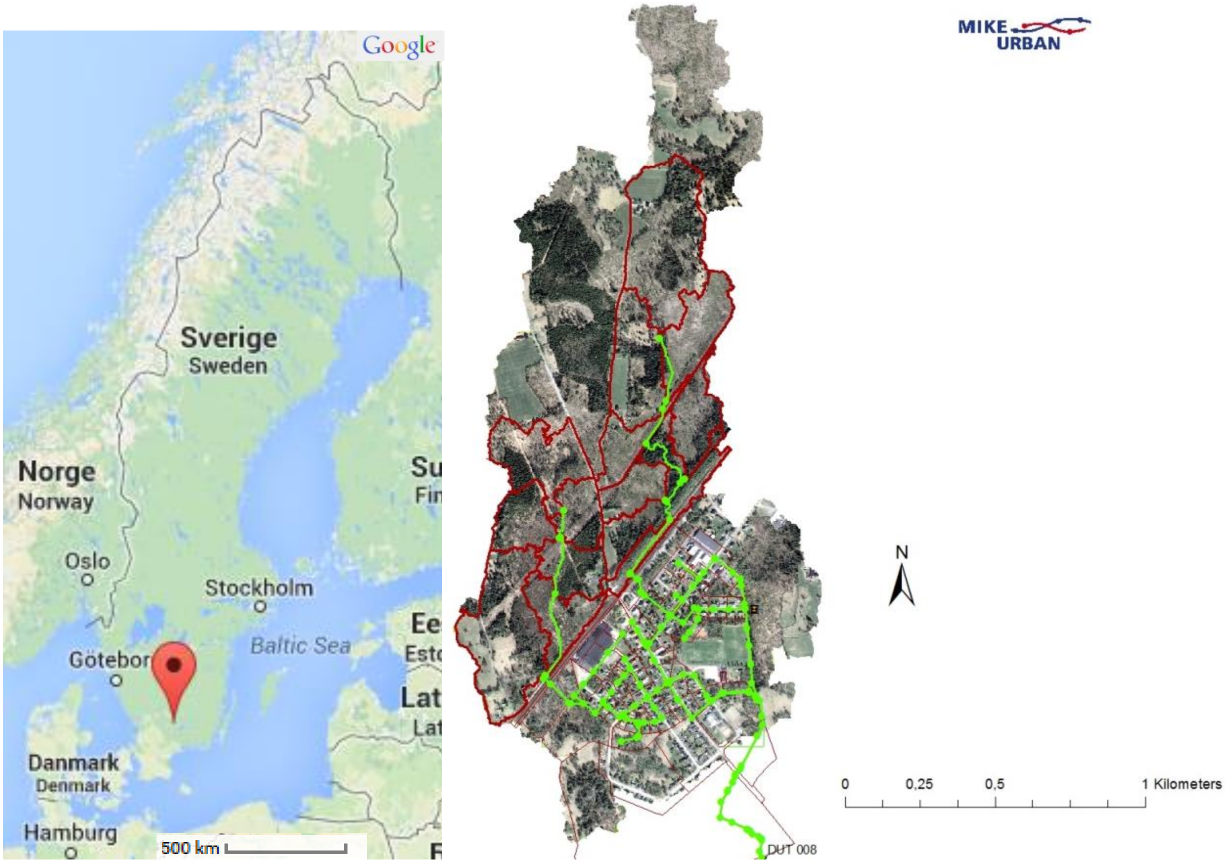

Figure 2: The study area Eneryda and its location in Sweden. The MIKE URBAN model is shown in terms of network (shown in green) and the rural catchments (shown in red). (Map over Sweden www.google.com/maps)

The hydrograph over the largest rain event from the field measurements contains a rapid increase of discharge, peak, and then a slower recession (Figure 3). The peak is mainly caused by rapid surface runoff from impermeable surfaces in the urban area, while the recession curve is caused by runoff from the rural areas higher up in the catchment, arriving later. The initial model from Tyréns was calibrated to match the peak discharge from the period of measurement. It can be seen that the total volume and velocities projected by the model do not represent the total flow (Figure 3). Further development was needed to better model the recession curve, produced by flow from the rural area.

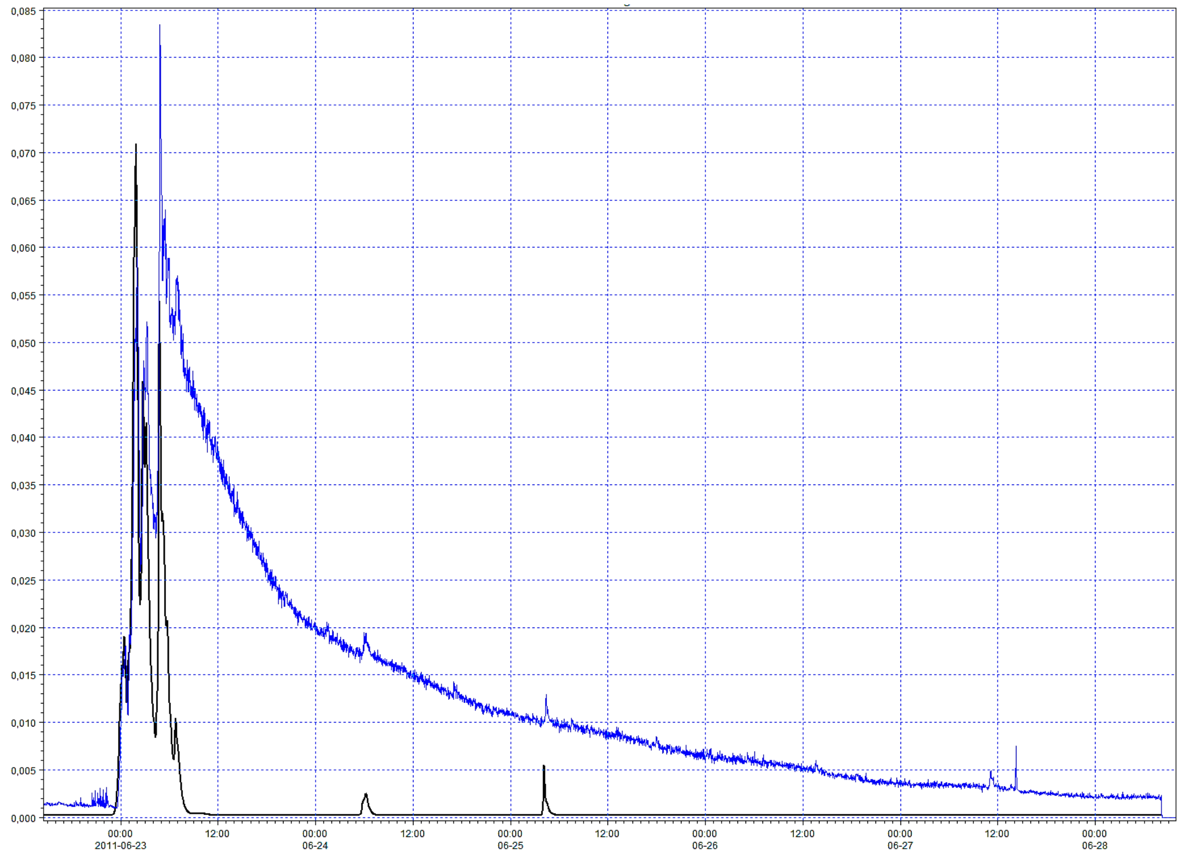

Figure 3: The initial MIKE URBAN model over the catchment of Eneryda provided by Tyréns (2013b). The measured discharge at Hördagatan (shown in blue) can be compared with the model simulation (shown in black).

3.2 Input Data

3.2.1 Precipitation

Precipitation is continuously measured at the pumping station in Eneryda by the municipality. The largest rain event during the time of parallel discharge measurements occurred during the evening and night between the 22/6- 23/6 year 2011. It brought 52.2mm of precipitation over a period of about 8 hours. This corresponds to a reccurrence interval[19] of about 10-years for this area using the historical distribution of rain events (Svenskt Vatten, 2004b); more precisely, somewhere between 9-14 years, depending on the time for when the precipitation is considered to start and end.

To be able to project the effect of precipitation with higher intensity and duration than captured during measurements, design rainstorms can be constructed according to recurrence intervals to be used in hydrological models. For the simulations I have used CDS-rains[20] representing recurrence intervals of 10- and 100-year with durations of 1 hour and 24 hours provided by Tyréns (Appendix 2). These recurrence intervals are selected based on the common value of a 10-year interval for the

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[19] Recurrence interval shows the likelihood for different precipitation to occur, the more extreme the longer recurrence interval. The amount of precipitation for different recurrence interval is less if they are a more local spatial scale (Vägverket, 2008).

[20] Chicago Design Storm -rain is built on block-rain with different intensity and duration distributed around the intensity maximum in the middle of the rain event this to include several types of rain intensities.

dimensioning of infrastructure (Vägverket, 2008) and a 100-year interval for representing a high-risk scenario. As rural areas are systems with slow runoff processes, a duration of 24 hours is used. The duration of precipitation, in association with t_c, effects whether the rural area, and specifically how much of the rural area, contribute to the peak discharge.

There is consensus in the scientific community that climate change leads to an increasing amount of extreme weather events including extreme precipitation (IPCC, 2014, Rummukainen, 2010). For Sweden, an increase in the total amount and intensity of precipitation expected, with a seasonal bias towards more precipitation during winter projected (Olsson and Foster, 2013). The authorities Svenskt Vatten (2011a) and SMHI (2010) assess that it is likely that short-term precipitation will increase by 5-30% by the year 2100. A compilation of results from climate models of short-term precipitation over Sweden, with the purpose of functioning to provide as recommendations and new guidelines from SMHI, has recently been conducted by Olsson and Foster (2013). They show a general increase in precipitation of 0-20% to 2050 for intensities less than 1 hour, and 0-15% for 24 hour rains. The projected increase to year 2100 for 1 hour and 24 hour precipitation is 15-25% and 10-30%, respectively. These values could be applied to reccurrence intervals other than 10-years, as no clear trend regarding recurrence interval has been observed (Olsson and Foster, 2013).

The impact from climate change will be included in my simulations by adding a climate factor to the precipitation. A regional report over Kronoberg states that the maximum 24 hour precipitation is projected to increase around 20% by 2050 and 40% by 2100, with an even larger increase during the winter (Johnell et al. 2010). I chose to use +20% as the climate factor for all my recurrence intervals and durations for projections concerning the year 2050.

3.2.2 Discharge

Discharge was measured in Eneryda at two locations, Hördagatan and Larmgatan, between 2011-04-28 and 2011-06-28 by Tyréns. The two locations represent runoff from the west with respect to the east rural catchment. The discharge has been separated according to the largest rain event recorded by the precipitation data (Figure 4, for Larmgatan, see Appendix 3). I have used this for calibration and validation of the model. The discharge was measured in water pipes using a VH-meter that detect the velocity and the height of the water level (Svensson, 2013 pers. comm.). The data was automatically read every other minute. At low base flow between rain events errors occur in the data showing negative values (Figure 4). This is due the fact that a low flow will not cover the VH-meter with water (Svensson, 2013 pers. comm.). Negative discharge can only occur if the sewage system is saturated and water is forced backwards in the system. By comparing the discharge data with the precipitation data from the same time, these negative values can be excluded and set to 0.

The largest rain event also generated the largest discharge of the measurement period with 5801m^3 at Hördagatan and 7278m^3 at Larmgatan. The peak occurred in the night/early morning of the 23 of June, with 103 l/sec for Larmgatan and 83 l/sec for Hördagatan. A linear pre-storm base flow was calculated based on the mean value for 35 measurements before the increase of discharge to 1.11 l/sec for Hördagatan and 0.528 l/sec for Larmgatan. After eliminating the base flow from the total discharge (Mays, 2011 p. 329 and 333) and through using the already set imperviousness for the urban area, from Tyréns, I calculated the corresponding φ for the rural area to be 29.17% for the western catchment and 29.35% for the eastern catchment. For further information see Appendix 4.

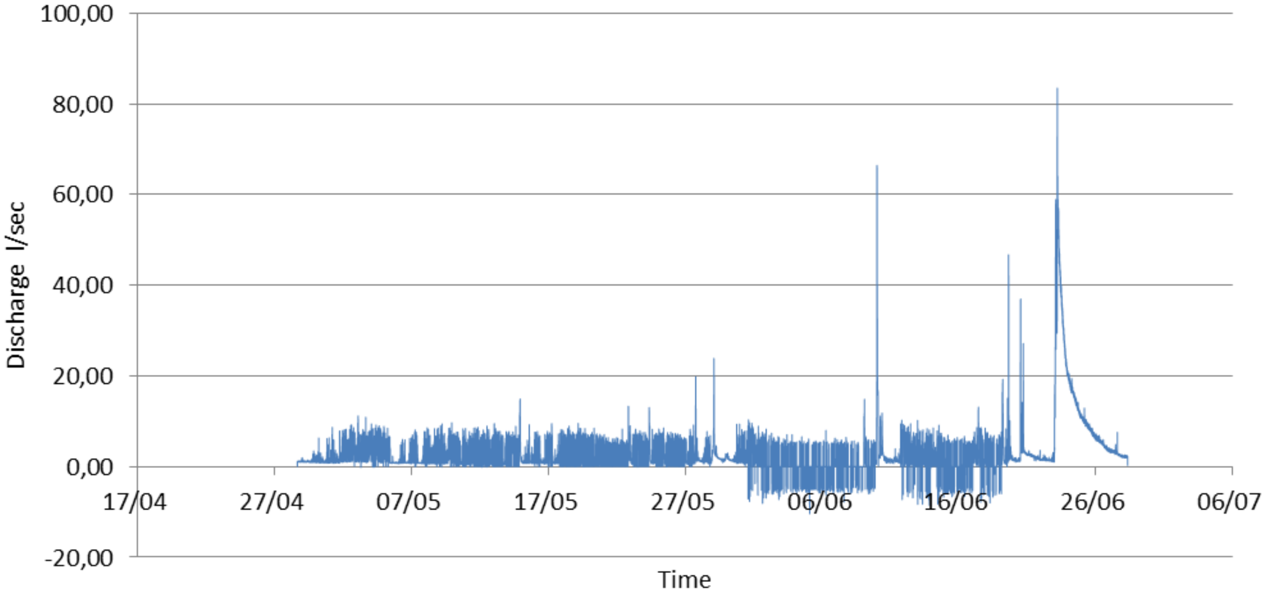

Figure 4: Measure discharge at Hördagatan, 2011. The largest rain event is used for calibration and validation of the model.

3.2.3 Digital Elevation Model

A new digital elevation model (DEM) over Sweden is currently being produced using LIDAR[21]. The horizontal resolution will be worst of 2 meters, with a standard deviation of 0.4 meter in plane and 0.1 meter vertically (Lantmäteriet, 2013). The accuracy for specific laser spots on a flat impermeable surface are higher, while in areas with steep slopes and/or dense vegetation, the accuracy could be lower (Lantmäteriet, 2011). For Eneryda, I have used the 1 meter DEM from 2010 provided by © Lantmäteriet [i2012/927]. The laser scanning was conducted before the vegetation season, giving better results for the ground elevation (Lantmäteriet, 2011). However, it was very wet when the scanning was performed (Svensson, 2013). This influenced the scanned result of elevation, as the laser is reflected back from water surfaces, thus not revealing, for example, the depth of a ditch. I have taken this into consideration when interpreting the DEM.

3.2.4 Current Land Use

The classification of land use cover over Enerydas catchments is based on the national database of land use and vegetation *Marktäckedata* from around the year 2000. I updated it to the current land use according to air-photo *Ortofoto* from 2013 (© Lantmäteriet [i2012/927]). The reclassification was made by converting *Marktäckedata* from raster to polygons in ArcGIS 10.1, and then by splitting the polygons and reclassifying them according to *Ortofoto* (Figure 5). This land use is assumed to correspond well to the land use during the precipitation and discharges measurement taken in 2011. This is important since the land use reported in *Marktäckedata* has changed dramatically due to the large storm Gudrun in 2005. Several areas categorized as forest have been deforested. Locations of drainage infrastructure details have been provided from the County Administrative Board of Kronoberg in the form of polylines in GIS and historical documents (Appendix 1).

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[21] Airborne laser scanning.

