Modeling grass zones as a land use measure in the Skuterud catchment using the Limburg Soil Erosion Model

Modellering av gressoner som tiltak i Skuterud-feltet ved bruk av Limurg Soil Erosion Model

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PREFACE

This thesis has been submitted as part of a Master of Science in Environment and Natural Resources at the Department of Plant and Environmental Sciences (IPM), Norwegian University of Life Sciences. The paper has been written as a part of the Exflood research project and the work has been carried out during the spring of 2013.

After months of demanding work, hours of frustration and occasions of accomplishment, I am happy to conclude my thesis work. Although the process has been challenging I am grateful for the opportunity to study within a scientific field which I love and admire.

I thank my supervisor Helen French (IPM), for good advice and support throughout the work and always making me feel welcome in her office. I would also like to thank the kind and helpful people at Bioforsk for taking time out of their busy day to assist a badgering master student: Jannes Stolte for providing guidance on the modeling and results, Torsten Starkloff for presenting the LISEM model and always taking the time to answer any query about the data and model, and Stein Turtumøygard and Robert Barneveld for technical support. Finally, thanks to my family and friends for encouraging words, hugs, food and love throughout the process. And most of all for believing in my studies and master project even when I had momentary doubts.

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SUMMARY

The frequency and intensity of rain events are expected to increase in the future, causing excess surface runoff and flooding situations in many areas. Hydrological models can be used to assess the impact of implemented conservation measures and guide decision-makers within the context of land use planning. At the same time, the value of models is highly dependent on the accuracy of predictions and sufficient understanding of model processes. For this study, the hydrological and soil erosion model LISEM has been used to investigate the modeling of grass strips as a land use measure in the Skuterud catchment in Ås, Norway. The main focus has been on evaluating modifications of the input parameters and analyzing the effect of spatial extent and placement on total discharge and peak discharge. The grass strips were modeled for three different locations within the catchment, and three rain events of various magnitudes were simulated.

The main results from the simulations show that: For small to moderate rain events the model simulates that a single measure downstream in the catchment along the main water channel is the most effective in reducing total discharge and peak discharge; it is the placement in the catchment rather than the size of the measures that defines the effect; for events with increased precipitation intensity the variation between the effect of the simulated measure is reduced; although flow properties respond similarly for all approaches when rain intensity increases, there are large variations in simulated soil loss between the approaches.

The simulation outcomes demonstrate some of the complexities of quantifying surface runoff within the model. The results of the analysis suggest that flow velocity, rainfall intensity and placement of measures are important factor when modeling watershed runoff with the LISEM model.

SAMMENDRAG

Det forventes at hyppighet og intensitet av nedbørshendelser vil øke i fremtiden, noe som kan føre til betydelig overflateavrenning og flomsituasjoner i mange områder. Hydrologiske modeller kan benyttes til i å vurdere av effekten av flomreduserende tiltak og veilede beslutningstakere i landskapsplanlegging. Likevel er nytten av slike modeller avhengig kvaliteten av estimerte verdier og forståelse av modellprosessene. I denne oppgaven har LISEM modellen blitt benyttet til å undersøke modellering av vegetasjonssoner som tiltak i Skuterud området i Ås kommune, Norge. Hovedfokuset i denne oppgaven har vært å evaluere effekten av endringer i parameterverdier og analysere innvirkningen av tiltakenes plassering på den totale avrenningen og flomtoppen i nedbørsfeltet. Gress soner har blitt modellert med tre ulike plasseringer, og tre nedbørshendelser av ulik størrelse har blitt simulert.

Resultatene fra simuleringene viser at: for små til middels store nedbørshendelser vil en plassering av tiltak nederst i nedbørsfeltet langs elveløpet gi størst reduksjon i total avrenning og flomtopp; plasseringen av tiltakene innad i nedbørsfeltet er mer avgjørende enn størrelsen på tiltakene; for hendelser med høy nedbørintensitet er det liten variasjon mellom effekten av tiltakene; for hendelser med høy nedbørintensitet, er avrenning relativt lik for alle tilnærminger, men simulert mengde erosjonstap varierer.

Simuleringene demonstrerer at kvantifisering av nedbørsmengder i modellen gir komplekse estimeringer. Resultatene av analysen indikerer at strømningshastigheten av overflatevannet, nedbørintensitet og plassering av tiltakene er avgjørende elementer for modellering av tiltak med LISEM modellen.

CONTENT

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 BACKGROUND

It is expected that climate change is likely to increase precipitations amounts and rainfall intensity in many areas in the future, also within the Nordic regions (Hanssen-Bauer et al. 2009; IPCC 2012; Lindholm et al. 2007; Miljøverndepartmentet 2012). More frequent and intense precipitation can cause situations where excess water flow leads to flood events and damage on settlements, property and infrastructure. It seems highly probable that changing weather patterns is one of the largest challenges for management of land use, natural resources and society in the future. Sustainable land use management can provide multiple benefits in reducing such negative impacts through stabilizing soil structure, reducing erosion, ensuring decent water quality and buffer against flood situations.

Box 1.1 Climate change in Norway: According to Hanssen-Bauer et al. (2009) and Lindholm et al. (2007) several climate change impacts related to changing weather patterns are likely in Norway in the future.

- Annual precipitation is expected to increase with between 5- 20 %, depending on the region. The increase will be greatest over the coastal area in the southwestern part of the country and in the northern region.
- Fall precipitation will have the largest increase, with more than 20% increase on the West-coast, in Mid-Norway and Northern-Norway.
- Summer precipitation is expected to be reduced by up to 15 % in the eastern and southern part of the country.
- Heavy rain days (precipitation above 20 mm) will increase by 15 days on the west coast.
- Extreme precipitation events will occur more often in all parts of the country

Figure 1.1 Flooding in Norway (Dagbladet 2010; Miljøverndepartementet 2007)
1) Flooding of agricultural land in Norway 2) Urban flooding in the city of Bergen in 2005

Surface runoff can be defined as water that gathers on the terrestrial surface and does not infiltrate into the soil. This occurs when the soil is already infiltrated at full capacity or the surface is impermeable, such as tarmac, roads or buildings. The quantification of surface runoff is then a factor of the amount of precipitation and its ability to enter into the surface. As such, surface runoff can increase under conditions of saturated or frozen soils where potential infiltration volume is reduced. Surface runoff with a high sediment load can cause waterways to clog and congests sewer systems, causing damage on roads, infrastructure and crops (Roo 1996). It is expected that climate change will generally lead to increased runoff, with higher amounts during the autumn and winter and less during summer (Hanssen-Bauer et al. 2009).

Flooding occurs when water accumulates and inundates a surface area due to excess water runoff. Most floods in Norway are a result of snowmelt and/or heavy precipitation over a prolonged period. During extreme weather events, runoff of surface water leads to a significant peak flow which can cause flash flooding in parts of the basin. In agricultural areas, flooding can cause direct damage through erosion and sedimentation and influence the quality of the crops. Local flooding in urban areas often arises where water flows into communal sewerage systems that are not dimensioned for excess water flow or that clog easily. The increase of impermeable surfaces in urban and semi-urban catchments further challenges the management of excess surface water.

Surface water management in multi-functional catchments is today a challenging issue and requires the consideration of climate change, urban development and various land uses. For efficient and preventive management at municipal level there is a growing need to integrate conservation measures which reduce excess runoff and flooding situations. As such, attention has been given to identifying and developing land use planning tools that support this process. In Norway, the government funded Exflood project is an example of a research program which is looking towards analyzing measures and incorporating them into land use management strategies (see section 1.4 Exflood - Extreme weather in small catchments: new method for flood protection).