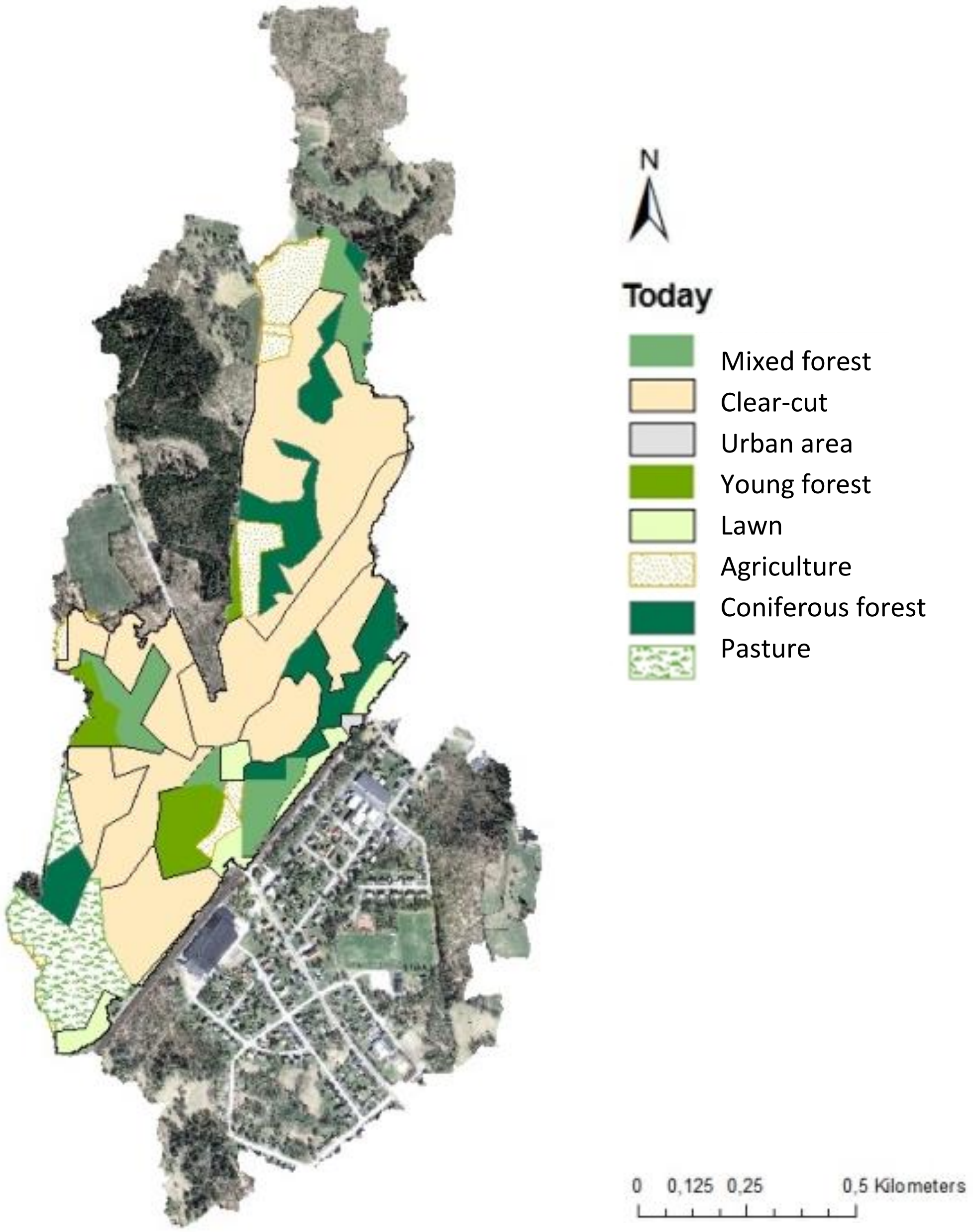

Figure 5: Classification of current land use in the catchment of Eneryda based on “Marktäckedata” and “Ortofoto“ (©Lantmäteriet [i2012/927]).

3.2.5 Future Land Use Scenarios

I have down-scaled the assessed impact from the A2 and B1 scenarios projected by Dyna-CLUE[22] to the landscape of Eneryda. These scenarios represent the degree of global market integration and different levels of policy regulation relevant to climate change outcomes (Verburg et al. 2010). As the resolution in Dyna-CLUE is 1km^2, a 20km*20km area is chosen for calculating the land use change between 2010 and 2050 for each storyline (Figure 6). The difference in land use between the different years and different scenarios is summarized in Table 1 (for detailed calculations see Appendix 5). The agricultural decline due to competition from other areas and the regeneration of

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[22] Data provided by Peter Verburg, Amsterdam. The data is similar to the one presented in Verburg et al. 2010 except that the temporal extend is increased until 2050.

natural vegetation on abandoned farmland can clearly be seen in the two scenarios (Verburg and Overmars, 2009).

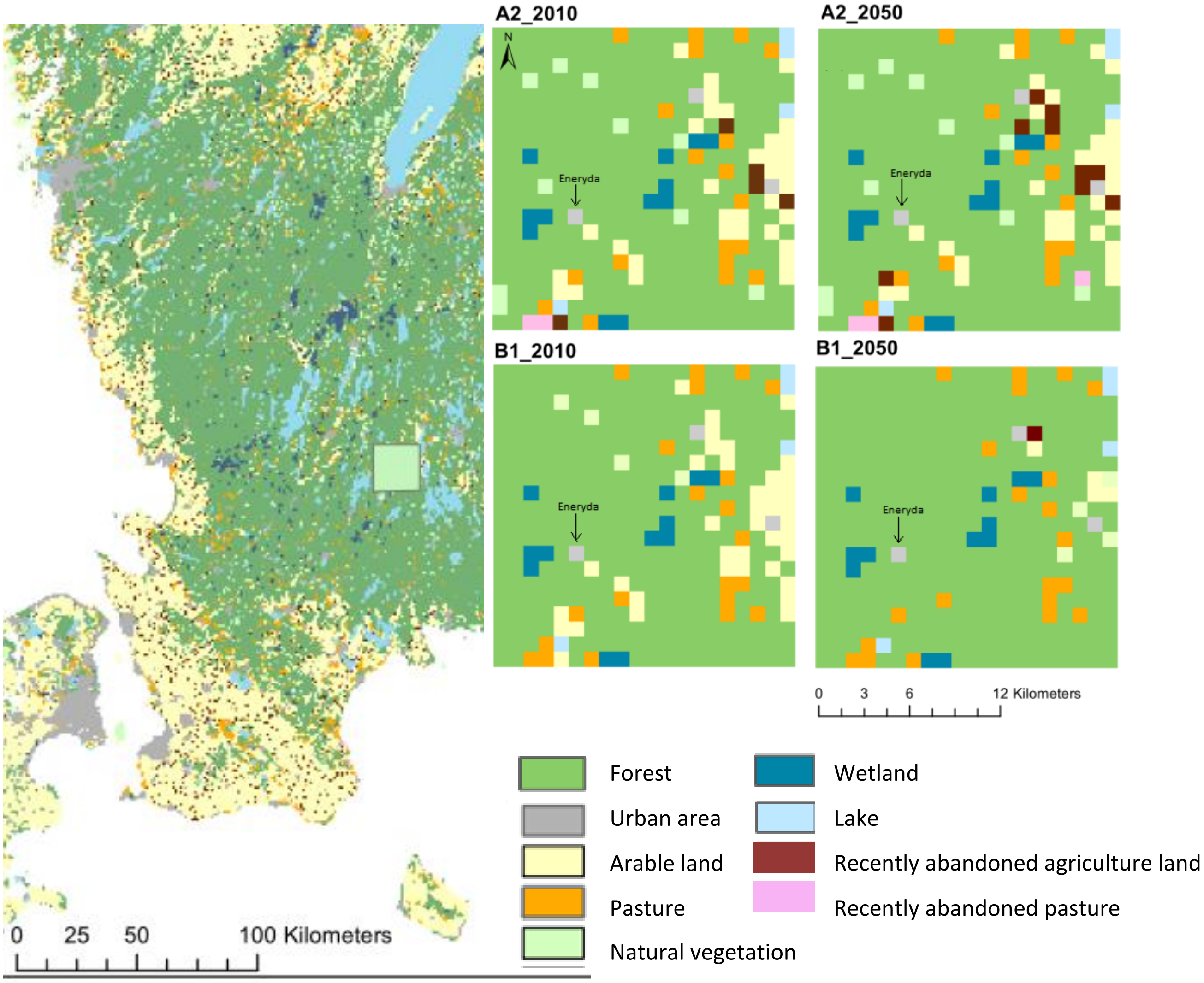

Figure 6: Land use and land use change according to Dyna-CLUE. The large figure shows the climate storyline A2 for the year 2010. An area of 20km*20km (green square) is zoomed in the top right corner. They have been used to represent the change in land use between 2010 and 2050 for Eneryda for the climate scenarios A2 and B1 (further calculated in Table 1).

Table 1: Land use change (%) for the area of Eneryda between year 2010 and 2050 according to climate scenarios A2 and B1, data down-scaled from DYNA-CLUE.

Change 2010-2050	**A2**	**B1**
Arable land	-8.8	-89.7
Pasture	-10.5	0
Recently abandoned agriculture land	+100	+100 *
Forest	-0.3	+10.7
Recenty abandoned pasture	+50	-

* from 0 to 1km^2

To the landscape of Eneryda I have further applied more local climate strategies regarding rural land use discussed above in Section 2.1. This gives in total four scenarios for investigations in regards to flooding (Figure 7).

- **A2** represent a scenario with continental markets where regions are striving for self-sufficiency with a minimum of involvement from government i.e. weak directives and regulations and no policies regarding biofuels (Verburg et al. 2010). The land use is set according to the land use change projected by Dyna-CLUE. The coniferous forest that grows today is assumed to contain 10% deciduous trees according to "good practice" in FSC-certification[23] (2013). The partitioning of clear-cut locations is set according to a rotation time of 50 years in agreement with current forest regulation (Skogsvårdslag 1979:429, Kunskap direct, 2011). Annual cropping is used in agriculture. Recently abandoned agriculture and pasture are classified as afforested agriculture or afforested pasture, respectively. I chose to use the φ-values for abandoned agriculture and pasture instead of values for fallow land, since fallow land in Table 6 represents bare soil, which is not the case for the abandoned agriculture land in Eneryda.

- **B1** is a global cooperation scenario with international cooperation for reducing poverty and environmental issues, and protecting the cultural and natural heritage (Verburg et al. 2010). Trade barriers are removed and 5.75% of biofuels is mixed in the transport-fuel (Verburg et al. 2010). The land use is set according to the land use change projected by Dyna-CLUE. The mixture of tree species, rotation time and agriculture crop is treated similarly to *A2*. The large difference between the *A2* and *B1* scenarios is that agriculture and pasture is abandoned earlier in B1 according to Dyna-CLUE. This leads to a land use change to forest in 2050, not abandoned agriculture and abandoned pasture as is found in the A2 scenario. Agriculture and pasture that has become forest is set to become mixed forest in this scenario.

- **The substitution principle** is a development of the *A2* scenario, with everything being the same, but assuming an intense forestry approach according to the substitution principle. The forest will be deforested when it is mature. The forest is young today and assuming the same rotation time of 50 years, gives the same area of deforestation as for current land use plus the deforested area in the *A2* scenario.

- **The carbon storage** is a development of the *B1* scenario. Following the carbon storage strategy no forest is deforested in this scenario, instead the forest can grow up, mature, be maintained and protected. The annual crops in agriculture are replaced with perennial vegetation.

Even if energy-forest has been discussed as an alternative for both substitution and carbon storage I chose not to include such plantations in my scenarios. This is because the conversion of agricultural land in the *A2* and *B1* also is interpreted as the areas most likely for conversion to plantations of energy-forest (Jordbruksverket, 2007).

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[23] Forest Stewardship Council, certification system for forestry.

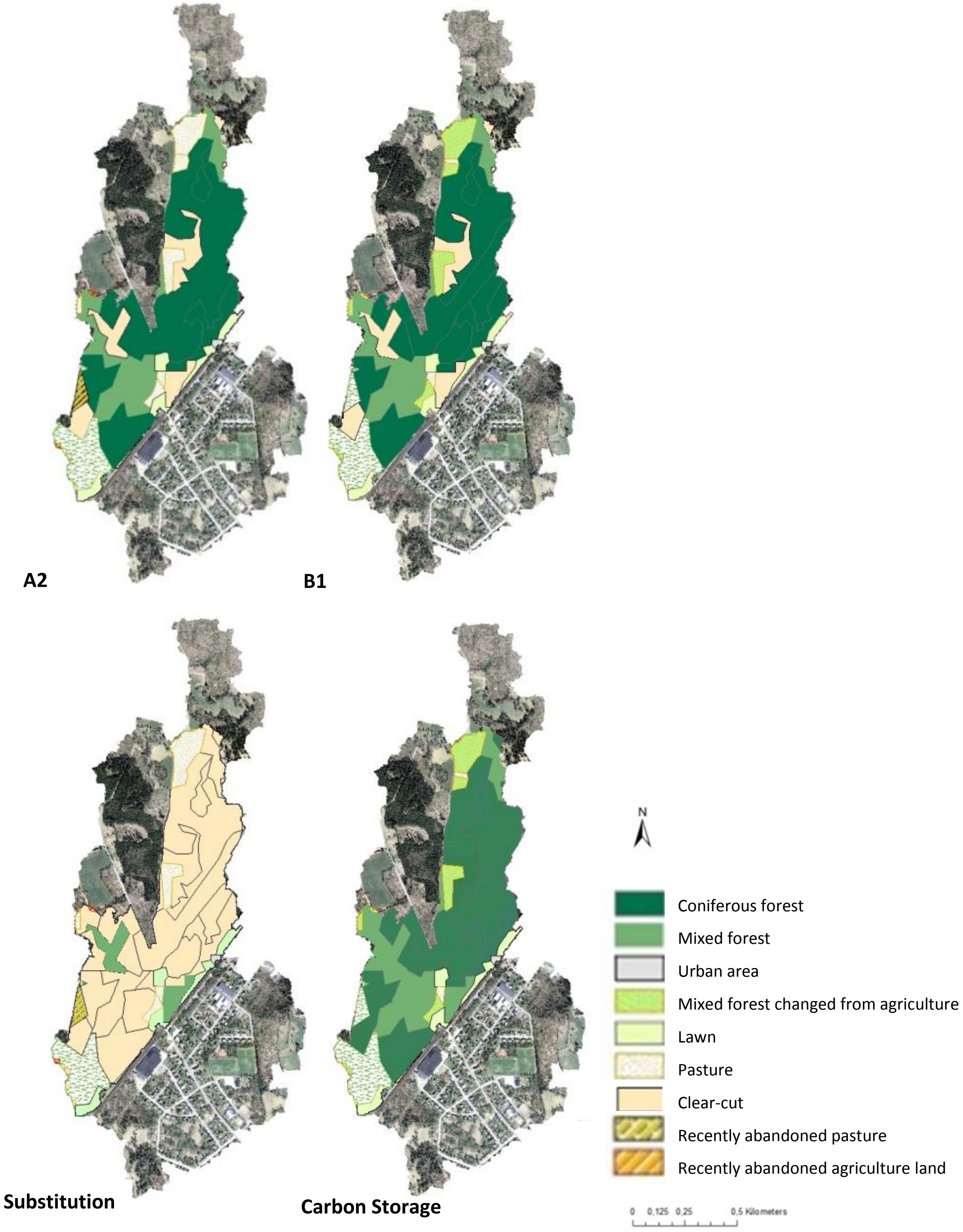

Figure 7: The different land use scenarios for Eneryda for year 2050.

3.3 Set-up of the Model

I developed the MIKE URBAN/MIKE FLOOD model by using a DEM with higher resolution, 1 meter instead of 2 meter, and adding information regarding drainage infrastructure. The tool ArcHydro in ArcGIS 10.1 (Spatial Analyst) was used to create routing of runoff drainage lines based on the DEM. To do this, depressions in the terrain model were first identified and filled. This filled layer was then used for creating the flow direction, namely how the water will flow out of the cell depending on the elevation of the eight neighboring cells. From this, accumulation grids, containing the number of cells that drain to a specific cell, was calculated. The method to create drainage lines are further described in Jenson and Domingue (1988). For depressions and drainage line, see Appendix 6.

I used the drainage line to make sub-catchments upstream of elected locations. Culverts passing under the railway were added in MIKE URBAN according to field observations. Two large catchments, west and east, based on the culverts under the railway and 14 smaller sub-catchments were created. The slope of the area was calculated in ArcGIS using the Spatial Analyst. With this set-up an area of 16 hectares in the north eastern corner drains outside of Eneryda as a result of the new DEM. A 30 hectare area in the north west drains outside of Eneryda as a result of the ditching affected area (Appendix 6). This gives the total rural catchment an area of 72.5 hectares.

I supplemented the original MIKE URBAN model with a network of links corresponding to small streams and ditches. Routing of the links was based on the created drainage lines. This created drainage lines match well with the small stream and ditches visualized in the DEM. In a few cases where these two do not match, it is because of a depression, and the drainage line will due to this, take the shortest (and incorrect) route. In those cases, the routing of the link will be decided according to what is visualized by the DEM. For set-up reasons, the links are connected by fictional manholes (nodes), also up in the sub-catchments where no actual manholes exist. As these are the same size and “No Cross Sectional Change” is used as a default outlet head loss these nodes shall not influence the flow. Based on the DEM and 3D tool in ArcGIS Viewer, I set the size of the links according to earlier size classifications of ditches made by Tyréns. The wet conditions during the laser scanning to DEM was here taken into consideration, since this might have influenced the depth given for the ditches in the DEM.

Rural parameters to be added in MIKE URBAN are initial loss, reduction factor, t_c, Time-Area curve and imperviousness, as well as precipitation. I chose to set initial loss to 0 and reduction factor to 1 as my default values. T_c and Time-Area curve is used for calibration. The impervious-parameter I interpret to be equivalent to φ [24](Svenskt Vatten, 2004).

The need for improving the conventionally used φ -values for rural areas in Sweden (Table 2) (Svenskt Vatten, 2004, Vägverket, 2008) is visualized in Figure 8[25]. The difference between applying minimum and maximum φ -values only give a marginal difference in the hydrograph. The t_c applied is based on the velocities for surface runoff from hillslope respective channels of 0.1 m/sec, and 0.5 m/sec from the same report (Svenskt Vatten, 2004) (calculations in Appendix 7). The mismatch is

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[24] Schueler (1987) related the runoff coefficient to imperviousness *by equation:* $\varphi = 0{,}05 + 0{,}9(\mathrm{I}/100)$
This gives an imperviousness (I) of 100% a runoff coefficient (φ) of 0, 95. An area with an imperviousness of 0% (i.e. pervious) will in the same way have a runoff coefficient of φ =0,05. Schueler (1987) argue that an 100% runoff from total paved areas is not likely due to loss from evaporation.