1.2 LAND USE MEASURES

Several land use measures can be implemented to reduce negative effects of excess surface runoff. These are often divided into structural engineering and non-structural engineering measures (Kelman & Rauken 2012). Engineering measures are physical measures implemented to reduce surface runoff and flooding in an area, e.g. dams, dikes and piping of water flow. Such measures are commonly implemented in large catchment areas where, for example, reservoirs can be created by damming up part of the natural water system, and flow can be regulated according to water demand and electricity production. For most catchments with urban development, excess water is led into local drainage systems that transport water to areas that are more tolerable to water, or to the sea. Engineering measures are most often calculated from anticipated hydrological dimensions, and based on known weather conditions and runoff data in a given area.

Non-engineering measures involve the use of natural elements in the ecosystem to alter the overland flow to avoid damage from surface runoff. These can be e.g. ponds, vegetation zones or cultivation of water-resistant plants. Ideally, these alterations lead to excess surface runoff being taken up as a part of the natural hydrological cycle through infiltration and evapotranspiration. In agricultural dominated catchment areas, controlling surface runoff is considered important to limit loss of nutrients and avoid soil erosion (Al-Wadaey et al. 2012; Syversen 2002). Examples of measures include trenches and drainpipes that direct excess water flow. Other measures are vegetation zones that detain water and filter particles, nutrients and pesticides from the farming area.

1.3 MODELING LAND USE MEASURES

When evaluating land use planning and management practices models are often applied to estimate the extent of a land use problem and evaluate possible land use strategies in a given area. Accurate quantification of runoff volume and time distribution is an important element in evaluating drainage techniques, land use planning and conservation measures. Hydrological modeling is potentially a valuable instrument in this process.

1.3.1 Hydrological modeling

A model can be defined as a mathematical representation of a real system. Models of physical conditions are useful for two main purposes; (1) to increase process understanding of current observations, and/or (2) to predict patterns under altered conditions (E.g. Fetter 2001; Hessel 2002). The choice of model should reflect the objective and purpose of the simulation Hydrological and erosion models are largely used to quantify and analyze the effects of various land uses, and several research models have been developed for this purpose. Examples of models are provided in the box 1.2.

According to Hessel (2002), it is possible to subdivide the models in relation to their main characteristics: For *process based models* natural processes are classified within a model based on general laws. The basic processes incorporated into hydrological models are driven by elements such as rainfall, interception and infiltration. The output depends on physically described mathematical equations of interception, infiltration and runoff. Such a model is universal in the sense that it is applicable to other areas than those it was developed for if place-specific parameters are inserted. *Empirical models* on the other hand are developed specifically for certain conditions and can therefore not be considered universal. In any case, many processes upon which the models are based are rarely fully understood, which may cause defects in the model structure (Hessel 2002).

Runoff and erosion models can further be categorized to reflect if they simulate a single weather event or continuous conditions over a prolonged period. *Single event/storm based models* require detailed parameter information of the start of an event, while the intermediate conditions are only relevant in defining the initial conditions of the next event. *Continuous models* on the other hand depend on information of the conditions in-between larger events. Such models may consider factors such as vegetation growth, soil properties and evapotranspiration, and therefore require a significant amount of input data (Hessel 2002).

Box 1.2 Some hydrological and soil erosion models (Roo et al. 1996):

The CREAMS (Chemical Runoff and Erosion from Agricultural Management Systems) is designed to model chemical run off from agricultural areas, and considers water quality from different farming practices. It is not developed to model at basin-scale or single storm events.

ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation) is a soil erosion model that simulates hydrological responses in basins where the main land use is agriculture. It can model conditions during or immediately after a single event. The infiltration is based on an empirical equation.

The EUROSEM model predicts soil erosion in small catchments. It is process based and simulates single events. However, there is limited representation of planes and channels in a catchment, meaning lumped representation is necessary in larger catchments.

The Limburg Soil Erosion Model, (LISEM), simulates infiltration, overland flow and erosion on a catchment scale, during and after a single rainfall event. The model can utilize a physically based infiltration equation.

Finally, models can be classified as being either distributed or lumped. For *distributed models,* the spatial resolution is high and the number of elements can be thousands. These require a large data input and long computing time. *Lumped models* simplify the distribution and utilize only a few spatial elements for an application.

1.3.2 Input parameters

For hydrological and erosion models, essential input elements are meteorological data, topography and soil data, which determine water flow and mass transport. Many models require a large amount of input data; their output accuracy will depend on the ability to sample data or alternatively, estimate input parameters. As the collection of detailed and site specific information is time-consuming and costly, globally-approximated plant and soil parameter ranges are often applied (Breuer et al. 2003). For the same reasons, homogeneity of a component is regularly assumed for simplification of the modeling process, which leads to the disguise of real nuances in nature. Soil physical properties are often regarded as the most time-consuming and costly to measure as they vary highly even at small-scale (Bonta 1998; Kværnø 2011).

A sensitivity analysis investigates how “sensitive” a model is to alterations in the input parameters, and helps understanding the dynamics of the model. Such analysis can be useful both for development and for evaluation of the simulation. An analysis makes it is possible to evaluate how much model generalization “costs” and how much the output differs from real representation (Breierova & Choudhari 1996). Experimentation with a range of input variables provides insight in the behavior of the model, identifying variables that significantly influence the output. At the same time, if a large change in a parameter leads to a relatively insignificant change in the model, it can be assumed that it is sufficient to use an estimate rather than real measurements.

1.3.3 Uncertainty and error sources

As a model is a simplification of a natural system, the level of detail in comparison to actual circumstances will always be reduced. It is recognized that simulation is associated with significant degree of uncertainty, which can stem from, for example, the model conceptualization, accuracy and adequacy of data input, selection of initial conditions and calibration of the model. Because of the variability of natural vegetation and real conditions, computed values should only be considered estimates (Temple 1999). Regarding input data, sources of error that contribute to uncertainty include measuring errors, inadequate sampling procedures, averaging of data, data interpolation and derivation of remotely sensed data (Kværnø 2011). Differences in measuring techniques can also influence the parameter results. Pre-set regional parameters not be suitable or sometimes even wrong to use to model a given condition and thereby contributing to the inaccuracy of the model (Breuer et al. 2003).

1.4 EXFLOOD - EXTREME WEATHER IN SMALL CATCHMENTS: NEW METHOD FOR FLOOD PROTECTION

1.4.1 The Exflood Project

NORKLIMA is a large- scale Norwegian research funding program, which extends over 10 years (2004 – 2013), and aims towards generating knowledge on climate change and effects in Norway (NORKLIMA 2010). The Exflood Project (2010 -2013) is a sub-project funded by NORKLIMA. The objective of the Exflood Project is to identify measures to reduce negative impacts of extreme weather events in small watersheds and to promote the measures in land use planning.

The specific objectives of the Project are to:

- Review existing approaches of different stakeholders to extreme weather events
- Develop modeling techniques to quantify discharge in catchments

- Develop and analyze land use strategies aiming to incorporate measures as a land use planning tool, collaborating with various stakeholders
- Construct a land use planning tool designed to consider extreme weather events

The activities of the Project have been divided into four work packages: 1) analysis of the practices of common stakeholders, 2) modeling, 3) analysis and review of measures and 4) synthesis (Bioforsk 2012). It is aspired that the end result will provide a model that can be used as a land use planning tool for municipalities to use locally (NORKLIMA 2009). The measures should consider multifunctional basins that encompass various land uses such as urban areas, agriculture, woodlands and infrastructure, and consider the catchment as a whole. Figure 1.2 demonstrates an example of the drainage in a multi-functional catchment, where the upper part of the basin consists of agricultural land and the lower part of the basin is dominated by semi-urban or urban development.