[25] Simulated by me as a background.

similar to that from the initial model (Figure 3). As also other equations for surface flow on hillslopes give similar result (example USDA, 2010, Persson, 2011, Mays, 2011 p. 446) it is obvious that surface runoff is not well represented for the rural catchment in Eneryda during the measured period. This is in agreement with the theory regarding rural runoff in Sweden (Gripe and Rodhe, 2003). As this model does not contain subsurface runoff processes I instead chose to apply velocities directly on the hillslope. The same velocity was used for all different land use types.

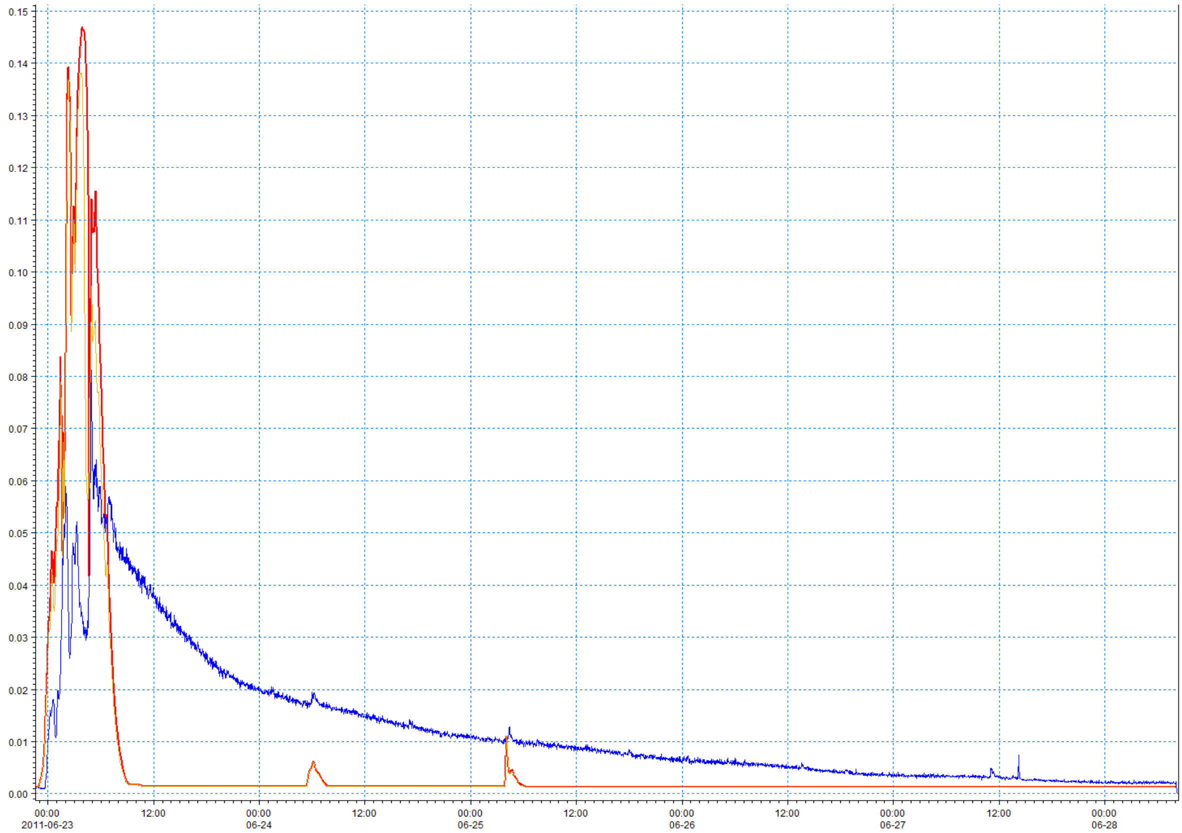

Figure 8: MIKE URBAN carried out on Eneryda. The measured discharge at Hördagatan (shown in blue) to be compared with the conventional φ -values from Svenskt Vatten (2004) with minimum values shown in orange and maximum values shown in red. The difference between applying minimum and maximum φ -values only give a marginal difference.

Table 2: A compilation of runoff coefficients for rural land use provided by Swedish authorities (Svenskt Vatten, 2004, Vägverket, 2008). The values apply to a precipitation recurrence interval of 5-10 years.

Land use	**Runoff coefficient**
Forest (hilly)	0.1
Forest (flat)	0-0.1
Arable land, grass, meadow	0-0.1

The low detail in the φ -values for rural land use from Swedish authorities (Table 2) is not sufficient to answer my research questions. Due to this, I have developed more detailed φ values; see below. φ values are applied directly on the rural catchments in MIKE URBAN. I finally connected the MIKE URBAN model with the overland flow model MIKE 21 through the software MIKE FLOOD by coupling the two at the manholes. The overland flow is calculated in a defined grid selected from where overpressure is found in the network through MIKE URBAN, and is dependent on the accuracy of the

DEM (DHI, 2012a). For more detail see DHI (2007 and 2012a ch. 9). The coordinate system used for all mapping is SWEREF 991330.

3.3.1 Runoff Coefficients for Rural Land Use

To create more detailed values of φ for forest and agricultural lands, I have further developed the compilations of φ from Dunne and Leopold (1978 p. 300)[26] and the CN (USDA, 2004) (Table 6). The compiled φ -values are for a precipitation recurrence interval of 5-10 years. I developed the values for sandy and gravelly soil, corresponding to the moraine derived soils in Eneryda[27].

3.3.1.1 Forest

To create more detailed φ values for forests I have used the proportional difference in terms of volume and peak flows between forest management approaches found through paired catchments and sprinkle experiments (Table 3).

- **Tree species** and tree species composition can influence the processes of evapotranspiration and infiltration, as different species intercept differently and can modify soil properties in different ways (Jost et al. 2012, Dunne and Leopold 1978 p.87, Grip and Rodhe, 2003, p.14-15). Sprinkle experiments from Jost et al. (2012) and Hümann et al. (2011) result in a lower φ value for coniferous forest compared to deciduous tree stands. I have calculated the mean value between deciduous and coniferous forest based on the 100 mm sprinkled experiment from Jost et al. (2012) and the second day of experiment from Hümann et al. (2011). This mean value is set to represent a 50/50 mixture of coniferous and deciduous trees. This gives a deciduous forest a value of +24% of runoff compared to a mixed forest, and a coniferous forest a -24% runoff compared to a mixed forest. The difference in φ values between different tree species can also be traced back to the difference in evapotranspiration (interception) (Dunne and Leopold, 1995 p.87, Grip and Rodhe, 2003 p.14-15). I use this difference assuming similar soils; worth to notice is that different species tend to grow on different soils, also influencing the runoff.

- **Deforestation** will decrease evapotranspiration from vegetation (for example Hawett 1970). This leaves a larger amount of precipitation to infiltrate, leading to a higher groundwater level, favoring the transmissivity feedback (Vikberg, 2010). Forestry also impacts the soil that negatively affects infiltration, which may lead to a substantial increase in runoff (Anderson et al. 1976, Robinson et al. 2003). Robinson et al. (2003) conclude, based on paired catchment studies, that cutting coniferous forest in northern Europe leads to short-term increases in both peak flows and baseflows at the local scale but that the influence of forest management will be diluted on a regional or larger scale. To create a value of φ for deforestation to be used in my model I have used the result from the Guillemette et al. (2005) review. It gives an average increase in bankfull peak flow of +49% based on 50 paired catchment studies. As the increase is based on the peak, this needs to be transferred to a change in volume. I chose to interpret peak and amount as directly proportional to each other, according to the unit hydrograph principle (USDA, 2000). The effect of logging decreases with vegetation succession after deforestation. An exact time for a given lovation is hard to assign (Dunne

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[26] Compilation based on America Society of Civil Engineers, 1969, Rantz, 1971, and elsewhere.

[27] For lawn the value for heavy soils with a flat slope has been used since this value is assumed to be similar to pasture according to Chow et al. (1988).

and Leopold, 1995 p. 152, Robinsson et al. 2003). I chose to count 10 years after deforestation as deforested according to Ring et al. (2008).

- **Afforestation.** Soils within a forest are relatively porous with high infiltration rates due to roots and other biological activity (Bronsert and Plate, 1997). Anthropogenic compaction of a porous soil may, however, take centuries to redevelop under afforestation. Arable lands that recently have been afforested are therefore still likely to react similarly to runoff as they did under their former land use (Hümann et al. 2011). I have used the difference in φ values between the 1-year afforestation and the arable land from the second day of sprinkling experiment conducted by Hümann et al. (2011) to create my proportional difference for afforestation on agriculture and pasture land. This gives a value of 82.5% for the φ value used for agricultural lands and pasture, respectively, depending on the former land use.

- **Energy crops**. During field measurements on energy crop in Sweden, conducted by Persson and Lindroth (1994) *Salix viminalis* was shown to have high evapotranspiration. The seasonal value is considered to be higher than traditional agricultural crops and forest in the same climatic region (Persson and Lindroth, 1994). The estimated crop coefficient[28] for willow is similar to those of other water-consuming crops, like cotton, potato, sugarcane and tomato (Persson and Lindroth, 1994). Based on this information, I estimated the φ value from energy crops as represented by *Salix* plantations to be similar as a good perennial crop, according to CN, and/or close to forested values.

Table 3: The proportional difference (%) in runoff coefficient (φ) between different forest land use, summarized by the literature study.

Land use/Land use change	**Change from the φ -value**		
	Forest	*Agriculture*	*Pasture*
Mixed forest	100		
Decidious	124		
Coniferous	76		
*Deforestation (Mixed forest)**	149		
Agriculture land		100	
Afforestation on agriculture land		82.5%	
Pasture			100
Afforestation on pasture			82,5
Salix plantation	Similar value as forest or perennial agriculture		

* For deforestation on deciduous and coniferous forest respectively, the φ values are calculated based on +49% from those different forest types´ respective φ values.

3.3.1.2 Agriculture

I have conducted an interpolation between CN and the compiled φ values. The CN takes four different soil classes and tree different antecedent soil moistures into consideration (today called antecedent runoff condition) (USDA, 2004, Ponce and Hawkins, 1996). The moraine soil type in the catchment of Eneryda is classified to belong to soil group A i.e. deep sand, deep loess and aggregated silts. The soil moisture condition in Eneryda during the largest rain is classified to *Low moisture* (I)

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[28] *"A coefficient expressing the difference in evapotranspiration between the cropped and reference grass surface" (FAO, 1998, ch.5)*

based on the total precipitation of 29,6 mm during the 5 days before the large precipitation event (>35mm is classified as average moisture conditions (II)) (Dunne and Leopold, 1995 p.296). The interpolation from CN (II) to CN (I) follow the Dunne and Leopold approach (1978 p.296). Four known φ -values from the compilation by Dunne and Leopold (1978 p. 300) were interpolated with rural CN for soil group A and soil moisture (I) through exponential regression ($y = 0{,}0697e^{0{,}0262x}$ r^2=0,9999) to get values for unknown φ (see Table 4). The φ values assume good ground cover, which is why I also chosed the corresponding CN according to good ground cover. By assuming that the ratio between agriculture and forest from the used compilation of φ is valid this proportion will be maintained after interpolation due to the high r^2. It would though have been desirable to conduct the interpolation with several values, as this indicates the dispersion, and with that the uncertainties, within the used φ.

Table 4: Known values for CN (USDA, 2004) and runoff coefficient (φ) (Dunne and Leopold, 1995 p. 300) for soil class A and antecedent soil moisture (I) and the result from the interpolation between them used to create values for the unknown φ.

Land use	**CN (I)**	**Known φ**	**Interpolated φ**
Agriculture (Annual)	40.35	0.2	0.201
Pasture	29.18	0.15	0.150
Lawn (max)	29.18	0.15	0.150
Agriculture (Perennial)	31.08	x	0.157
Fallow	60.95	x	0.344
Meadow	13.88	x	0.100
Mixed Forest	13.88	0.1	0.100
Coniferous			0.076
Decidious			0.124
Deforestation (Mix forest)			0.149
Deforestation (Coniferous)			0.114
Deforestation (Decidious)			0.185
Afforestation agriculture			0.166
Afforestation pasture			0.124

3.3.1.3 Runoff Coefficients and Up-scaling

To be able to use the interpolated φ values (Table 4) in the model over Eneryda I have further adapted these values to the hydrological situation that occurred during the largest rain event. The total φ values of 29.17% (see 3.3.2 *Discharge*) for the west catchment has been used for this adaptation, giving a factor for adaptation of 2.14 (for further details see Appendix 8). In this procedure, I assume that the proportions of flow volume contributed by various land uses are the same, independent of the amount of precipitation. The adapted φ values are presented in Table 6. I assume these to be the “base- values” corresponding to a recurrence interval of about 10 years.

For larger precipitation than that associated with the 10-year interval, further up-scaling is necessary since processes like infiltration and interception have a proportionally smaller effect on runoff from more intense precipitation (ODOT, 2005). The φ value can be enhanced with an up-scaling factor when applied to larger precipitation. Two methods to up-scale φ values depending on precipitation are the *Design Storm Frequency Factor* from FDOT (2012)[29] or the up-scaling factors calculated from the values given in Chow et al. (1988 p.498)[30] (Table 5). The *Design Storm Frequency Factor* uses the same proportion of up-scaling, independent of land use, while the compilation in Chow et al. (1988) recommends different up-scaling depending on land use and slope. The value for flat slopes (0-2%) is presented, as this represents the conditions in Eneryda. I chose to use the *Design Storm Frequency Factor* as these are similar to those recommended by Swedish authorities Svenskt Vatten (2004) and Vägverket (2008). This choice is further discussed based on a sensitivity analysis results below.

Table 5: Up-scaling factor for φ to adapt to precipitation with different recurrence interval recommended by 1. Chow et al. (1988) 2. FDOT (2012).

	10 year	**25 year**	**50 year**	**100 year**
Agriculture[1]	1	1.11	1.19	1.31
Pasture[1]	1	1.13	1.23	1.37
Forest[1]	1	1.11	1.25	1.40
All land use[2]	1	1.1	1.2	1.25

Table 6: φ conducted for low antecedent soil moisture (I) on moraine soil (A). Adapted to a local rainfall with a recurrence interval of about 10-years for Eneryda and up-scaled to larger precipitation through the *Design Storm Frequency Factor* (FDOT, 2012).

Land use	**~10-years**	**50-years**	**100-years**
Agriculture (Annual)	0.429	0.514	0.536
Pasture	0.320	0.384	0.340
Lawn	0.320	0.384	0.340
Agriculture (Perennial)	0.336	0.403	0.420
Fallow	0.735	0.882	0.918
Meadow	0.214	0.257	0.268
Mixed Forest	0.214	0.257	0.268
Coniferous	0.163	0.195	0.203
Decidious	0.266	0.319	0.332
Deforestation-Mixed forest	0.320	0.383	0.399
Deforestation-Coniferous	0.243	0.292	0.304
Deforestation-Decidious	0.396	0.475	0.495
Afforestation agriculture	0.354	0.425	0.443
Afforestation pasture	0.264	0.317	0.330

3.4 The Impact of Rural Land on Flood Risk in Eneryda

As a background before validating the model and answering my research questions I investigate if the influence from rural land is of importance for flood risk in Eneryda during a single rain event. This is accomplished by including the slow flow recession that is expected from natural areas (similar to Figure 3). A precipitation event with a recurrence interval of 100-years (duration of 1 hour and 24 hours) is applied in MIKE URBAN and MIKE FLOOD. The results are compared with a model that does not include this slow flow recession, but only the peak.

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[29] Original source Wright-McLaughlin Engineers, 1969

[30] Standard used in the City of Austin, Texas.

3.5 The Validation Process

Uncertainty in models can be derived from the uncertainty associated with the data used, model parameters and the structure of the model (Bellocchini et al. 2009). A calibrated model is assumed to contain less uncertainty within the range for which that the model has been calibrated (Bellocchini et al. 2009). The validation process is based on calibration and validation operations, comparing results to physical measurements and other field observations. For a hydrological model this can involve measured hydrographs and observations of distribution for flow and flooding (Bellocchini et al. 2009).

I have conducted the validation process on measured precipitation and discharge from two months in the study period. I have used both visual and statistical methods for comparison between the measured and the simulated discharge in terms of the hydrograph, volume and peak flow. The focus has been on the event with largest precipitation, as this runoff regime best represents a situation when flooding will occure. The parameters used for the calibration are t_c and the Time-Area curve; these parameters have been changed individially, and then in combination. As I have calculated φ to adapt to the individual rain events; this is not a parameter for calibration. The validation is conducted on the same rain events as used for calibration, but as the rural catchment of Eneryda contains two large subcatchments, one west and one east with similar conditions, I have been able to conduct the calibration for one of the catchments and the validation for the other. This process has also been repeated by switching the roles of the two catchments.

3.6 Sensitivity Analysis

Sensitivity analysis can further investigate the size of the uncertainty or errors of different parameters, and in this way indicate for which parameters a higher quality/accuracy is needed (Bellocchini et al. 2009). I have conducted two sensitivity analyses. One is concerned with the choice of an up-scaling factor, conducted on the *Today* scenario, and the other is regarding the value of the climate factor, with possible values of 0%, 20% and 30% increases in precipitation, conducted using scenario *B1*.