Figure 1.2 Multifunctional catchment (NORKLIMA 2009)

Demonstrates the drainage in a catchment with multiple land uses

1.4.2 Study Areas

To examine the Exflood approaches, study areas in three Norwegian municipalities have been selected, Trondheim, Sandnes and Fredrikstad. The study areas have been chosen based on reported significant flooding events, data availability, geographical spread and existing research. Due to the extensive data availability, a test area in Ås Municipality, the Skuterud catchment is used to test and study the Exflood modeling approaches in detail. The test catchment area has been the subject of several previous land use studies and data and results are widely available.

Figure 1.3 Exflood study areas (Bioforsk 2012a)

The map indicates the three study areas and the test area for the Exflood approaches

1.5 THESIS OBJECTIVE AND RESEARCH QUESTION

1.5.1 Thesis objective

Many catchments are vulnerable to surface runoff and soil erosion, and soil and water loss from sloping croplands is considered a major environmental issue (Xiao et al. 2012). The expansion of urban areas and intensification of agricultural practices in combination with a changing climate further contributes to this problem. Hydrological and soil models can function as useful tools for understanding the landscape dynamics and assist in land use management to reduce such problems. They provide a consistent method for approximating characteristics of a specific area and land use, and can contribute to increased understanding of issues such as discharge, soil erosion and potential hazards. Although climate change scenarios have been assessed and modeled for Norway, this has mainly been done at a coarse spatio-temporal resolution. As local extreme weather events are becoming more evident, there is a need for a higher time and spatial resolution to evaluate their effects on smaller areas (Hanssen-Bauer et al. 2009; Lindholm et al. 2007; NORKLIMA 2009). In addition, the modeling of land use measures such as vegetation zones and depressions is limited for temperate regions (Xiao et al. 2012).

As presented in Box 1.2, LISEM is hydrological and soil erosion model that simulates single rainfall events in small catchment areas. It is one of the models that have been applied within the Exflood Project to quantify discharge from multi-functional catchments. The objective of this thesis is to increase the understanding of the input parameters and modeling processes related to simulating conservation measures in LISEM, with focus on vegetation zones in a small multifunctional catchment. It is anticipated that the increased understanding of LISEM gained through this thesis work can both provide useful knowledge of model dynamics and a basis for further model development regarding land use measures.

1.5.2 Research question

The specific aim of this thesis and testing of LISEM model is to address the following questions:

- How do changes in input parameters for vegetative zones affect simulated features of the surface runoff in the catchment?
- How does placement and size of vegetation zones influence simulated total discharge and peak time of discharge?

using the Skuterud catchment in Ås municipality as the case study area.

1.5.3 Restraints

The aim of Exflood Project Work Package II is to develop models that support the understanding of surface water flow and flooding within a catchment area. In that context, the main focus of this thesis is on water flow characteristics and soil loss, which is highly related. For this thesis grass strips has been selected as an example of a land use measure for further investigation, and three different spatial extents will be examined.

For this study the LISEM model is used to model conservation approaches, and input parameters and calculations relevant for this specific model will be focused on. Regarding input parameters, conditions especially relevant for Nordic climate have been used where appropriate. Analysis of modeling results is based on the site specific data collected from the research site from previous studies by Kværnø (2011). Attention is given to the selected study area, and relevant hydrological factors for this particular catchment are accentuated. Although the results generated are mainly applicable to the particular study area, it is believed basic approach of this thesis, its findings and conclusions may also be relevant for similar catchments.

1.5.4 Thesis structure

A short introduction to the background of modeling land use measures has been presented in **Chapter 1**, and it is within this context that research questions have been constructed. For an understanding of the conceptual modeling, a theoretical framework is descried in **Chapter 2**. Here, a general overview of the function of vegetation zones is presented, as well as an introduction to the mathematical representation of the model features. It can be noted that many of the LISEM parameters and general theory also apply for other models. Research area and specific model approach are presented in **Chapter 3**, which also includes as description of the initial circumstances and basic input parameters. In **Chapter 4**, the results of the simulations are presented for the various approaches under conditions of three different rain events. In addition to discharge characteristics for the catchment and hydrographs for the main outlets, a description of the simulated soil loss is featured. Results are discussed in **Chapter 5**, where the change in land use input parameters and the models applicability to natural conditions is assessed. Future modeling perspectives are also be considered. Finally, a conclusion of the results and analysis are presented in **Chapter 6.**

2 THEORY – MODELING VEGETATIVE ZONES

2.1 VEGETATIVE ZONES AS A LAND USE MEASURE

Surface runoff can cause negative environmental impacts such as flooding, erosion and transport of pollutants. Agricultural areas are identified as the main contributor of nutrient runoff, for example nitrogen and phosphorous can lead to contamination of surface and drinking water and eutrophication (Al-Wadaey et al. 2012). Grass strips, vegetation zones and riparian buffers function as important conservation measures to reduce runoff and soil erosion, especially in agricultural areas. Such vegetative barriers reduce flow velocities and erosion potential of flowing surface water, and also function to increase deposition of sediments and nutrients (Al-Wadaey et al. 2012). Vegetation also contributes to increased soil stability and cohesion due to the root system of the plants, and can be beneficial for biodiversity by providing additional habitats within an area.

According to Van Djik et al. (1996) the vegetation reduces negative impacts of overland flow in several ways;

- Enhance infiltration in the planted area
- Filtration and sedimentation of suspended material in the surface runoff is increased
- Flow velocity and transport capacity is reduced, enabling more local sedimentation
- Increased adsorption of material to vegetation and soil surface

The effect of vegetation zones on the water flow pattern is illustrated in figure 2.1. The extent of these functions will depend on several factors such as the flow properties and the characteristics of the vegetative surface. Significant flow properties are velocity (and hence the slope gradient) and water volume, the size and concentration of the sediment in the runoff and duration and intensity of precipitation. The effectiveness will depend on the vegetation species, density, width and interval of the vegetative zone, the species ability to remain unaffected by flow and underlying soil properties. The function of the zone will also depend on factors such as the depth of the root system, water tolerance and ability to grow through overlaying sediment. Infiltration capacity is usually higher in vegetative zones in comparison to agricultural areas do to a more extensive root system and more permanent vegetation. Also, vegetative zones are not influenced by soil compaction from agricultural machinery which reduces infiltration capacity (Syversen 2002).

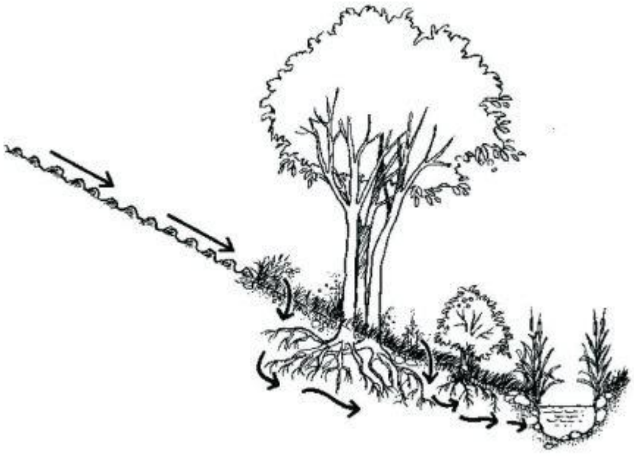

Figure 2.1 Flow pattern in a vegetation zone (Klimakommune.no 2008)

The illustration demonstrates the flow path of surface water entering into a vegetation zone, adjacent to a water channel.