In an effort to help answering my first research question, I have also conducted a comparison study. The response to the same change of land use by my MIKE URBAN model is compared with the physically-based model, MIKE SHE, as used by Kalantari et al. (2014). Through changing the proportions of land use in a fashion that is similar to that used by Kalantari et al. (2014), I wish to investigate the impact of rural land use on discharge as represented by the Time-Area Method, and validate some of my rural φ values. As this comparison also is made for precipitation with different recurrence intervals, I also wish to analyze how well the model responds to a change in precipitation.

I have first applied the percentages of land use from Skuteruds catchment, Norway, in my model and then the percentages of land use change following the Kalantari et al. (2014) scenarios (Figure 9):

- Clear-cut (corresponds to the scenario with 30% clear- cut)
- Reforestation of 60%
- Reforestation 30% upstream (further away from the village)
- Reforestation 30% downstream (closer to the village)

The location of the different land uses in the catchment is similar to the placement in Skuterud. Precipitation of 10- and 50-years with both 1-hour and 24-hour duration has been used to run the simulations. The forest in the Skuterud catchment is described to be coniferous forest with elements of deciduous forest. I have chosen to use the φ value for mixed forest for this comparison.

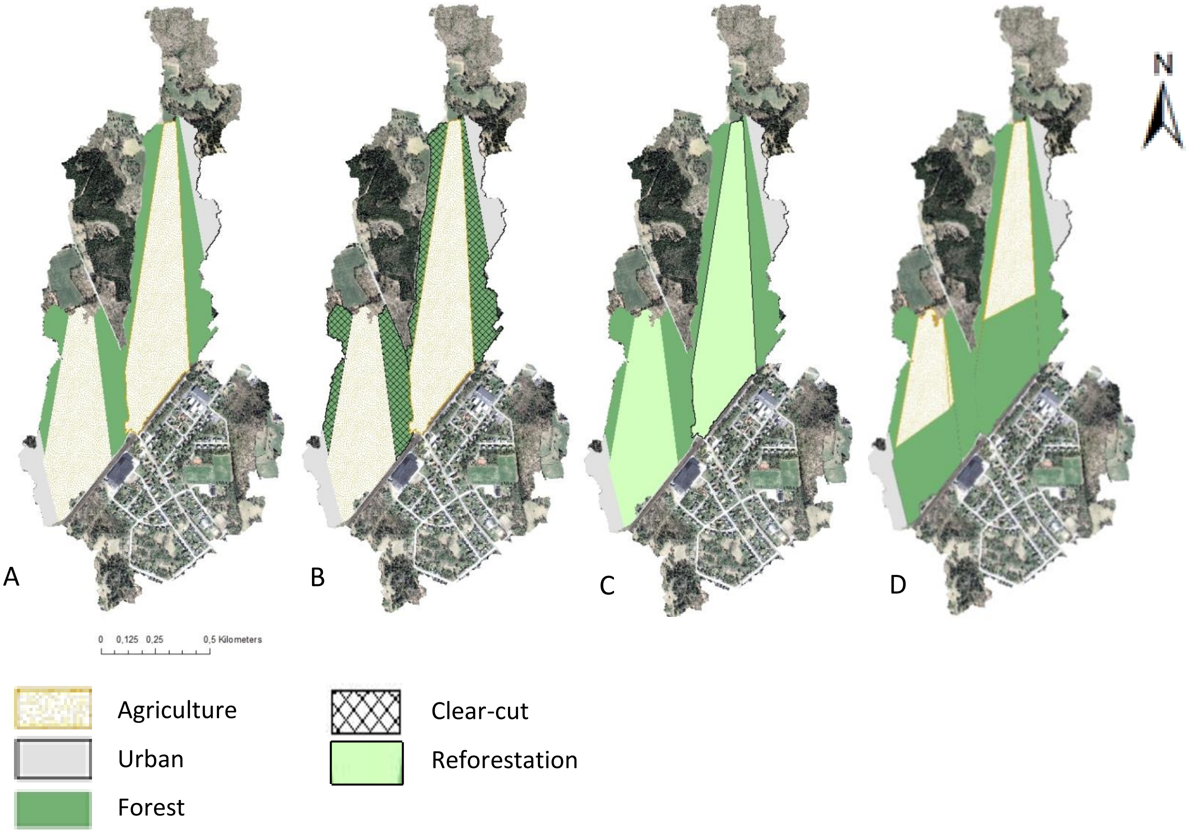

Figure 9: The proportion of land use in the MIKE SHE model over Skuteruds catchment (Kalantari et al,. 2014) has been applied in the MIKE URBAN model over Eneryda. a) base scenario b) clear-cut 30% c) reforestation 60% d) reforestation 30% upstream verses downstream.

3.7 Evaluating Flood Risk from Climate Change Coping Strategies in Eneryda

Due to the importance of the timing of peaks, and the dilution of peaks in stream networks, Hawlett (1970) argues that an "*increase in peak flow from a small watershed is insufficient evidence to prove an influence on valley flooding*". He claims that volumes are more additive in nature, and that the impact on storm flow volume from land use change is *"the real link between cause and effect*" in terms of flood risk. The changes in the magnitude of peak flow may, however, be complemented by changes in storm flow volumes (Hawlett, 1970). For a location with flood risk, peak flow is quite important, and it can, for example, be the difference between an overload or not in the Swedish sewer system.

To answer my second research question, and analyze the impact from different climate change coping strategies, I have compared the peak flow, volume and duration of runoff in MIKE URBAN. Also, the geographical distribution and depth of the maximal flooding from my results in MIKE URBAN and MIKE FLOOD have been compared over the scenarios.

4. Results

4.1 The Impact of Rural Land on Flood Risk in Eneryda

As a background for my continuing investigation I proved that the influence from rural land is of importance for understanding flood risk in Eneryda from a single rain event. By including the slow recession of flow from rural areas in MIKE URBAN, this gives a prolonged time where nodes are under overpressure i.e. has a pressure higher than the ground level (Table 7). The simulation in MIKE FLOOD also shows a stretched period of time over which areas can experience flooding (Table 7). As water is spread out over an area in MIKE FLOOD, and this is likely to be more accurate way of representing the reality, this time is shorter that the overpressure shown in MIKE URBAN when no connection to MIKE 21 is made.

The risk for prolonged flooding increases with the duration of precipitation, but even simulations using durations of 1 hour for precipitation show a difference in duration of overpressure/flood likelihood (Table 7). The increased effect with longer precipitation is in agreement with the t_c theory. The duration of precipitation decides if and how much of the peak flow from the rural catchment will contribute to the urban peak flow. The precipitation with the highest intensity occurs in middle of the CDS-rain, and that coincides with the peak from urban area. A large rural area contributing substantial flow close to the timing of the peak flow can prolong the duration when the network exceeds its capacity.

It can be seen that the impact from the rural area is not limited to the direct flow path from the rural areas towards the outlet southeast of the village. The duration is also influenced beyond this flow path. A water level found in one part of the network can influence the water level found in another location, as this can prevent water from passing. Theoretically, a prolonged duration of overpressure/flooding can also result in an increased risk for a larger extent and depth of flood.

Table 7: Increased duration of overpressure (MIKE URBAN) and flooding (MIKE FLOOD) at different manholes when the recession flow from rural areas is included.

Precipitation	**Model**	***Manhole 051***	***Manhole 052***	***Manhole 053***	***Manhole 055***
100-year (1h)	MIKE URBAN	9min	23min	25min	2min
	MIKE FLOOD	7min	9min	10min	<1min
100-year (24h)	MIKE URBAN	1h and 2min	1h and 58min	2h and 1min	7min
	MIKE FLOOD	18min	50min	53min	7min

4.2 Calibration and Validation

4.2.1. MIKE URBAN

The validation process for the largest rain event gave similar results when 1. the west catchment was used for calibration and east catchment was used for validation, compared with 2. when the east catchment was used for calibration and west for validation. For both sub-catchments, the best fit was found when applying a t_c of 0.00055 m/s and the constructed *Time-Area curve2extreme* was used (Appendix 9). As the same velocities and Time-Area curve is applied, the difference found between the different validations is only because φ has been adapted to the total discharge from the different catchments:

1. With φ adapted to the west catchment, the calibration of MIKE URBAN to the hydrograph of Hördagatan gives $r^2 = 0.9633$ from the linear regression (Figure 9a). Comparing the total

volume of discharge (urban +rural), the simulation gives 1% more runoff than the measured discharge. The peak is instead -2% of the measured flow (Table 8). The validation resulted in an r^2-value of 0.8691 and a 3% decrease in volume and a less than 1% decrease in peak flow for the largest rain event, when compared to the measured discharge at Larmgatan (Figure 10b and Table 8).

2. With φ adapted to the eastern catchment, the calibration in MIKE URBAN gives an r^2=0.8719 from the linear regression when compared to the hydrograph from Larmgatan. The difference in measured and simulated peak flow is less than 1%, and the difference in volume is -2%. When validated this gives an r^2-value of 0.9653 and a 3% increase in volume and a 4% decrease in peak flow when compared to the measured discharge at Hördagatan (Table 8).

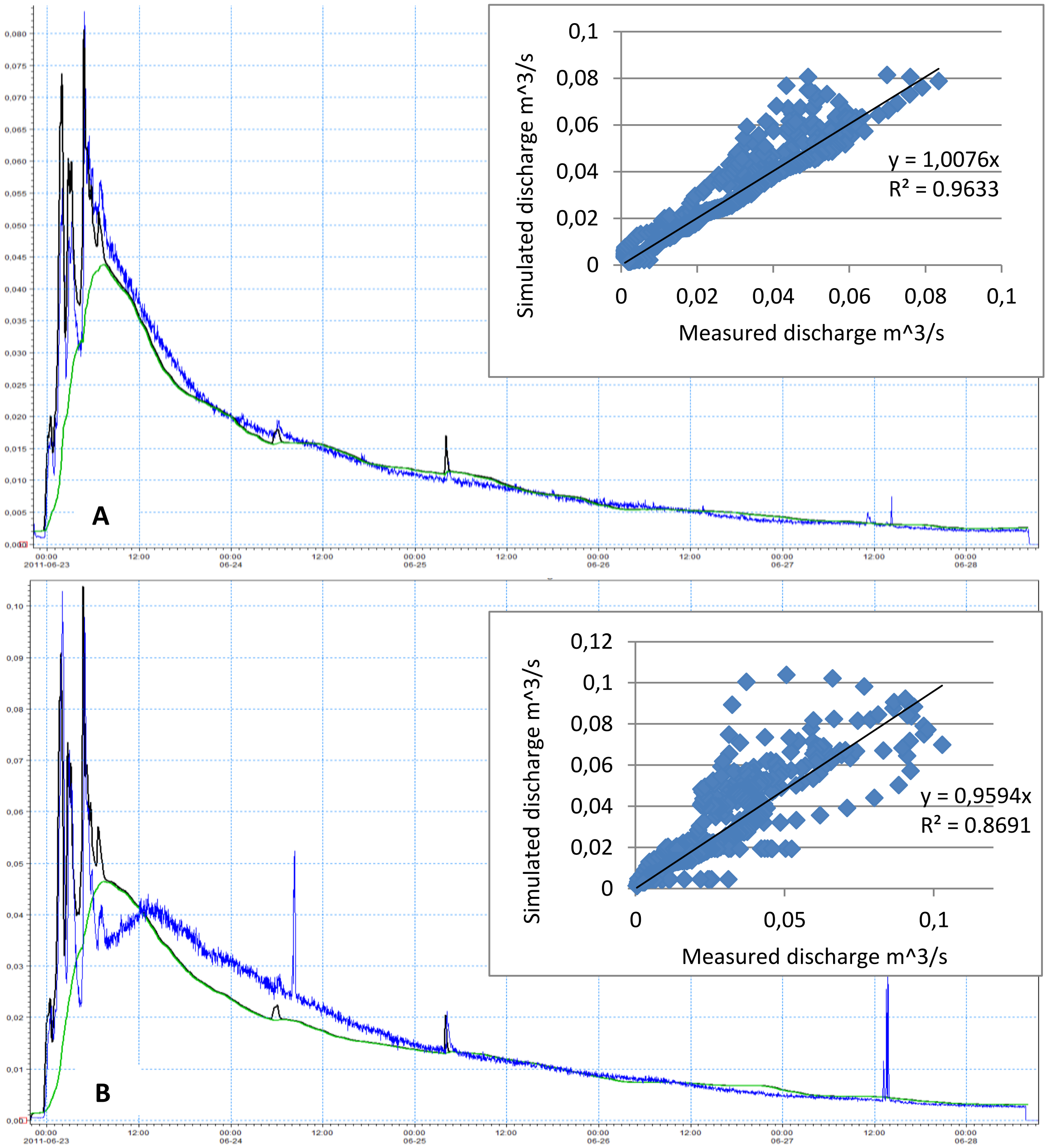

Figure 10: The total simulated hydrograph (urban+rural) (shown in black) and the rural hydrograph (shown in green) from MIKE URBAN over Eneryda compared to the measured hydrograph (shown in blue) at A) Hördagatan, used for calibration and B) Larmgatan, used for validation, also presented with the results from a linear regression.

Table 8: The calibration and validation of the MIKE URBAN model over Eneryda in terms of total volume (m^3) and peak flow (m^3/s) of discharge from largest rain event at the Hördagatan and Larmgatan locations.

Location	**Measured**		**Simulated for calibration**		**Simulated for validation**	
	Volume	*Peak flow*	*Volume*	*Peak flow*	*Volume*	*Peak flow*
Hördagatan	5801	0.083	5726	0.081	5975	0.081
Larmgatan	7278	0.104	7294	0.103	7078	0.103

As can be seen in Figure 10 the shape of the hydrograph is different between the west and the east catchment. One reason could be a blocked culvert in the eastern catchment that postpones the peak flow from the rural areas. I chose to continue with the original set-up with no blocked culvert represented since several other factors could influence the shape of the hydrograph, like the movement of the rain cloud, the division between surface and subsurface flow from different areas etc.

4.2.2 MIKE FLOOD

The simulated hydrograph when using MIKE FLOOD is compared to both the measured hydrograph and the MIKE URBAN-simulated hydrograph at Hördagatan and Larmgatan (Figure 11a and b) for the largest rain event. Only the MIKE URBAN and the MIKE FLOOD simulated hydrographs are compared at the point where the west and east catchment merge (Figure 11c). The difference in peak discharge at the point where the west and east unite is 4.5% between MIKE URBAN and MIKE FLOOD. The volume is not quantitatively comparable, since the MIKE FLOOD simulations not are run for the whole time-period due to time limitations. However, the visual agreement between the results produced by MIKE URBAN and MIKE FLOOD, and the general conformity of the volume is considered to be satisfying.

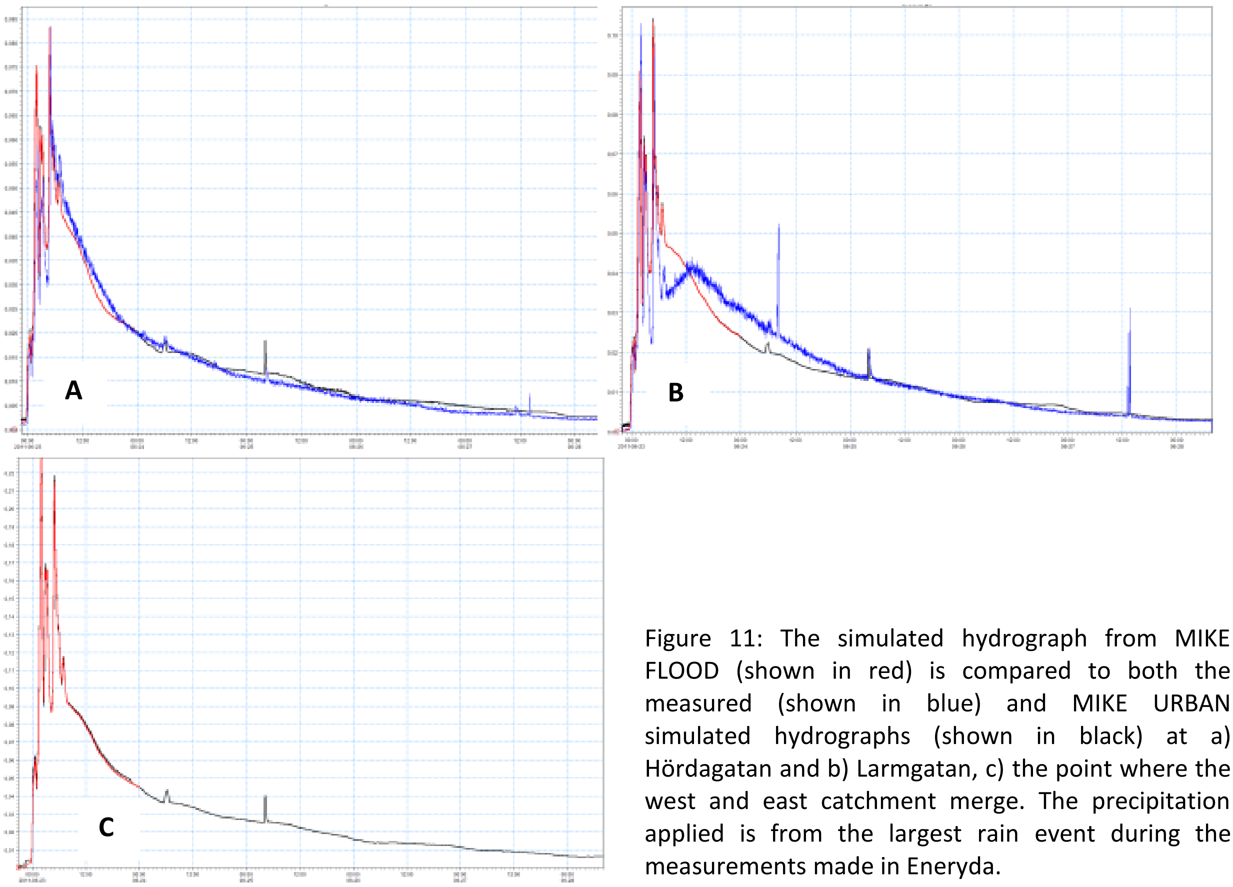

Figure 11: The simulated hydrograph from MIKE FLOOD (shown in red) is compared to both the measured (shown in blue) and MIKE URBAN simulated hydrographs (shown in black) at a) Hördagatan and b) Larmgatan, c) the point where the west and east catchment merge. The precipitation applied is from the largest rain event during the measurements made in Eneryda.

4.3 Visualizing Discharge from Rural Land use through the Time-Area Method

The discharge produced when different land use proportions, following Kalantari et al. (2014), is applied in the MIKE URBAN model of Eneryda is shown in Figure 12. In the figure, the east catchment is exposed to a 10-year rain event (24 hours). The result for the west catchment is similar. The difference in volume (%) and peak flow (%) when comparing the *base scenario* with the other land use scenarios is presented in Table 9, together with a similar summary made up of results from Kalantari et al. (2014). For peak flow, the average difference between the west and east catchment is presented.

Comparing the sensitivity to land use change for the two models the volume seams to conform reasonably, especially for the clear-cut and reforestation 60% , with precipitation corresponding to a 10-year event. In the MIKE SHE model, the capability to decrease runoff is halved with an increase of precipitation from the 10-year to the 50-year recurrence interval (Kalantari et al. 2014). This indicates that more focus is needed on the factors used to up-scale φ to different precipitation events in my model. Reforestation of 60% of the catchment area was the most efficient measure in reducing both volume and peak flows in my model. The MIKE SHE model responds more strongly to the scenario with 30% reforestation downstream in terms of volume. Location of reforestation can have an effect on volume as well as velocity, but I question the reliability of this result.

The agreement between the models is not as good for peak flows. The large differences in peak flows between the different applied precipitation events can not be seen with my rural Time-Area Method simulations in MIKE URBAN. As my model only adapts t_c to a change in runoff in the channel, but not on the hillslope it is expected that the difference in peak flow is not as pronounced in this model.

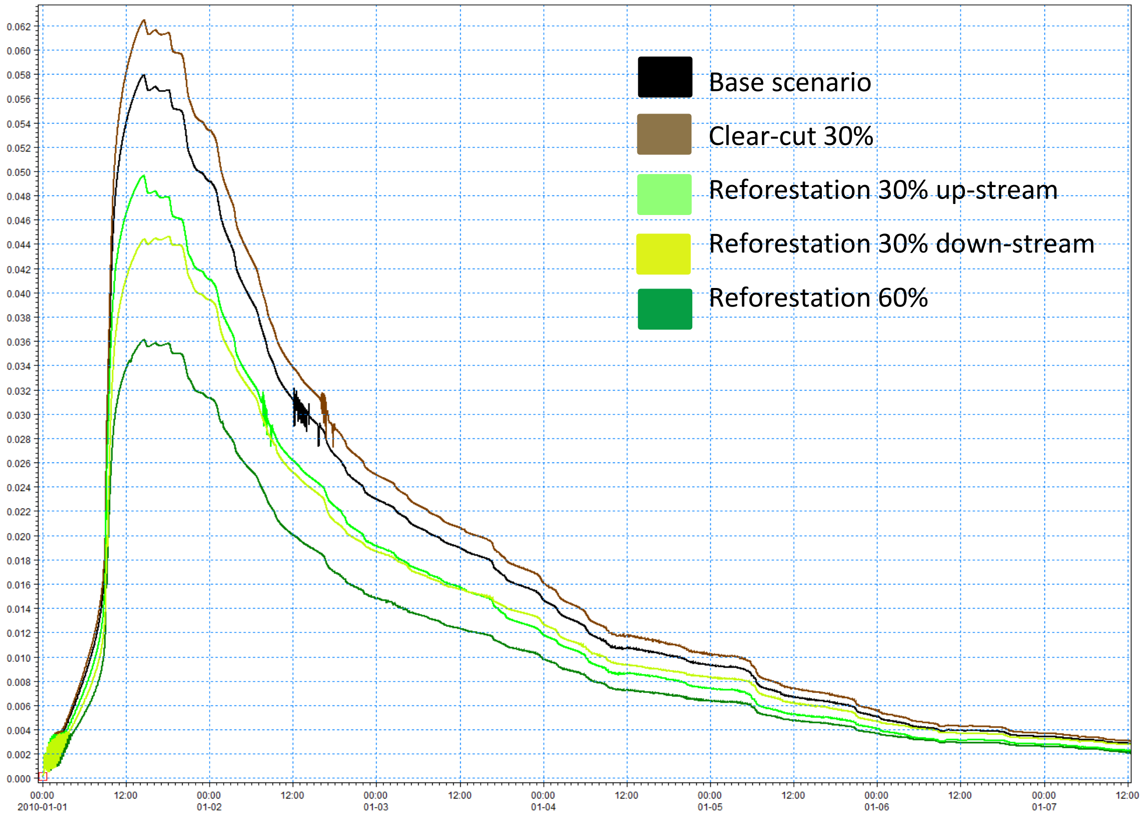

Figure 12: Hydrograph at Larmgatan for different land use scenarios, based on land use from Kalantari et al. (2014), applied on the east catchment of Eneryda, simulated in MIKE URBAN with precipitation corresponding to a 10-year recurrence interval (24-hours).

Table 9: The differences (%) in discharge, volume and peak flow from the different land use scenarios when compared to the base scenario. Simulation results from the MIKE URBAN model over Eneryda are compared to the base scenario 10-year (1-hour): volume 6672m^3 and peak flow 0.029m^3/s, 10-year (24-hour): volume 16733m^3 and peak flow 0.055m^3/s, 50-year (1-hour): volume 13297m^3 and peak flow 0.057m^3/s . The MIKE SHE model over Skuterud from the study made by Kalantari et al. (2014) is given in *italics* (interpreted from figure).

Precipitation	**Clear-cut**		**Reforestation 60%**		**Reforestation 30% up-stream**		**Reforestation 30% down-stream**	
	Volume	*Peak flow*	*Volume*	*Peak flow*	*Volume*	*Peak flow*	*Volume*	*Peak flow*
10-year (1h)	8.8	8.6	-33.0	-36.2	-24.4	-16.6	-20.0	-19.7
10-year (24h)	8.8	8.7	-35.9	-36.4	-17.7	-16.6	-18.2	-19.9
50-year (1h)	8.9	8.8	-36.5	-37.1	-18.0	-17	-18.5	-20.1
10-year	*Ca 10*	*Ca 4*	*Ca -35*	*Ca -80*	*Ca -35*	*Ca -35*	*Ca -41*	*Ca -68*
50-year	*Ca 10*	*Ca 62*	*Ca -15*	*Ca -6*	*Ca -23*	*Ca -6*	*Ca -23*	*Ca -6*

4.3.1 Up-scaling Factor

The influence of the choice of up-scaling factor on φ from the sensitivity analysis show that it has an effect in the volume of discharge (Table 10). The influence is not noticeable on peak flow. The simulations using the method from Chow et al. (1988 p.498) give a +2% increase in the total volume of discharge with precipitation of 50-year (1-hour) compared to the *Design Storm Frequency Factor* approach that I used. With a precipitation of 100-year (1-hour and 24-hour) the up-scaling based on Chow et al. (1988 p.498) results in a 7-8% larger volume of runoff. Also the comparison with MIKE SHE (Table 9) indicates that it may be important to understand how different land uses respond to different precipitation events.

Table 10: The difference in total accumulated flow in m^3 from all catchments (urban+rural) depending on the choice of up-scaling factor used, either Chow et al. (1988) or the FDOT approach (2005).

Precipitation	**Duration 1h**		**Duration 24h**	
	Chow et al. 1988	*FDOT, 2005*	Chow et al. 1988	*FDOT, 2005*
50-year	13238	12972	-	-
100-year	18041	16864	39732	36829

4.4 Climate Change Coping Strategies Influence on Flood Risk

The different land use-scenarios impact on discharge in 2050 from the MIKE URBAN simulations are compared in Figure 13. *Today* is included for comparison also with a climate factor of 1.2. The result in terms of volume, duration and flooded area from the MIKE URBAN and MIKE FLOOD simulations for the different land use-scenarios are compared in Table 11 and 12. Precipitation events representing both 10- and 100-years recurrence intervals have been used for this comparison. The 100-year (24-hour) events have been simulated in MIKE FLOOD; the comparison in area is only conducted regarding this precipitation.

Volume -*Today* gives the largest volume of discharge. The volume for *Carbon storage* is about 75% of the runoff from *Today* independent of precipitation. The volume of discharge for current land use is larger also compared to *Substitution,* since the area with abandoned agriculture land can compensate for the larger area of deforestation. The impact of increased perennial agriculture in *Carbon storage* does only give a small response in the volume of discharge, with a 45m^3 decrease for the 100-year (1-hour) precipitation, and a marginal change in peak flow. The response would have been more pronounced if less land would have become abandoned and reforested; then more agricultural land would have be exposed to the change from annual to perennial crops. When comparing *A2* and *B1* with *Today,* the regression and the total volume is less in *A2* and *B2*. This is mainly because the forests have grown from clear-cut to forest during this time period, but this is also due to the abandoned agricultural land.

Peak flow **-**No difference in peak flow was found between the different land uses with applied precipitation of 10-year and 100-year intervals (Figure 13). The peak range between 0.39 m^3/s and 0.41 m^3/s for all land use scenarios. This is in agreement with the theory that mainly the urban area is contributing to the peak flow during a single rain event. This is also visualized in Figure 10.

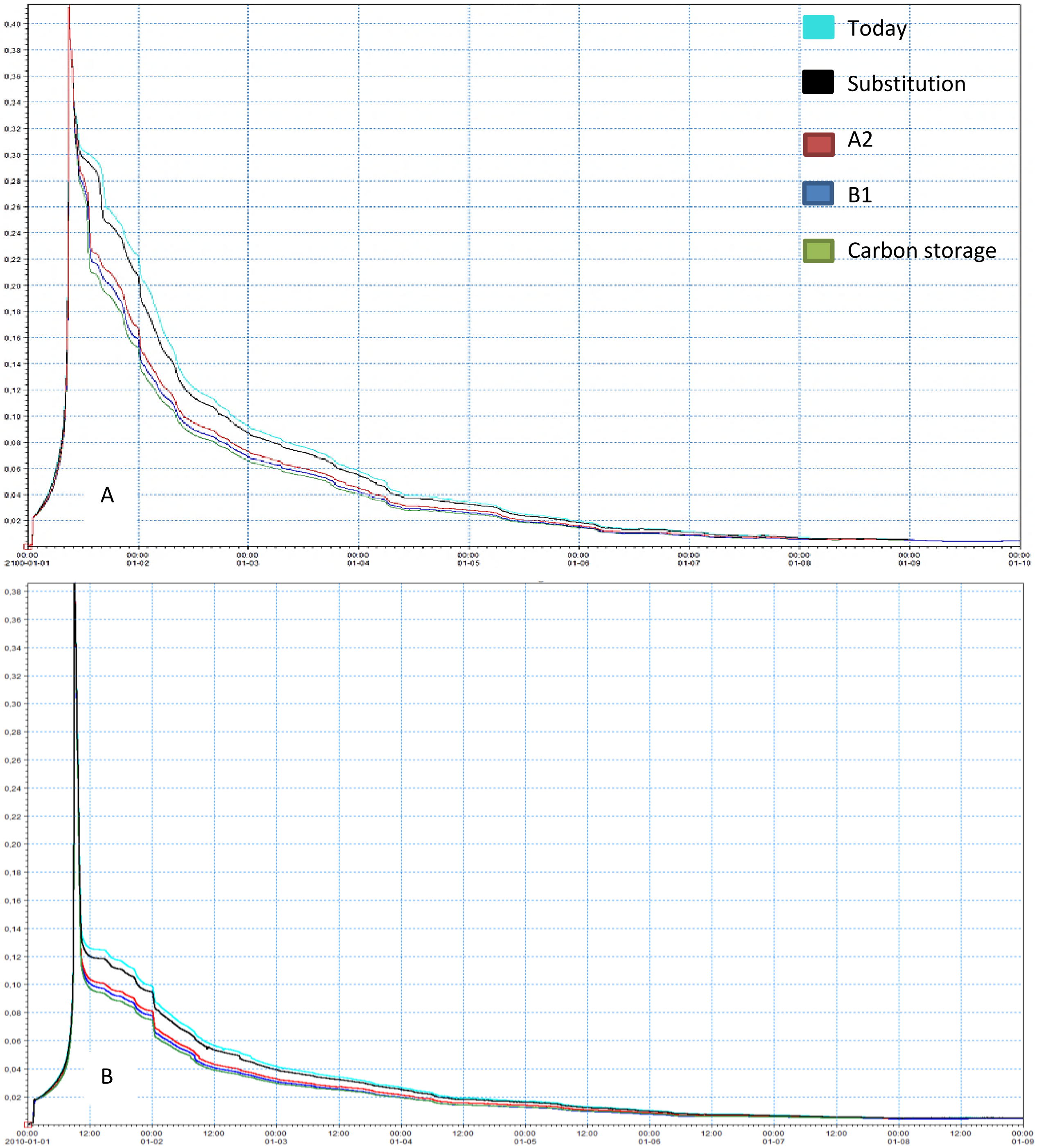

Figure 13: Hydrograph for the comparison of land use scenarios in 2050. Results from a MIKE URBAN model over Eneryda applying a precipitation of a) 100-year 24-hours and b)10-year 24-hours. All precipitation here has a climate factor of 1.2.

Table 11: Comparing volume (m^3), duration and distribution (m^2) for different land use-scenarios for the year 2050 to a precipitation of 100-year (1-hour and 24-hour) in MIKE URBAN and MIKE FLOOD (*in italics*) over Eneryda. Results are from an 8-day simulation.

Scenario	**Volume**		**Duration (manhole 053)**			**Area**
	1h	*24h*	*1h*	*24h*		*24h*
Today	20243	44200	2h 20min	7h 23min	*3h 44min*	*19726*
A2	16390	35796	2h 4min	4h 15min	*1h 59min*	*18853*
B1	15627	34203	2h 3min	4h 10min	*1h 57min*	*18806*
Substitution	19217	41963	2h 17min	6h 43min	*2h 59min*	*19226*
Carbon storage	15032	32745	1h 1min	3h 55min	*1h 51min*	*18771*

Table 12: Comparing volume (m^3), duration and distribution (m^2) for different land use-scenarios for the year 2050 to a precipitation from the 10-year 2050 (24-hours) in a MIKE URBAN simulation over Eneryda. Results are from an 8-day simulation.

Scenario	**Volume**	**Duration (manhole 053)**
Today	19905	40min
A2	16261	38min
B1	15540	37min
Substitution	18934	39min
Carbon storage	14978	36min

Duration - The difference in duration of flooding has been analyzed for the west catchment of Eneryda. The impact from the different land use scenarios influence on the pressure in the network is not limited to the direct flow path from the rural areas, but also influences how prone the network is to flooding in other parts of the network. Manhole 053 has been used for the analysis, as this showed the longest period of overpressure in MIKE URBAN with respect to flooding in MIKE FLOOD (Table 7). The largest difference in duration can be found between the *Today* and the *Carbon storage* scenarios (Table 11). Analyzing the difference in overpressure between the *Today* and *Carbon storage* scenarios for MIKE URBAN reveals a 3 hour and 28 minute difference for a 100-year storm, but only a few minutes difference for a 10-year storm. For MIKE FLOOD (100-year, 24 hour) the difference is 1 hour, 53 minutes.

Extent -Maximal flooding is used for comparing the extent of flooding even if this is the extension of flooding for the whole period and does not occur at once in reality as shown in Figure 14. The largest difference in area is also found between the scenarios of *Today* and *Carbon storage* with 95% of *Carbon storage* flooding when compared to *Today*. The peak flow appears to have the greatest effect on the size of the flooded area. As described above, the main part of the rural discharge for a single rain event will arrive in Eneryda later than the urban peak flow, i.e. not contributing to the size of the peak. A large difference in distribution of flooding is, therefore, not to be expected between the scenarios. The 5% differences that can be seen are a result of the higher pressure in the network with an increased amount of rural discharge (note that complete flooding in the northeast corner is not captured within the grid for MIKE FLOOD; this results in a too small extent of flooding for those simulations that reach to this area i.e. decreasing the difference between the extreme scenarios).