Vegetation zones comprising of grass and trees can reduce sediments and nutrients with up to 50% of the original amount during the first year of establishment (Blankenberg & Hougsrud 2010). Studies of Norwegian conditions indicate that the most relevant factor for function of the vegetation zone is the character of the vegetation (height, robustness and density), rather than the type of vegetation (Blankenberg & Hougsrud 2010). As the efficiency of vegetation is comprised by a variety of factors, the implementation of the measures is to a large degree site specific (Al-Wadaey et al. 2012; Kværnø & Stolte 2012; Van Dijk et al. 1996). A change in land cover and plant composition may have several effects on the hydrological flow conditions in an area and over a longer time period the changes in land cover may alter underlying soil properties (Breuer et al. 2003). For this study the focus will be on grass strips as a vegetative measure, and further, different variants will be presented.

Box 2.1 Vegetation zones in Norway:

Over the past decades agriculture in Norway has increased in efficiency and soil compaction, tillage, removal of natural wetlands and vegetative buffer zones have led to an escalation of soil erosion and nutrient runoff from agricultural fields (Syversen 2002). In Nordic countries the surface runoff is most significant during winter, and especially during periods of high snowmelt (Blankenberg & Hougsrud 2010; Syversen 2002). Agricultural runoff is one of the most significant sources of pollution load which leads to eutrophication of surface water and Norwegian authorities have over the recent years increased attention to this issue. One of the suggested measures to reduce the negative impacts of surface runoff and pesticide and nutrient pollution is the use of vegetative zones in agricultural areas (Syversen 2003).

2.1.1 Vegetative buffer zone along watercourse

A vegetative buffer zone is transition zone between a patch of arable land and a significant watercourse in the catchment. They can also be termed filter or buffer strips and/or have the prefix of their specific vegetation (Syversen 2002). The vegetation often consists of grass species, though more robust bushes and trees are also common. Soil particles and soil aggregates of nutrients from surrounding farm land are deposited in the vegetation zone and are held by the soil or plants in the zone, and water is filtrated before it enters the main channel. This placement of vegetation also prevents mass movement along the side of the channel. Regarding conservation of agricultural fields, vegetation zones are often considered a secondary measure, because they do not have direct effect on the agricultural area as for example plowing techniques (Blankenberg & Hougsrud 2010). The purpose of the measure is to a larger degree to control nutrient runoff and prevent water pollution and flooding of the channel banks during extreme runoff events. Most vegetation zones in Norway are of this character (Syversen 2002).

Figure 2.2 Vegetation along channel (Blankenberg & Hougsrud 2010; Klimakommune.no 2008)

Examples of vegetation zone between agricultural field and water channel

2.1.2 Grass strips

Grass strips are segments of dense and erect grass along patches of arable land, designed to slow down runoff and reduce soil erosion in sloping croplands. They are usually between 1 -25 meters of width and are normally of permanent vegetation, but can also be a part of a crop rotation cycle (Van Dijk et al. 1996; Xiao et al. 2012). Whilst vegetation buffer zones are most often located at the edge of objects for protection, e.g. the bottom of a field, grass strips frequently intersect arable land. They are commonly placed along the contour lines of the landscape and are effective in reducing sheet and rill erosion. The change in slope characteristics alters the overland flow pattern and in addition functions to filter sediments and restrain nutrients in runoff.

2.1.3 Grassed waterways

Due to small variations in topography overland flow is concentrated and creates small rills in the surface. If flow is sufficiently able to transport particles, gullies and new waterways are generated (Hessel 2002). Vegetation can be placed in these water courses to disrupt the water flow, but more importantly protects the soil from erosive forces. The choice of grass species will depend on if there is intention of for example using the grass for fodder (Bioforsk 2012b). These measures are commonly used in areas where waterways are especially erosion prone or where slopes are extensive. They are normally placed along natural depressions, but can also transect slopes to lead water away from agricultural fields (Bioforsk 2012b).

Figure 2.3 Grassed waterway (Bioforsk 2012b)
Vegetation planted in a natural waterway in the landscape

2.2 MODELING VEGETATION COVER AND SURFACE PROPERTIES

Several hydrological models consider the interactions between the flow fields and the vegetal cover to predict surface runoff and erosion, and can be used to model vegetation measures. Parameters describing characteristics of vegetation and soil properties are applied, and many models are based upon the same descriptive inputs. As the collection of detailed and site specific information is time-consuming and costly, globally approximated parameter ranges are often used (Breuer et al. 2003; Temple 1999). Commonly used plant parameters for hydrological models are interception capacity, leaf area index, plant height and root depth (Breuer et al. 2003), whilst soil properties often are defined by hydraulic conductivity, water retention and soil cohesion.

2.2.1 Vegetation features

The *interception* is an important element in calculating the water balance in a catchment and can be defined as the amount of precipitation stored on and in the canopy after a rain event, given conditions of no evapotranspiration and after dripping of water to the ground surface has stopped (Breuer et al. 2003). The vegetation is significant for the storage capacity and the potential quantity that can be evaporated back into the atmosphere, by factors such as the sum of the leaf area, the surface texture and plant architecture (Breuer et al. 2003). Interception is usually determined the amount of rain throughfall from total precipitation. Several techniques have been applied to estimate the storage capacity of vegetation, for example through artificial rainfall experiments and weighing of vegetation after rain events (Breuer et al. 2003). According to Breuer et al. (2003) research and information on forest tree interception is abundant, whilst data on pasture species and crops is limited and should be given further attention (Breuer et al. 2003). The interception can be calculated by regarding the canopy as a simple storage (Jetten 2002) :

$$\boldsymbol{S = c_p * S_{max} * \left[1 - e^{-k * \frac{P_{cum}}{S_{max}}}\right]} \qquad \textbf{(I)}$$

Where: S= cumulative interception (mm)

C_p= is the fraction of vegetation cover

S_{max}= Canopy storage capacity

k= correction factor of vegetation density (0.046 *LAI)

P_{cum}= cumulative rainfall (mm)

The canopy storage capacity is the amount of water the canopy can hold, and can be calculated based on the *leaf area index* (*LAI).* The LAI represents the average leaf area of a vegetated zone per unit surface area and is therefore a dimensionless measure of leaf material (Jetten 2002). The LAI influences transpiration rates and interception, and can vary according to season. For example, for deciduous trees the LAI is highest during growing season, whilst there is less variation when vegetation does not completely shed leaves. The LAI can also be affected by factors such as fertilization, thinning and the density of the vegetation. In modeling, forest and pasture species generally maintain a LAI above zero throughout the year, whilst arable land acquire a LAI of zero after plowing (Breuer et al. 2003). Based on the equation of Von Hoyningen- Huene (1981) the LAI is used to calculate the canopy storage capacity (S_{max}).

$$S_{max} = 0.935 + 0.498 * \mathrm{LAI} - 0.00575 * \mathrm{LAI}^2 \qquad \text{(II)}$$

Crop/plant height is frequently applied in hydrological models, used to calculate for instance potential evapotranspiration and above ground biomass. For erosion models it is relevant to calculate the effect of throughfall kinetic energy from plants for the estimation of splash erosion. Plant height for coniferous and deciduous trees can often be obtained from regionally adapted forest growth tables (Breuer et al. 2003).

2.2.2 Surface properties

Most hydrological and soil erosion models utilize the *Manning's N* empirical equation to calculate surface resistance to overland flow. The equation calculates the cross sectional average flow in open channels or fields driven by gravity (Hessel 2002).

$$n = \frac{R^{\frac{2}{3}} * S^{\frac{1}{2}}}{v} \qquad \textbf{(III)}$$

Where: R= hydraulic radius (Area/ wetted parameter)

S= Slope (Sine of slope angle)

V= average velocity (m/s)

The hydraulic radius is a function of the channel or area over which water is flowing, and is the ratio between the area of the channel and the portion of the cross section that can be considered "wetted". The greater the hydraulic radius the more water volume a channel can carry. On slopes, overland flow will move as a shallow sheet of water, with diverging and converging flow around obstacles. The resistance to flow is variable in space and time, as conditions are constantly changing, therefore calculating the variations of the formula is challenging. As flow velocity increases the resistance to flow decreases rapidly. Manning's N is often assumed to be constant within an area or a land use, but can in reality vary under different circumstances. Factors that can affect the Manning's N under natural conditions are vegetation, depending on height, distribution, density and type of vegetation. An already submerged surface may increase velocity, as the texture of the surface is reduced when surface elements are under water. Manning's N will therefore decrease as water level increases (Hessel 2002). The Manning's N is used to calculate the flow velocity (m/s) of a field, and the following equation can be used (Jetten 2002).

$$V = R^{\frac{2}{3}} * \frac{\sqrt{S}}{n} \qquad \textbf{(IV)}$$

Where: R=hydraulic radius

S= sine of the slope

n= Manning's N

The surface roughness can be described as the micro variations in the soil surface, and is a result of natural soil texture or tillage practices. The micro relief is relevant for calculating water storage on the surface, infiltration and local drain direction (Moreno et al. 2010). One of the most used statistical indexes applied to account for the surface variability is the *random roughness (rr),* which is the random standard deviation of the surface height when tillage marks and slope orientation are excluded. This can be calculated based on a pin meter, where pins of equal lengths are placed on the soil surface. The soil surface is the reproduced on the top of the pins and the standard deviations can be calculated from the measurements of the pins (Hessel 2002). The random roughness is useful to calculate the maximum depression storage in a raster based model. This is expressed as a threshold value above which the water content of a surface micro depression will overflow. The runoff is a spatial process where micro depressions are filled with water and overflow into each other. If the surface depression is full, then any excess infiltration will be overflow into a connected downstream cell. If the random roughness is high, the storage capacity of an area increases.

2.3 SOIL PROPERTIES IN HYDROLOGICAL MODELS

Soil physical properties are basic factors for defining water flow and mass transport, and are therefore fundamental within in hydrological and erosion modeling. Basic soil physical properties can often be derived from soil maps. In Norway soil maps exist only for arable land, which encompasses merely 3 % of total land use. Information on the soil characteristics of other land uses, e.g. forest is limited (Kværnø 2011). The main characteristics that can be derived from soil maps are the topsoil texture and organic matter content, additional information may also exist in the national soil survey database. However, the accuracy of the soil maps is uncertain and variability within map units is likely to occur. In Nordic regions the temporal variability of soil properties is also of high relevance due to temperature variations, freezing and thawing processes are common (Kværnø 2011).

Saturated hydraulic conductivity (K_s) describes the ease to which water can flow through a saturated porous medium, measured in meters per second. The soil water retention curve is the relationship between the soil water content and the soil water potential, measured in kilopascal (kPa). It is relevant in hydrological modeling because it defines the water remaining in the soil and infiltration rate in the soil profile. These properties are often problematic to incorporate into models because they are highly variable and can diverge largely even over small distances. Soil variability is highly contingent with local conditions and transferability of parameter information is therefore difficult (Kværnø 2011; Kværnø & Stolte 2012). Many models, including LISEM, are highly sensitive to K_s values and their measurement and predictions should be considered carefully (Kværnø 2011; Stolte et al. 2004). It should also be considered that the initial moisture is relevant for the transformation of precipitation into surface runoff, the evapotranspiration and the percolation into deeper soil layers. The variability of initial soil moisture occurs as a result of several factors such as heterogeneity in rainfall, topography, soil structure and vegetation (Sheikh et al. 2010). Due to difficulties in soil moisture measurements, especially in deeper layers, there is no sufficient measuring method. Therefore there is a large degree of uncertainty around soil moisture information used in models (Sheikh et al. 2010). The soil moisture content may influence the effect of vegetation measures such as grass strip as high water content will reduce the infiltration effect of the conservation.

Pedotransfer functions (PTFs) are predictive functions that can be applied to obtain further information on soil physical properties such as hydraulic conductivity and soil water retention curve (SWRC), which are often difficult and costly to measure. PTFs for these parameters can be found in various literature, functions frequently used are those by Rawls and Brakensiek (1989), Wösten et al. (1999) and Schaap et al (2001) (Kværnø & Stolte 2012). To estimate the functions input information such as texture, soil organic matter are required. Although such functions may provide calculations where there is lack of measured data, they may also contribute to the uncertainty and error of the model as they are only predictions (Kværnø 2011).

Many hydrological models are primarily developed as soil erosion models, focusing on *soil detachment and deposition*. Erosion can be modeled as the sum of particles that have been detached from the surface through splash detachment by rain drops, in addition to the erosive forces from surface runoff. Splash detachment (Ds g/s) is a function of aggregate soil stability, rainfall kinetic energy and the depth of the surface water and can be calculated by:

$$\boldsymbol{Ds = \left(\frac{2.82}{As} \times Ke \times e^{(-1.48 \times h)} + 2.96\right) \times P \times A} \qquad \textbf{(V)}$$

Where: As= aggregate stability (median number of drops to decrease the aggregate by 50%)

K_e= kinetic energy (J/m^2)

h= the depth of the surface water layer (mm)

P= amount of rainfall and throughfall (mm/s)

A= surface area of which the splash takes place (m^2)

For erosion from flowing water it can be assumed that amount of sediment in the water flow is suspended, and is thus a function of the energy of the flow. Both soil detachment by flowing water (D_f kg/s) and deposition during flow (D_p kg/s) can be calculated from the following equation in a raster based model:

$$\boldsymbol{D = Y \times (T_c - C) \times V_s \times w \times dx} \qquad \textbf{(VI)}$$

Where: Y= efficiency factor

T_c = transport capacity of flow (kg/m3)

C = concentration of sediment in flow (kg/m3)

V_s = Velocity at which particles settle (m/s)

W= width of flow (m)

D_x = the grid cell size

When the concentration is higher than transport capacity and deposition takes place, the efficiency factor is 1. If not the efficiency factor can be expressed by the soil cohesion (Coh, kPa):

$$\boldsymbol{Y = \frac{1}{0.89 + 0.56 \times Coh}} \qquad \textbf{(VII)}$$

The amount of suspended sediment in the overland flow is the erosion minus the deposition (Kværnø 2011).

The *soil cohesion* describes the shear stress a soil can sustain under conditions of overland flow and is useful to estimate the soil erosion in an area. It is also possible to include cohesion exerted by plant roots, to account for the additional effect of vegetation on soil strength (Jetten 2002).