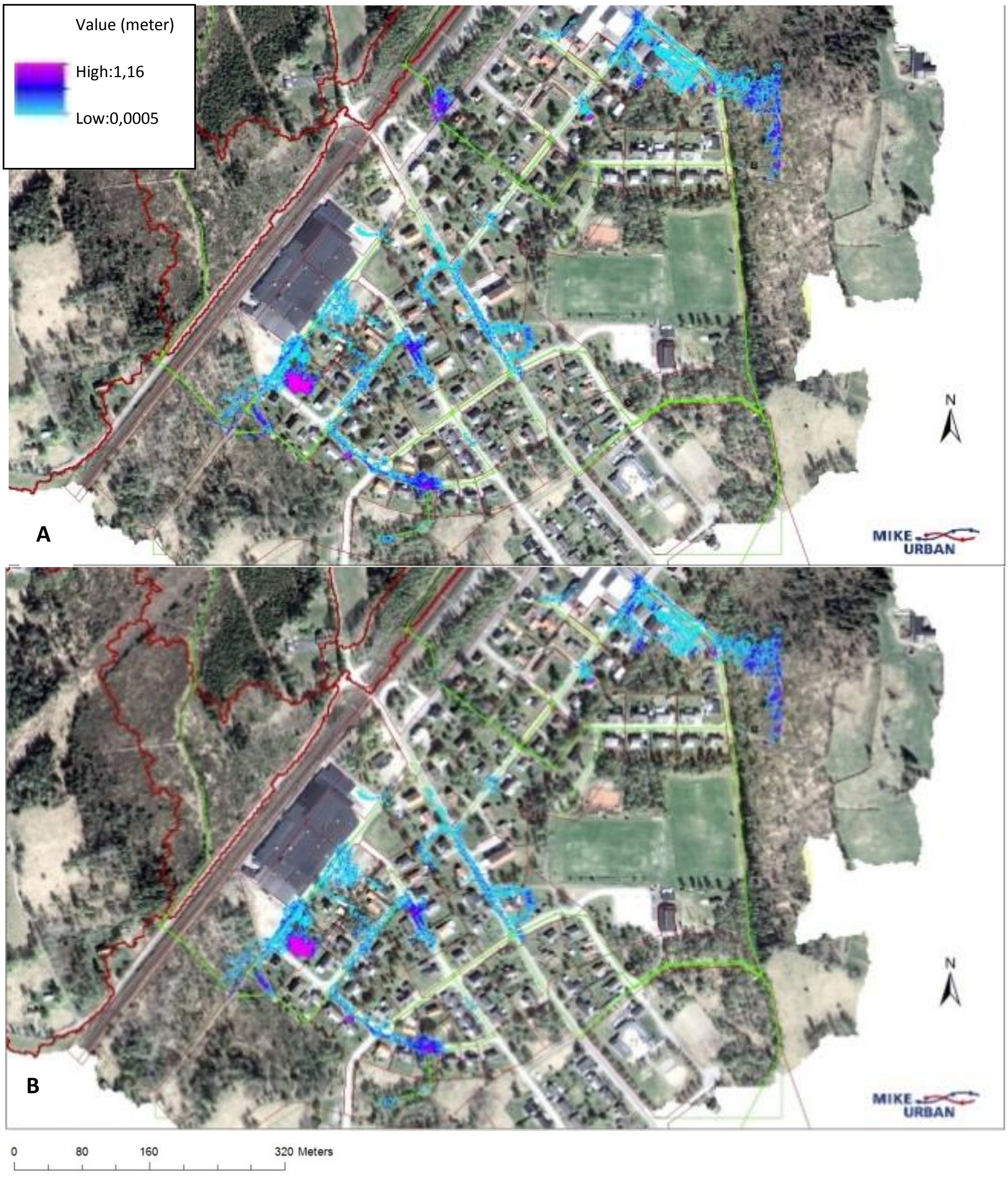

Figure 14: Comparison of the projected maximal flooded area in Eneryda during a precipitation event of 100-years (24-hour) for climate scenarios A)*Today* and B)*Carbon storage.* The difference in flooding extent is 5%, the difference in depth between the two scenarios is given in Figure 15.

Depth- In terms of flood damage, it is also interesting to investigate if there are differences in depth of flooding between the different land use scenarios. When the depth of flooding from the *Carbon storage* scenario is subtracted from that of the *Today* scenario, the result shows that the depths from *Today* are deeper than the depth in *Carbon storage,* between 0-10 cm in most of the flooded areas (Figure 15). Only the small, light blue areas have a deeper flood depth in *Carbon storage* due to the fact that MIKE FLOOD is dynamic model.

Figure 15: The difference in depth between the climate scenarios *Today* and *Carbon storage,* visualized through subtracting the projected maximal flooded extent in *Carbon storage* from *Today*. The simulations are made using a precipitation of 100-year recurrence interval (24-hour) with a MIKE FLOOD model over Eneryda.

4.4.1 Climate Factor

By applying a climate factor of 1.2 to the precipitation for a 100-year rain event (1-hour) for the *B1* scenario, the total accumulated flow increased by 20%, and the peak flow by 1.7%. If, instead, a climate factor of 1.3 would have been applied, the sensitivity analyses show a 30% increase in volume and a 2.5% increase in peak flow. When it comes to the recession flow, the difference in land use between *Today* and future climate scenarios could play a larger role than the direct impact from climate change as simulated with a climate factor (Figure 16). *Today* (shown in light blue) and the *B1* scenario, with no climate factor (shown in blue), have the same peak flow due to the use of the same precipitation on the urban area, but a different recession, due to the different rural land use. An increase in precipitation of 30% gives a higher discharge close to the peak, likely to be the contribution from the rural area, but the discharge decreases with higher amplitude in all the *B1* simulations, as compared to *Today*, regardless of the climate factor used (Figure 16).

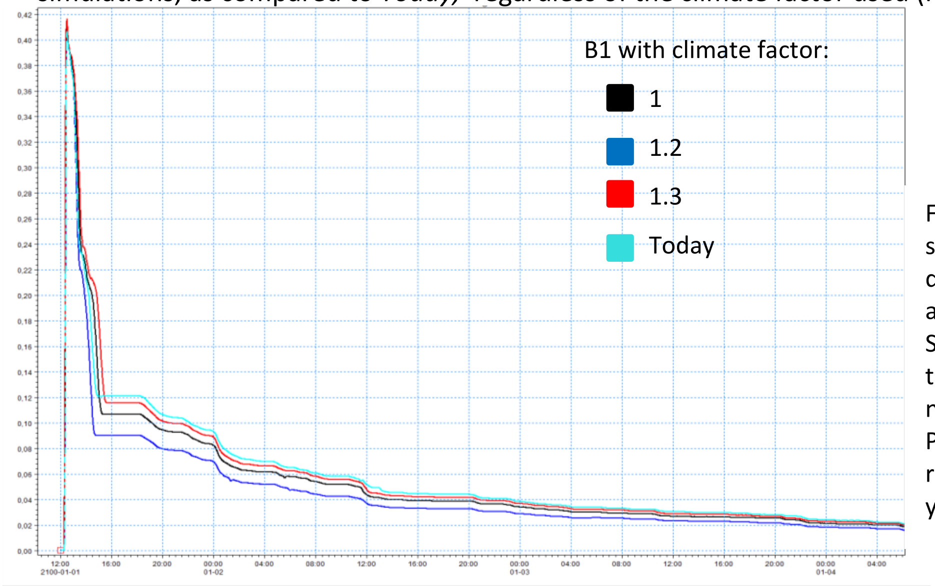

Figure 16: Result from the sensitivity analysis regarding different climate factors applied on the *B1 scenario*. Shown in comparision with the scenario of *Today* with no climate factor applied. Precipitation used had a recurrence interval of 100 year (1h).

5. Discussion

5.1 To Visualize Rural Land Use through the Time-Area Method

Although φ is used as a key concept in engineering hydrology, it must be taken into consideration that this concept is mainly valid for urban land cover (Vägverket, 2008). To explain the complex catchment conditions behind rural runoff with a single value, such as φ-, and to separate the spatial and temporal variation in terms of soil, climate, precipitation, vegetation, land use etc. has been proven to be difficult (Robinson et al. 2003, Merz et al. 2006). Some, therefore, recommend treating rural φ as a random value (Naef, 1993). Several studies have, though, investigated the impact on runoff of different land use and land use change scenarios, and have found that land use does make a difference to the flood regime (examples include Andersson et al. 1976, Robinson et al. 2003).

5.1.1 Development of Runoff Coefficients

To produce proportionally different- φ values from often site-specific literature, will result in a range of uncertainties, depending on the choice of literature. A lack of paired catchment research with Swedish conditions can call into question how applicable other results are for Sweden (Robinson et al. 2003). Also, the particular treatment is of importance, since different management approaches produce very different results in terms of runoff (Robinson et al. 2003). For example, the wide range in runoff responses possible from clear-cut areas are quite clearly demonstrated in the review by Guillemette et al. (2005), from a decrease of 22% to an 172% increase reported. This must be interpreted as a considerable uncertainty surrounding my mean value of +49%, and will likely depend on local site and situation in determining the applicable parameter value.

The CN approach provides higher detail in soil and antecedent soil moisture conditions when compared to any compilation of φ values that I have found. Though, the review by Ponce and Hawkins (1996) highlight that low CN-values, low rainfall, and application to land uses other than agriculture, and application to different biomes, as disadvantages of the SCS-method. Results from Norbiato et al. (2009), where the highest CN did not correspond to the highest runoff, also indicate that the accuracy and detail of CN should be interpreted with caution. Slope is not included in the CN or in the φ-compilations upon which I based my interpolations. In some compilations, slope is instead one of the important factors in the choice of φ (example Chow et al. 1988 p.498).

Effects from land use, as represented when using CN or φ, can be outweighed by climatic and geologic effects (Norbiato et al. 2009). The impact from the same land use can be distinguished and found to be important in smaller sized catchments; recommendations for maximum catchment size for this approach varies between up to *some tens of* km^2 to 80 km^2 (FAO, 2002 p. 2, Merz et al. 2006). A larger size of basin can mask the influence that land use and land use change may have on the runoff regime (Norbiato et al. 2009, Merz et al. 2006, FAO, 2002 p. 2). There may, therefore, be a scale limitation for explaining runoff in terms of land use, independent of the particular method, whether φ or CN. In theory, CN is assumed to apply for small and midsize basins (Ponce and Hawkins, 1996). Recommendations of appropriate size when using φ in the rational method differ between 2-3 hectares (VattenSvenskt 2004) to <200 hectares (Dunne and Leopold, 1995 p.299.) In the Time-Area Method, the area is split to meet the conditions in the rational method, after which the discharge is summed up (Svenskt Vatten, 2004). Svenskt Vatten (2004) discusses the influence of size on φ-, but this is not included in any of the other authorities' compiled recommendations of φ -values found in the literature. I have applied φ directly on the land use polygons in MIKE URBAN meeting the recommended conditions from Svenskt Vatten (2004). My presented results are discharge values down-stream in the village of Eneryda. As the village is located close to this 72.5 hectare basin, the influence of land use in the headwaters still is noticeable in the village, even after dilution with urban storm water. This is in agreement with the size theory described above.

The importance of size makes the results from sprinkler experimentr not suitable for up-scaling to larger areas. My presented differences between φ for deciduous and coniferous forest, and reforestation, are therefore expected to be overestimates. It is worthwhile to notice that different species also can influence antecedent soil moisture conditions, and this factor and possible feedbacks are not analysed in referenced sprinkler experiments.

My "factor to adapt" is larger than the *Design storm frequency factor,* even for the 100-year recurrence interval. The reason could be due to low-set φ values in the compilation that I used to create my values. Another compilation in Chow et al. (1988 p.498) has, for example, higher values for a 10-year rain event, and is in the same order of magnitude as my values after the adaptation to the largest rain event. The reason why I did not use these values to begin with is due to their lack of soil information; for interpolation with CN, this was an important criterion. My high φ value for a 10-year storm could be viewed as supported by the values in Chow et al. (1988 p.498). It is worthwhile to notice, though, that those values are used as standards in the City of Austin, Texas, which has a considerably different climate (National Oceanic and Atmospheric Administation, 2014) from Eneryda.

Also, the variation in values that considering antecedent soil moisture conditions can support my high φ values for a 10-year storm. The specification in the first versions of the National Engineering Handbook (USDA-SCS, 1972) of how to include antecedent soil moisture effects was not meant for general application, and was removed in later versions as it did not cover regional or scale effects (Ponce and Hawkins, 1996). Another antecedent soil moisture condition of (II), or even (III), may have been more appropriate for Eneryda, as it is likely this landscape has lower evaporation when compared to the conditions for antecedent moisture classification in the U.S[31]. The impact of applying another antecedent soil moisture condition is shown in Appendix 10. Antecedent soil moisture can, through this, show some variation during different conditions; validation for Swedish conditions is needed.

5.1.2 Development of the Model

The demonstrated decrease in basin area through a representation based on the new DEM and the existing drainage infrastructure shows the importance of details in input data for the improvement of models. Since I calculated φ based on the measured discharge and the contributing area, this is important for this research. The aforementioned drainage line was also found during my field investigations. During my field visit, I also found several ditches due to current forestry activity that are not represented in my model (for an example, see Figure 17). In reality, ditching due to the cultivation of conifers has been found to "*significantly increase peak flows and shorten the rise time of flood hydrographs*" (Robinson et al. 2003). The distance of links in MIKE URBAN is of considerable importance for the calibrated velocities. This means that with even more ditches present in reality

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[31] Location in U.S unknown (Ponce and Hawkins, 1996).

than in my model, the calibrated velocity for hillslope processes of 0.00055 m/s are higher than those found in reality.

During the calibration process, I constructed a Time-Area curve that was more extreme than the Time-Area curve conventionally applied. A contributing factor for this could be that the conventional way to calculate t_c using an equation for surface runoff did not apply well here. The same velocity was therefore applied directly using the land use polygons, and in order to make time for the contribution from different areas to be accounted for, a more extreme Time-Area curve was needed.

Figure 17: Ditching in the catchment of Eneryda due to drainage practices supporting current forestry activities.

5.1.3 Validating the Model

One of the main difficulties with modeling flood events is the lack of observed data for larger rain events. This is an issue that not even long term and high-resolution datasets can easily solve. To validate the model, data independent from the calibration would have been desirable (Bellocchi et al. 2009). To segregate the measured data was, though, not possible due to the limited data available. The linear regression and its r^2 value indicate minor overestimation of flood risk for the west catchment, and a minor underestimation for the east catchment during a rain event of about a 10-year recurrence interval, with the local conditions for that specific time. It does not give any indications of the accuracy of the individual φ values. It is important to note that model parameters are model specific (Kleidorfer, 2009). The effective imperviousness for urban area used for an urban application has been found not to be transferrable to another model (Kleidorfer, 2009); a similar conclusion could be assumed to be valid for this rural application.

The different theories regarding how different land uses will respond to an increase in precipitation indicate through my sensitivity analysis that my choice of up-scaling factor could result in an underestimation of total runoff. The values given by Chow et al. (1988) also reduce the possibility of forests being effective means of managing floods during larger rain events; this is also in agreement with, for example Kalantari et al. (2014) and Schüler (2006). If this is the case, this phenomenon is demonstrated neither by the *Design storm frequency factor,* nor by my “factor to adapt”. This could create an overestimation in my presented difference between land use scenarios as the main difference can be attributed to the proportion of forest present in the scenario.

I have developed the rural part of the model, meaning that the initial values of φ for urban areas similar to rural areas, should be increased for larger precipitation events. But no up-scaling of the urban φ values have been applied. As this is not conducted the model is expected to underestimate the discharge from the urban area for precipitation larger than 10-years. Most important for the flood risk is the likely increase in peak flow that this can create, as a larger proportion of runoff will originate within the urban area.

5.1.3.1 Comparison with MIKE SHE

Co-validation, when comparing the degree of conformity between two models, is said to not increase the validity of either model, but just demonstrating that they are capable of producing similar results (Bellocchini et al. 2009). I have compared the response to the same proportions of land use change using two different models built for two different areas; thus, the results should not be interpreted without great caution. A model is never the reality, and the MIKE SHE model build by Kalantari et al. (2014) can therefore not be seen as necessarily representing reality. The validation of that model does not say anything about how well the model corresponds to the effects of land use change in other areas and situations.

Having this in mind when comparing my models´ sensitivity to land use change, the results still reveals similar trends in both models. The conformity regarding flow volume indicates that similar proportional differences are modeled by MIKE SHE as are given by my φ values for mixed forest, agricultural land and clear-cut land uses. The comparison does not include other land use; this is why no examination of the utility of those other φ values can be conducted. Reforestation on agricultural land is, for example, not examined, since “normal” forest is applied in my models.

My model includes neither partitioning between surface and subsurface flow, nor the change of speed required to adapt to higher flows on the hillslope. This is likely to be the main reason for the difference in peak flow between different land uses and quantities of precipitation between the two models. Only the distance over which the water flows in the channel network in MIKE URBAN is automatic adapted to the volume of water. For small rural catchments, the impact from not scaling the hillslope flow is expected to be substantial, since the time spend traversing the hillslope is significantly longer when compared to the time spend in the channel (Åkesson, 2013-10-10 pers. comm.). Because my model does not up-scale t_c nor adapt the Time-Area curve to different precipitation or land use conditions, I assume a rain event with a 10-year recurrence interval, implying lesser uncertainty than a rain of 50- or 100-year recurrence interval.

No effect on velocity due to different vegetation, land use or soil type is explained in my model. The difference between the models in terms of peak flow from clear-cut land use is evident for precipitation events of 50-year recurrence interval, and is much higher in the MIKE SHE model. This result is in agreement with the transmissivity-theory described above, namely, that forested areas contribute with more and faster discharge if harvested as compared to non-harvested areas (Vikberg, 2010). Saturated surfaces due to less evapotranspiration and soil disturbance can also lead to an increase in surface runoff. On the other hand, my result is more in agreement with Hawletts`s theory (1970), that subsurface storm water rises slowly and peak flow therefore, is less affected when compared to the amount after clear-cutting.