Infiltration is the process of water entering into the soil. In many models infiltration in the soil profile can be simulating using empirical or physically based equations according to the data available and objective of the simulation. Examples of empirically based calculations are the Holtan and Green and Ampt equations for one or two layers (Jetten 2002). The SWATRE model is a physically based model which is a finite difference solution to the Richardson equation, combining the Darcy equation and the continuity equation. For this kind of model, initial moisture content, porosity and K_s are required.

$$\boldsymbol{\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} K(h)[\frac{\partial h}{\partial z} + 1]} \qquad \textbf{(VIII)}$$

Where: θ = Volumetric water content (m3/m3)

T= time (seconds)

Z= height above reference level (meters)

K= hydraulic conductivity (m/s)

h= matric potential (m)

2.4 RAINFALL IN HYDROLOGICAL MODELS

Rainfall data is most often added to models based on rainfall intensity and time scale, the accuracy of measurement and choice of timescale are essential for the model output (McMillan et al. 2011). In many models, such as LISEM, rain gauges can be identified in order to spatially distribute the rainfall input, in which case adequate placement and size of rain gauges is essential for accurate model representation. In models it is reflected that rainfall intensity which is larger than the infiltration capacity will produce overland flow. This can be done by adding the rainfall to the current estimated water height in an area. However, runoff of rain water does not occur horizontally in the terrain of the catchment, thus to the slope angle of the terrain must also be considered. In a raster based model the water height for each cell per time step can be calculated using the equation IX, assuming that the slope is in one direction (Jetten 2002).

$$\boldsymbol{h = h_i + P * \cos(a)} \qquad \textbf{(IX)}$$

Where: h= water height

h_i= initial water height (mm)

P= rainfall depth in the time step (mm)

a= slope angle

3 METHOD

3.1 SITE DESCRIPTION: SKUTERUD CATCHMENT

The Skuterud catchment (450ha) is located 30 km southeast of Oslo, in the municipalities of Ås and Ski (*Figure 3.1*). Based on average annual temperatures, the yearly mean in the area is 5.3 C˚, the maximum being 16.1 C˚ in July, and the minimum of - 4.8 C˚ occurring in January/February. During winter, temperature may fluctuate and periods of freezing and thawing are common. Annual precipitation lies at 785 mm, peaking in October which has a mean precipitation of 100 mm (Kværnø 2011; Oygarden et al. 2003). The main channel "Skuterudbekken" runs to the north and discharges in Østensjøvannet, north of the catchment. The elevation in the catchment varies between 92 – 150 m.a.s.l., averaging at 120 m.a.s.l. In the central area near the main channel the topography is relatively level, whilst it undulates more in the western and eastern parts of the catchment. The average gradient of the slopes is 5.2 %, the steepest gradients are found on the east side (up to 30%) where the slopes are also shorter (Engebretsen et al. 2008). The geology is defined mainly by fine marine deposits, although gravel and stone also appear. The predominating soils in the central part of the catchment are marine silt loam and silty clay loam, whilst in the fringes of the arable land and the forest area, coarser marine shore deposits transpire. A marginal moraine ridge ("Raet"), deposited during the ice cap melting of the last glaciation, transects the catchment (Kværnø 2011; Oygarden et al. 2003).

The area comprises of several land uses; agriculture, peri-urban areas and forest. About 60% (270ha) of the land is arable land, 31% is forest, 2% is forested peatland and 7 % is peri-urban construction. The main crops grown on the arable land are cereals sown during spring and winter. According to tree maps from the Norwegian Forest and Landscape institute, approximately 50% of the forest area is covered by coniferous forest such as spruce and pine, 30% is deciduous forest and the remaining is mixed deciduous- coniferous. In the forested peatland the dominating tree type is pine (Kværnø 2011; Kværnø & Stolte 2012).

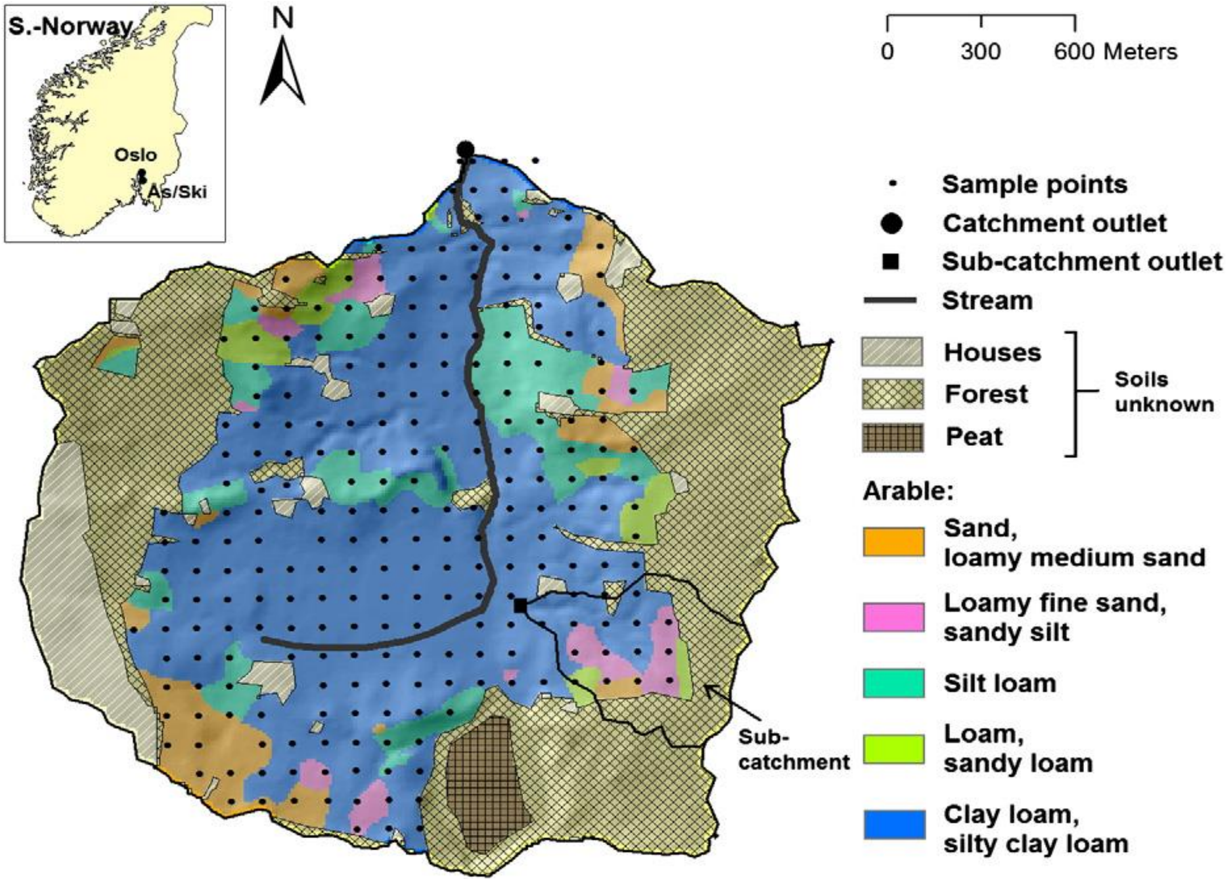

Figure 3.1 Land use and soil map of the Skuterud catchment (Kværnø & Stolte 2012)

The map displays the land use and soil distribution in the Skuerud catchment, located in the municipalities of Ås and Ski in Southern Norway. The map also indicates the hillshade, locations where soil samples have been conducted and the outlet monitoring stations

The Skuterud catchment is a part of the Agricultural Environmental Monitoring Programme in Norway (JOVA) which aims to research the effect of different agricultural production systems on erosion and nutrient losses to surface water in order to inform policymakers on sustainable agricultural production. This particular site is considered representative as an agricultural area on marine deposits concentrating on cereal crop production in southern Norway (Kværnø 2011). Flooding and overland flow are of special concern due to its effect on a national transport infrastructure, the E18 highway between Oslo and Stockholm, which passes the outlet of the area. Monitoring of discharge and water quality by the outlet has been carried out since 1993. In 2008 the monitoring of a sub-catchment area (27ha) in the southeastern part of the catchment (See *Figure 3.1*) was initiated to observe details of surface runoff, drainage discharge, precipitation and soil water content (Kværnø 2011). The Skuterud catchment was chosen because it is one of the Exflood study areas where the LISEM model has previous been applied and extensive data of local conditions is available.

3.2 THE LISEM MODEL

3.2.1 Introduction to the LISEM model

The Limburg Soil Erosion Model, LISEM, simulates infiltration, overland flow and erosion on a catchment scale. It models hydrological conditions and sediment transport during and after a single rainfall event. LISEM is a process based model and the main incorporated processes are precipitation, interception, surface storage in micro-depressions, infiltration, overland and channel flow, transport capacity and soil detachment. The original development of the model is described in Box 3.1. Conservation measures that can reduce the magnitude of erosion and runoff are incorporated in the model as storage basins, grassed waterways and buffer strips. The model is built to demonstrate conditions under current land use, but also to explore various land use measures, as such it can be used for planning and conservation purposes (Kvaerno & Stolte 2012; Roo et al. 1996). The simulation produces a series of maps indicating elements such as deposition, erosion and water flow velocity in addition to hydrographs for up to three locations.

Box 3.1 The origin of LISEM:

The LISEM model was developed by the Department of Physical Geography at Utrecht University and the Soil Physics Division of the Winard Staring Centre in Wageningen, the Netherlands. The initiative for the model was within the scope of a soil erosion project that was carried out in the region of south Limburg from 1991 – 1994. The model was originally designed to model the effect of small scale conservation measures on soil loss and erosion.

The construction of the model is based on experiences with the ANSWER erosion model and the SWATRE hydrological model, and was one of the first models to be incorporated in raster geographical information system (PCRaster) (Roo et al. 1996)

LISEM is a raster based model and can simulate details of spatial patterns on a grid cell basis. The model is fully incorporated into raster geographical information system (GIS), and in practice this means that it can be operated with a GIS command structure. The integration with GIS also allows the use of remotely sensed data and makes the model applicable to sizable areas as such systems are functional in handling data for a large amount of grid cells (Roo et al. 1996).

Infiltration is one of the main processes in the model and several options are available to simulate this feature. The choice of infiltration sub-model should be based on available data and input maps. The Green & Ampt and Holton empirical equations can be used for one or two layers. The Richardson equation is physically based and uses the SWATRE sub-model to simulate the infiltration and soil water flow in the soil profile. Maps and tables with soil physical properties are then defined to describe the soil characteristics, as a 3D perspective on the area is required (Jetten 2002). For the simulations in this study the SWATRE- sub model was applied.

The input database consists of a series of maps in a PCRaster GIS format, in addition to tables (ASCII files) describing rainfall and soil profile characteristics for the SWATRE sub-model. For the simulations of this study all basic input maps and tables have been provided by Bioforsk based on the work of Kværnø (2011) and Kværnø & Stolte (2012) who have previously researched the use of the LISEM model to simulate runoff in the Skuterud area, focusing on soil properties. Parameters describing the surface characteristics have also been based on these studies, which assume values based on coniferous forest and for mature cereal. An introduction to the basic input maps and tables will be provided, for further details on the specific data collection see Kværnø (2011) and Kværnø & Stolte (2012).

3.2.2 Inputs

A minimum of 24 maps is required to run the model, depending on the input options selected. All maps can be derived from four basic maps:

- Digital elevation model (DEM): The DEM shows the terrain surface and has been derived from remote sensing images. It is crucial for the simulation because it determines the slope angle and flow direction of water (Hessel 2005).
- Land use: Describes the various land uses of a catchment area and creates the basis for calculating land cover qualities of vegetation or urban surfaces.
- Soil type: The soil maps for the model are based on maps from available from the Norwegian Forest and Landscape Institute and locally measured data within the arable land.
- Impermeable areas (roads): for the selected study area roads are not considered to be significant for runoff as they are very few within the area.

From the basic maps and a unit-table describing parameter characteristic additional input maps are produced. The various input maps are described in **Table 3.1**. The model specifics applied throughout the simulations are provided in **Box 3.2.**

Box 3.2 Model specifics:

The LISEM model used was LISEM version 1.54

Pixel size was 10*10m

Simulation time = 800 min, time step = 60 seconds

Total simulation area: 450.63 (ha)

Table 3.1 The input maps for the LISEM model

Parameter	**Name**	**Unit**	**Range**	**Description**
Catchment area	area.map	-	1	Catchment boundaries
Drainage direction	ldd.map	-	1 - 9	Local drain direction, the number of the cell represents the direction of the surface runoff
Slope gradient	grad.map	Tangent	must be > 0 and ≤ 1	Slope gradient, sine of slope angle, in the direction of the local drainage direction.
Catchment outlet	outlet.map	-	0 -3	Values 0 = background, value 1 = main outlet. Two additional outlets may be added
Rain gauges	id.map	-	1 - n	The rain gauge ID number determines the spatial distribution of rainfall input
Rainfall data	Tbl	mm/h	0 - n	Text file with rainfall time series
Plant cover	per.map	-	0 – 1	Fraction of soil covered by vegetation
Crop height	ch.map	M	0 – 30	Vegetation height
Leaf area index	lai.map	-	0 – 12	Leaf area index
Manning's n	n.map	-	0.001 – 10	Surface resistance to flow, expressed as Manning's n
Random roughness	rr.map	Cm	0.05 – 20	Standard deviation of the micro relief heights
Road width	roadwith.map	-		Width of impermeable roads where no infiltration is calculated
Aggregate stability	aggrstab.map	-		The median number of drops that decrease the aggregate state of the soil by 50 %.
Soil cohesion	coh.map	kPa		Cohesion of the soil
Root cohesion	cohadd.map	kPa		Additional cohesion to simulate the effects on plant roots on the soil depth
Median grain size	D50	mm	25 – 300	Median of the texture of the soil used to simulate the settling velocity
Drainage direction	lddchan.map		1 - 9	Local drain direction of the channel network. Pit is the same as pit in ldd.map
Channel gradient	changrad.map	-	0.0001 – 10	Gradient of channel bed
Manning's n channel	chanman.map	-	0.001 - 0.6	Resistance of low of the channel
Cohesion channel	chancoh.map	kPa	> 0.196	Cohesion of channel bed, resistance to flow erosion
Channel width	chanwidt.map	M	0 - cell width	Channel bed with in meters
Channel shape	chanside.map	-	0 – 10	Channel cross section shape . Tangent of angle between channel side and vertical
Soil profile map	profile.map	-	≥ 1	Map with profile id numbers
Soil profile table	profile.inp	-	-	Lookup file describing the soil properties of the profile map units
Initial pressure head	inithead.	Cm	0 – 100000	Positive initial matric potential of each soil layer
K- unsat tables	Tbl	cm/day		Table with soil physical data

Input maps with information of topographical, soil and land use variables required by the LISEM model in a PCRaster format

Basin characteristics: One of the main components of the model is the local drainage direction map based on the DEM map which specifies to which downstream pixel water and sediment flows (Hessel & Tenge 2008). Each cell drains into only one adjacent cell, meaning that the modeled catchment has one single outlet (defined by the outlet.map). The rain gauge map provides each cell an id number, determining the spatial distribution of the rainfall input.