This co-validation, with MIKE SHE, can support the proportional differences in φ values that I developed for mixed forest, agricultural land and clear-cut. This supports my first research question, that general trends can to some extent be explained by relatively few parameters. The strong influence that land use change can have on peak flow in the MIKE SHE model highlights the need for models that integrate surface and groundwater flow. My model also does not produce perfectly predictions. Continuous models would take historical conditions into consideration, and as Kalantari et al. (2014) showed, it can be an important difference in local conditions that can then be understood. In the SCS-method can antecedent runoff condition represents some of this variability (Ponce and Hawkins, 1996).

5.2 The Impact of Climate Change Coping Strategies on Flood Risk in Eneryda

5.2.1 The Scenarios´ Reliability

My results estimating runoff from the different scenarios, especially with respect to the impact from abandonment of agricultural land has, shows the importance of including both market forces and the process of regeneration of natural vegetation when investigating future land uses. When facing competition, land abandonment will occur at locations with less favorable conditions for agriculture. Småland belongs to those areas, as shown earlier in Swedish history (Nilsson, 2004). Using an integrated land use model for the development of scenarios has therefore been highly relevant for the purposes of my research. The knowledge of the changing role of agriculture and the alternative uses of abandoned farmlands is also important for obtaining a holistic view and accounting for synergetic effects when evaluating policies and strategies (Verburg and Overmars, 2009). My choice to use the *B1* scenario for the development of my *Carbon storage* scenario is based on the fact that *B1,* from the beginning, was favoring carbon sequestration, as compared to the *A2* scenario. This choice can be discussed, since *B1* already assumes a production of biofuel that should be classified as a substitution strategy.

The new areas classified as forest in the *B1* scenario are given the φ value of mixed forest. As this value is within the range of what I discuss would be suitable for short-rotation energy-forests, I interpret the hydrological effect to be similar to that expected if the area would have been converted to energy-forest plantations. If the abandoned agricultural land in the *A2* scenario instead would have been converted to *Salix*-plantation an improvement in φ would have been seen. The area for agriculture in the *B1* scenairo is converted from annual to perennial crops in the *Carbon storage* scenario. This also decreases the runoff but due to the small proportion of agricultural land left, the difference is minor. During my the field visit, I observed that the proportion of young deciduous trees was higher than the 10% set in my scenarios. Deciduous trees may be thinned in the management of the forests. Setting the proportion of deciduous trees too low in my future projections is likely to be helpful with respect to the quality of my simulations, as it corrects, some of the discussed and assumed overestimation in φ for the difference between deciduous and coniferous forests.

5.2.2 The Impact from Climate Change Coping Strategies

My results show that climate change coping strategies in rural areas can, as well, have the potential to reduce flood risk through increasing the effectiveness of regulating ecosystem services. This is shown in terms of the volume, duration and distribution of flooding. My results show that that the worst-case scenario in terms of land use is actually the current situation, or to be more precise, the conditions existing directly after the recent large storm and the subsequent (necessary) timber harvesting. The projected abandonment of agricultural land in the *Substitution* can compensate for some of the deforestation.

Theoretically, the difference between land use strategies would be larger if a new rainstorm arrives and adds to the last storm´s recession flow in the sewer network. In my work as presented, the simulations have started with an empty sewer system, representing a condition with no significant precipitation for some time. For a longer period of wet weather, the risk for substantial rural contribution to the urban peak flow is also enhanced, since saturation overland flow or transmission of groundwater due to an elevated groundwater level could increase the velocity of storm flow.

The sensitivity analysis of my choice of the climate factor values shows that the climate factor influences the volume and peak flow, but the difference in rural land use between *Today* and future climate scenarios could play a larger role than the climate factor when it comes to the recession. My applied value, with an increase in precipitation of 20%, is in the upper range for 2050. Since the sewer system that is being built today should last longer than that, theoretically to around the year 2100[32], a value in the upper range is well applied.

According to my results the choice of particular locations need to be investigated before the extended implementation of the substitution principle, in order to increase and not decrease the effectiveness of regulating ecosystem services. Intensive conventional forestry in Sweden can cause severe damage to the soil and negatively impact infiltration due to compaction from heavy machinery, stump removal, pre-planting drainage and soil scarification. These impacts, along with the decrease of evapotranspiration, may lead to a substantial increase in runoff (Anderson et al. 1976, Robinson et al. 2003). At locations like Eneryda that also have suffered from wind damage as a result from a large storm, large soil disturbance can be assumed as clearing activities have been necessitated without a good possibility for advance preparation. The advantage where the land owner carries out best forestry practices and implement climate adaptation strategies, through a forestry approach that avoid clear-cutting and soil disturbance and increases resilience against storm and pest infestation by increasing the diversity of tree species, could be a good economic investment both for the land owner and for the societies down-stream. Similarly, high resilience can be derived from agricultural lands, including buffer zones for natural predators and perennial crops on water-logged areas with otherwise low yields, also serving as flood mitigation measures.

The costs for natural flood mitigation measures are mainly linked to the land-use requirements. For municipalities to buy important areas is not possible to any larger extent based on the available economic resources. To find win-win situations for private land owners and the society has the potential to decrease the cost for these land-use requirements. Above the avoided costs from flood damage, including the purification of water, these managements approaches provide a multifunctional approach "*allowing farming, forestry, recreation and ecosystems conservation to*

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[32] Estimated technical life time of 80 years (Svenskt Vatten, 2007).

operate together" with positive externalities in terms of maintaining, protecting and restoring biodiversity and defragmentation of the landscape (European Commission, 2011).

This approach appears to serve both the needs of decreasing flood risk and implementing carbon storage strategies. An adaptation concerning implementation for carbon storage strategy is, though, also necessary. As in the case for all land use, the local conditions decides what is a good/suitable strategy and what is not. For regions where water shortage is an issue, this is what needs to be considered, in some cases maybe even in addition to considering issues of flooding. Kathleen et al. (2005) raise this issue with regard to afforestation and reforestation during carbon sequestration programs and that this must be addressed in drier regions. In the view of other ecosystem services (e.g. biodiversity), a decrease in the open landscape is not desirable in this part of Sweden where Eneryda is located. A decentralization of land used for food production also increases the resilience of the human society as local/regional catastrophes of any kind will not have as large an impact of food security. The flexibility within agriculture to a relatively fast adaptation to a change in local conditions as compared to other sectors is a strength.

5.2.2.1 Combination with Other Measurements

As the water regulation from forest is most significant during small to medium storms but decreases in importance for larger precipitation events (Schüler, 2006) further measures are needed to mitigate flooding in Eneryda during larger rain events. Natural flood mitigation measures, with more distinct water retention can include the restoration of wetlands and green infrastructure in urban areas to withhold water, but also allow certain areas for flooding. These measures can also provide mitigation of greenhouse gases and be positive in terms of adaptation to other climate change induced issues, for example heat waves (European Commission, 2011). For dimensioning of water retention basins, such as wetlands, the impact from the surrounding rural area is of importance and its influence on the volume for runoff should certainly be considered (Svensson, 2013 pers. comm, Larsson, 2014 pers. comm).

The investigation by Tyréns resulted in the report "*Stormwater within Eneryda - measures against floods*". Proposed measures include dimensioning and renovation of the sewer system, and separation of storm water to a total cost of above 3 million SEK (Tyréns, 2013b). Among the proposal is a new ditch north (along the railway) and south west of Eneryda. This will prevent the water from the rural catchment up-stream from entering the urban area and charging the storm water system as it does today (Figure 18) (Tyréns, 2013b).

Figure 18: Current connection of the storm water ditch from rural areas to the urban sewer system.

When making this large investment in the sewer system, making correct assumptions when dimensioning is important (Svenskt Vatten, 2007). For the investigation by Tyréns a precipitation event of 10-20 years recurrence interval and current land use was applied in MIKE URBAN to arrive to these conclusions. As that rural land use is shown to represent the worst-case scenario likely for Eneryda in the next coming 40 years, in terms of flood risk, it is satisfying to have calibrated the model against this. An increase in agriculture and/or in urban area would create a larger risk, but this is not likely for Eneryda according to its future outlook. For other areas with currently strong regulating ecosystem services, for example with standing forest, it is important to investigate if the natural land can contribute to the flood risk in the perspective of land use and land use change. If land use in this area changes, including management approaches used in local forestry, my results show that this needs to coincide with, for example, the dimensioning of delay- and retaining reservoirs to not increase flood risk (Larsson, 2014 pers. comm).

During the implementation of measures, such as the ditch suggested by Tyréns or designing the drainage from forestry, a catchment perspective is needed to not increase flood risk downstream. It appears that the responsibility for a catchment perspective, including rural land use is a problem today. The responsibility for flood mitigation can be practiced by municipalities through their control over local land use in their Comprehensive plan and Detailed plan, as well as through the compulsorily notification of change in existing land use due to Environmental Impact Assessments (2010:900, 1998:808 ch.6). But, current land use management that is not responding to changing land use, for example forest harvesting, is not covered by this sort of regulatory intervention. Perhaps the implementation of flood management plans from the Flood directive (2007/60/EC) will help in improving the situation, as it stresses the need for a responsible catchment perspective (even if this is on a much larger regional level). The management plans "*may also include the promotion of sustainable land use practices (and) improvement of water retention*" (2007/60/EC ch.4, article 7 §4). The interim target for the environmental goals in Sweden of integration of ecosystem services, in for example Environmental Impact Assessments by the year 2018, could lead to positive developments here.

5.3 Future Development

If general projections of land use, even if they are not perfectly predictions, can provide enough detail for some policymaking, further development and validation of this rural hydrological modeling-application using the Time-Area Method is relevant. Merz et al. (2006) conclude that even if there could be effective use of a concept such as φ for rural areas as well, at this time, only a relatively limited number of studies have been conducted. To construct φ value compilations with more detail for rural areas for Swedish conditions, significant field research is needed. Regarding my developed φ values, especially the values for different tree species and reforestation conditions constructed from small scale sprinkling experiments, further investigation is needed.

Recommendations for future investigations for how the following factors can be incorporated within rural φ include investigating:

- the impact of catchment size
- the impact of slope conditions
- the impact of antecedent soil moisture for Swedish soils
- the need for different up-scaling factors for different land uses

The impact from different rural land uses on t_c and the Time-Area curve have not been included in the scope of this study. My research highlights the lack of incorporating process representation of different runoff processes, and the volume of water associated with them, as one of the main disadvantages when using this approach. Further development regarding how to incorporate situations when rural land can contribute to peak flow, for example through t_c and Time-Area curve methods, is needed. To investigate the potential for this rural application of the Time-Area Method it would also be interesting to compare MIKE FLOOD with a process model, for example MIKE SHE, for the same location and same conditions.

The ability to take a catchment perspective has been made possible due to development and availability of data and technology. The responsibility and resources for implementing this in reality needs further improvement and effort.

6. Conclusions

Rural land has an influence on the flood risk in Eneryda. The rural discharges that joins the local sewer system has been proven to prolong the duration of over pressure in the system. In this way, runoff from rural land adds to the storm water flow from urban areas, contributing to the probability and severity of flooding. This provides a key insight, namely that the contribution from rural runoff is important, for example for the dimensioning of delay- and retaining reservoirs. This leads to my research questions:

1. *Can the impact on runoff from rural land use be incorporated in the event runoff coefficient and visualized through the Time-Area Method?*

The rural application of the Time-Area Method can be used to represent the general impact of land use on runoff. The total volume of flow modeled using the applied φ values are valid for both the west and east catchments in Eneryda during a ~10-year rain event (with r^2 values of 0.9633 and 0.8691 respectively). The regression indicates a minor overestimation of flood risk for the west catchment and a minor underestimation for the east catchment. The individual φ values are higher then what is conventionally applied in Sweden, but these values are supported during conditions with high soil moisture in other countries. The result from a MIKE SHE model also supports that the proportional impact from mixed forest, agricultural land and clear-cut can be represented through the applied φ values in MIKE URBAN. The differences between the models are ~2% during projections of both clear-cut and reforestation land uses, when exposed to a 10-year rain event. The adaptation to larger precipitation appears to be less successful. As this comparison does not include other land uses, no validation for other φ values can be conducted, nor can the transferability of these model parameters to another model be evaluated.

The idea that there is a scale limitation when explaining runoff in terms of land use is correct. As Eneryda is connected to the 72.5 hectare basin, the projected results are in agreement with the described scale theory. Due to the importance of catchment size, the estimated proportional differences in φ values for different tree species and reforestation investigated using small scale sprinkler experiments are likely to be overestimated, and need further investigation. The substantial disadvantage with my model is the non-sensibility of different runoff processes. The impact on peak flow from different land use and different precipitation events is therefore not well represented. This should be modelled by different t_c values or Time-Area curves, but the conventional urban methods for this do not apply well for the rural situation in Eneryda. Ameliorating this shortcoming is an important area for further development.

My thesis shows that there is potential to improve the representation of rural impact in conventional hydrological modeling using the Time-Area Method. With further development, there is potential to incorporate some variability in φ values, but the model will still only simulate the general trend. Depending on the purpose of the model, the variance from different situations, for example antecedent soil moisture conditions and ditching, including integration of surface and subsurface flow, may be needed. To use a process-based continuous model, like MIKE SHE is, costly and time consuming, but could be socioeconomically profitable as this can give a more detailed view for sensitive areas by promoting process understanding of what is actually happening in the catchment.

2. *What impact will the effect from climate change coping strategies on rural land use have on flood risk for the village of Eneryda in year 2050?*

Climate change coping strategies, in combinations with other forces that will effect land use, have been proven to have an important effect on flood risk in Eneryda. As long as the ditches from the rural catchment north of the village are connected to the local sewer system, the choice of strategy will influence the duration, distribution and depth of flooding in the village. A substitution strategy including intensive forestry, is projected to increase the flood risk as compared to a climate strategy favoring carbon storage. The difference in the hydrologic performance of these two strategies entails increasing the water volume by 22%, giving a 1 hour longer and 2.5% larger flooded area, and increasing the severity of flood depth by a few centimeters when exposed to a 100-year rain event with a duration of 24 hours.

If implementing a policy with considerable substitution of fossil fuels by biomass, leading to an intense forestry, the choice of location of this needs to be investigated. Also, the best forestry practices, including climate adaptation strategies, need to be implemented to not increase the risk of flooding. Carbon storage strategies generally coincide well with decreasing flood risk. Adaptation to local conditions is necessary for all strategies to simultaneously achieve other management goals. For Eneryda, a projected increase in mature forest is the main causes of runoff reduction. Due to the projected abandonment of agricultural land at this location, climate change coping strategies for agricultural land only have a marginal impact in this study. Well-planned climate mitigation and adaptation strategies can create positive externalities in terms of ecosystem services and multifunctional use of land.

The impact from rural land also highlight the importance of working with flood measures using a wider perspective than only considering implementing grey infrastructure as land use, and with that runoff regime, change over time. Land use and the runoff regime can also change quickly due to direct effects from extreme weather events. Recently, large storm damages to the forests in the study area make the current land use the worst case scenario for flooding in this thesis. My results therefore stress the importance of adaptation strategies in the forest sector.

For areas with currently strong regulating ecosystem services, but where the natural land can contribute to the flood risk, the perspective of land use and land use change is important to take into consideration, both when developing strategies and dimensioning infrastructure. The ability to take a catchment perspective has been made possible due to development and availability of data and technology. The responsibility and resources for implementing this in reality needs further improvement and effort.

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9. Appendix

Appendix 1. Soil Map

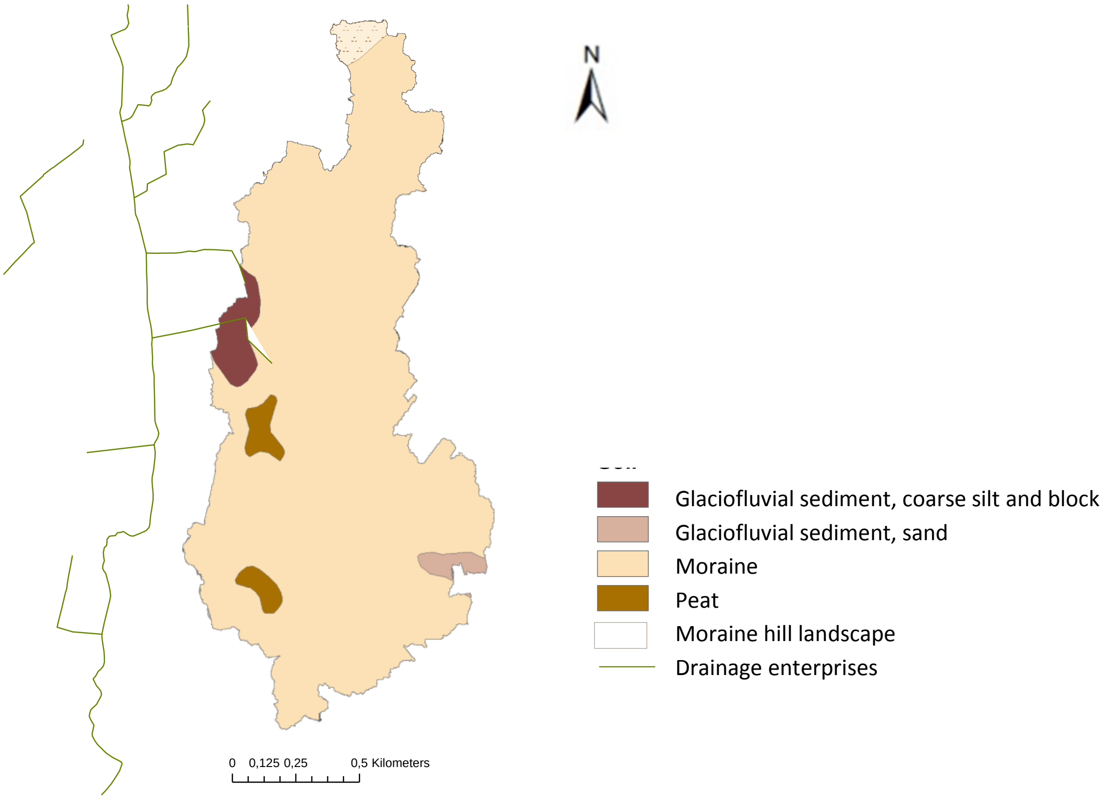

Figure: Soil map over Eneryda provided by © Sveriges geologiska undersökning.

Appendix 2. CDS-rain

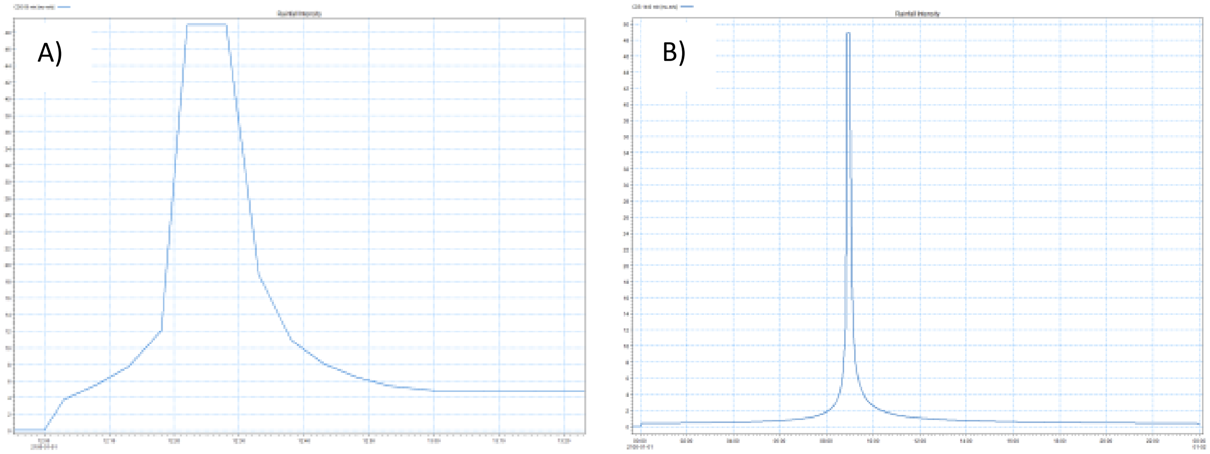

Figure: CDS-rain with a recurrence interval of 100-year, duration of a)1 hour and b)24 hour provided by Tyréns.

Table: CDS-rain (without climate factor) provided by Tyréns. The volume is read from MIKE URBAN runoff result-file.

Recurrence interval		**Accumulated value (mm)**	**Maximum value (mym/s)**
10-year	1h	25.7	22.8
	24h	64.6	22.8
50-year	1h	43.5	38.8
	24h	-	-
100-year	1h	54.6	48.9
	24h	119.2	48.9

Appendix 3. Measured Discharge at Larmgatan

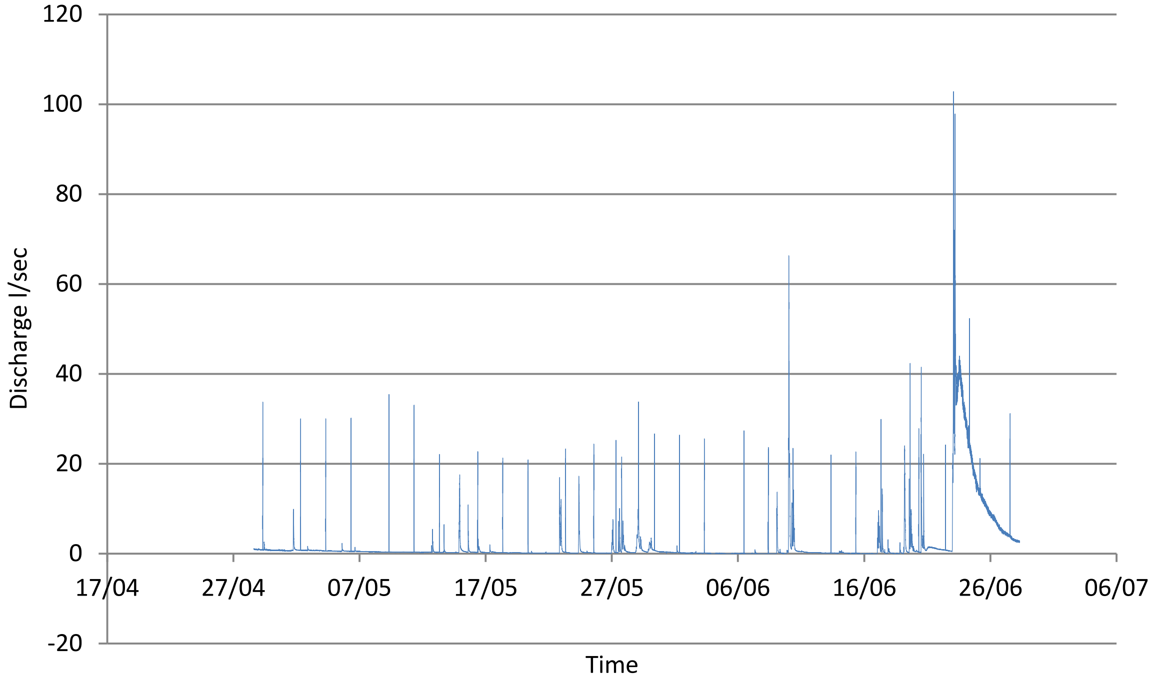

Figure: Measure discharge at Larmgatan, 2011. The largest rain event is used for calibration and validation of the model.

Appendix 4. Runoff Coefficient Calculations for the Largest Rain Event

Table: Calculation of the φ for the largest rain event during the field measurements. This table is based on the size of the urban catchments and already set imperviousness given from MIKE URBAN model provided by Tyréns, as well as the size from the added rural catchments, the measured precipitation (52,2 mm) for the largest rain and measured discharge from Eneryda. Impervious surfaces are assumed to contribute with 100% to the runoff.

	Area (ha)	**Precipitation (m3)**	**Imperviousness**	**Total Q (m3) (minus base flow)**	**Part of P that becomes Q**
Total catchment above Hördagatan	41,671	21752		5284	24.29%
Urban	10,486	5474	9.78%	535	
Rural	31,185	16279	-	4749	29.17%
Total catchment above Larmgatan	51,388	26825		7049	26.28%
Urban	9,091	4745,502	15.22%	722	
Rural	41,297	21557	-	6327	29.35%

Appendix 5. Calculation of Land Use According to Dyna-CLUE Projections

Table: Calculation of land use change between year 2010-2050 according to Dyna-CLUE projections using climate scenario A2 and B1. * from 0 to 1km^2

Land use:	**Scenario:**	*A2 2010* km^2	*A2 2050* km^2	*Change 2010-2050* *%*	*B1 2010* km^2	*B1 2050* km^2	*Change 2010-2050* *%*
Urban area		3	3	0	3	3	0
Arable land		34	31	-8.8	39	4	-89.7
Pasture		19	17	-10.5	21	21	0
Natural vegetation		10	10	0	4	4	0
Wetland		12	12	0	12	12	0
Recently abandoned arable land		5	10	+50	0	1	+100
Forest		311	310	-0.3	317	351	+10.7
Lake		4	4	0	4	4	0
Recenty abandoned pasture land		2	3	+50	0	0	0
Total		400	400		400	400	

Appendix 6. Drainage and New DEM

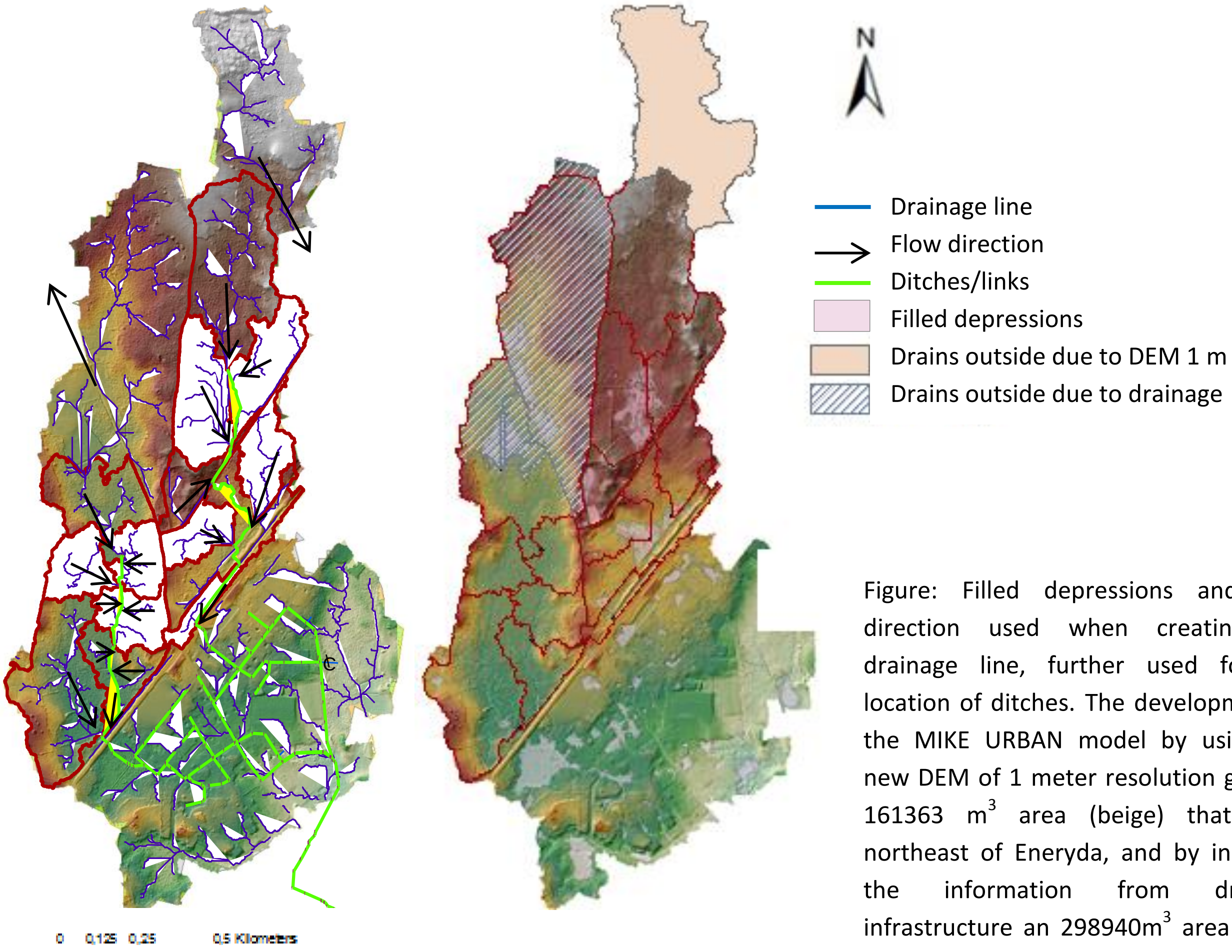

Figure: Filled depressions and flow direction used when creating the drainage line, further used for the location of ditches. The development of the MIKE URBAN model by using the new DEM of 1 meter resolution gave an 161363 m^3 area (beige) that drain northeast of Eneryda, and by including the information from drainage infrastructure an 298940m^3 area (lined) drain northwest of Eneryda.

Appendix 7. Calculating t_c Using the Conventional Method

Calculating t_c using the conventional method from Svenskt Vatten (2004) for surface flow.

Table: T_c calculated by using the velocity from Svenskt Vatten (2004) of 0,1m/s hillside and 0,5 m/s channel in the velocity eq. t=s/v.

Sub-catchment	Hillside (m)	Ditch (m)	T_c hillside (sec)	T_c channel (sec)	T_c total (min)
East catchment	777	1008	7770	2016	163
West catchment	525	603	5250	1206	108

Appendix 8. Adaptation of Interpolated φ to ~10 year Rain Event at Eneryda

Table: Calculation to adapt the interpolated φ to the runoff regime at the western catchment during the ~10 year rain event at Eneryda. The calculation are based on the total area of 311847 m^2 with a calculated φ of 0,2917 (see appendix 4) giving an active area of 90965 m^2. Through adapting the interpolated φ with a *"factor to adapt"* of 2.1362 gives this active area. The values given are for a soil A, soil moisture (I). Clear-cut is interpret as clear-cut on mixed forest.

Land use	**Area (m^2)**	**Interpolated φ**	**Active area (m^2)**	**Adapted φ**	**Adapted active area (m^2)**
Agriculture	7417	0.201	1488	0.429	3179
Pasture	58197	0.150	8713	0.320	18612
Mixed forest	25035	0.100	2510	0.214	5362
Coniferous forest	13495	0.076	1028	0.163	2197
Decidious forest	0	0.124	0	0.266	0
Lawn	10960	0.150	1641	0.320	3505
Meadow	0	0.100	0	0.214	0
Clear-cut mixed forest	157822	0.149	23576	0.319	50363
*Young forest **	36177	0.100	3618	0.214	7748
Total	309103		42582		90965

* counted as forest.

Factor to adapt:

$$\frac{\text{Total active area}}{\text{Total adapted active area}} = 2.1362$$

Appendix 9. Time-Area Curve2extreme

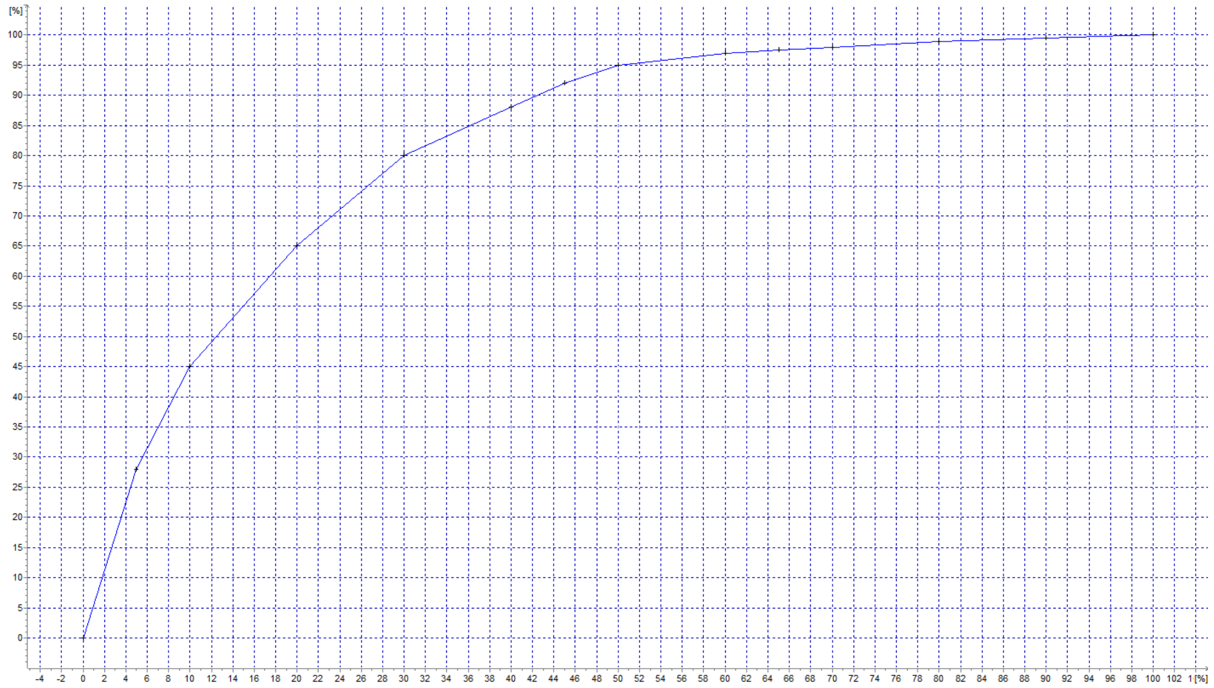

Figure: The constructed *Time-Area curve2extreme* during the calibration of the MIKE URBAN model over Eneryda.

Appendix 10. Runoff Coefficient: Antecedent Soil Moisture *Low* and *Average*

	Interpolated φ (I)	**Interpolated φ (II)**
Cultivated land Annual	0.201	0.336
Pasture	0.150	0.252
Forest	0.100	0.153
Lawn max	0.150	0.252
Cultivated land Perennial	0.157	0.265
Fallow	0.344	0.524
Meadow	0.100	0.153
Coniferous	0.076	0.116
Decidious	0.124	0.190
Clear-cut	0.149	0.228
Clear-cut on coniferous	0.114	0.174
Clear-cut on decidious	0.185	0.287
Afforestation agriculture	0.166	0.277
Afforestation pasture	0.124	0.208

Table x: The difference in applying soil moisture condition *Low* (I) compared to *Average*(II). CN (I) is used for the interpolation, exponential regression ($y = 0.0697e^{0,0262x}$ r^2=0.9999). The calculations are following Dunne and Leopold, 1995 p.296.

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