Rainfall data: Rainfall is the basic driving component of the model and is provided in an ASCII file as a precipitation per time interval. In simulating an event the model generates a map using the rain gauge identification map and a time series file, resulting in a display of the spatial distribution of rain intensity for each time step (Roo et al. 1996). The precipitation accumulates to the current water level in the cell, also considering slope angle (grad.map). As slope angle is taken into account the water level is assumed to be lower than if the area is horizontally projected (Jetten 2002). As LISEM is a single event based model the water that is infiltrated into the soil is "lost" and it cannot reappear at the surface. For this research data input is based on a rain event that occurred on the 13th of August 2010 and a rain event of 19th of August 2008. The data for the measured precipitation was provided from a monitoring station operated by the Norwegian water and Energy directorate placed in the urban area of the catchment (Kværnø 2011). As these rain events generate a relatively small discharge in the research area, the simulation has also been done with a hypothetical rain event, where the 2010 event has been intensified *3. The rainfall distribution is presented in *Figure 3.2*.

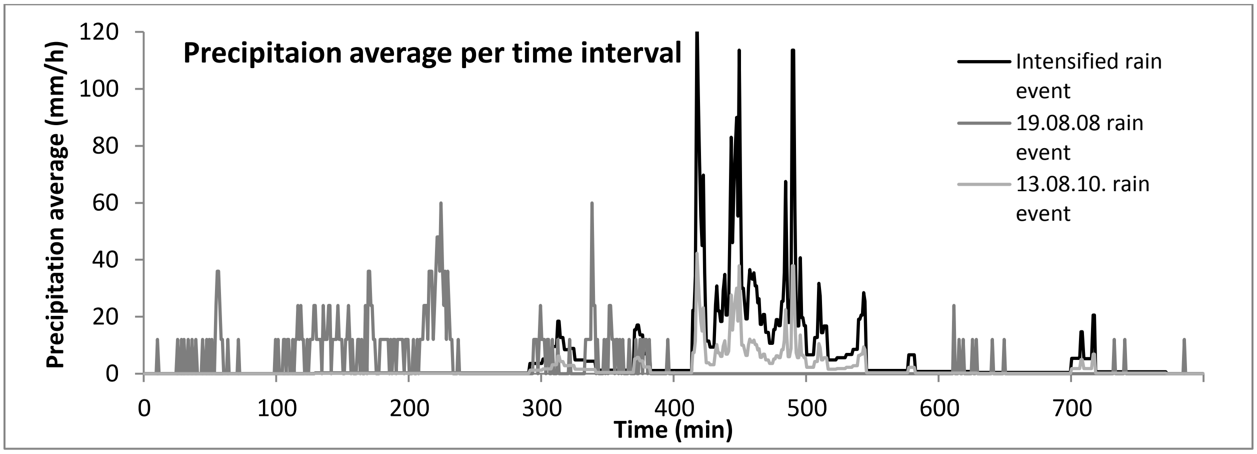

Figure 3.2 Precipitation average (mm/h) per time interval for the three simulated rain events

Land use: Several maps describing land use cover are required to determine the overland flow and canopy characteristics. Plant cover (% of a cell covered by vegetation), crop height and leaf area index describe the characteristics of the plant cover and the ability of vegetation to store rain water. By subtracting infiltration and surface storage the net runoff is calculated if a certain storage threshold is reached (Hessel 2002; Hessel 2005; Jetten 2002). The vegetation parameters were assumed from general calculated values for coniferous forest and mature cereal (Kværnø 2011). Flow velocity in the catchment is calculated based on the Manning's N equation. The roughness of the soil surface (rr.map) will also affect the overland flow, and as a function of this only part of the water will drain from the cell. The parameters applied are presented in **Table 3.2**.

Table 3.2 Applied input values in LISEM

Parameter	Urban	Forest	Peat	Arable	Grass strip	Stream
Fraction of soil covered by vegetation (per)	0.7	0.9	0.9	1	1	-
Crop height (ch)	0.2	7	7	0.7	0.2	-
Leaf area index (LAI)	1.5	6	4	2.5	6	-
Manning's N (n)	2.4	1.2	1.2	0.6	1.2	-
Random Roughness (rr)	0.8	3.2	3.2	0.9	1	-
Aggregate stability (aggr)	66	66	190	66	66	-
Cohesion of bare soil (coh)	20	20	158	20.0	20	-
Additional cohesion by roots (cohadd)	5	10	0.01	1	1	-
Median grain size (d50)	50	50	50	50.0	50	-
Depth of topsoil	25	25	25	25	25	-
Initial pressure head	-300	-300	-300	-300	-300	-
Manning's n channel (chanman)	-	-	-	-	-	0.04
Channel cohesion (chancoh)	-	-	-	-	-	15000
Channel width (chanwidt)	-	-	-	-	-	1
Slope of channel sides	-	-	-	-	-	45

LISEM input parameters applied for the various land uses.

Channel : The channel maps describe the characteristics of the main channel flow in the catchment area, such as the drain direction and width of channel. The shape of the channel was derived from a topographical map of the area (Kværnø 2011).

Soil characteristics: The soil characteristics of the area may influence detachment and transport of soil. The aggregate stability is the median number of drops that decrease the aggregate state of the soil by 50 %. The effects of soil and root cohesion are added as separate maps. The transport capacity is a function of the overland flow velocity and the energy of the slope, the material density and the median texture of the soil (d50.map). These values were calculated based on pedotransfer functions suitable for Norwegian conditions (Kværnø 2011).

Infiltration: If empirical infiltration equations are applied the saturated hydraulic conductivity can be added as a separate map. With the SWATRE sub-model (used for this simulation) infiltration and soil water flow are calculated by the Richardson equation (Equation VIII). The profile map defines the spatial distribution of various soil zones providing those with a soil profile ID. In order for LISEM to simulate infiltration and consider heterogeneity in a vertical soil profile, soil hydraulic tables (text file format) with respective hydraulic conductivity and soil water retention for the ID number are required. These properties were calculated using PTFs. For mineral soils continuous functional parameter PTFs of Wosten et al (1999) where applied, whilst for peat areas class PTFs of Wosten et al (1999) where used (Kværnø 2011). For the peatland, forest and housed area no soil data was available. For the peatland a 100 cm soil profile, without distinction between topsoil and subsoil was assumed. For the forest and housed area the soil profile is assumed based on a geological map, with a 25 cm topsoil overlaying a 75 cm layer subsoil (Kværnø 2011).

Land use measures: For this study grass strips have been included in the model as conservation measures by incorporating them in the profile map, recognizing the grass strips with particular soil profile. Three different grass strip locations have been identified;

- 10m grass strip along the main channel. The forest areas along the channel where maintained.
- 10m grass strips along 15m contour lines. The grass strips were only implemented in the arable land area and small patches where excluded to simplify the map.

- 10m grassed waterways. The location of the grassed waterways was based on a map of gully erosion (threshold 2ha) derived from a DEM with a 2m resolution.

All grass strip areas were set to have the topsoil layer (top 25cm) as sand to account for increased infiltration, and maintained the original subsoil properties of the area. The placement of the vegetation zones in the catchment are presented in *Figure 3.3*.

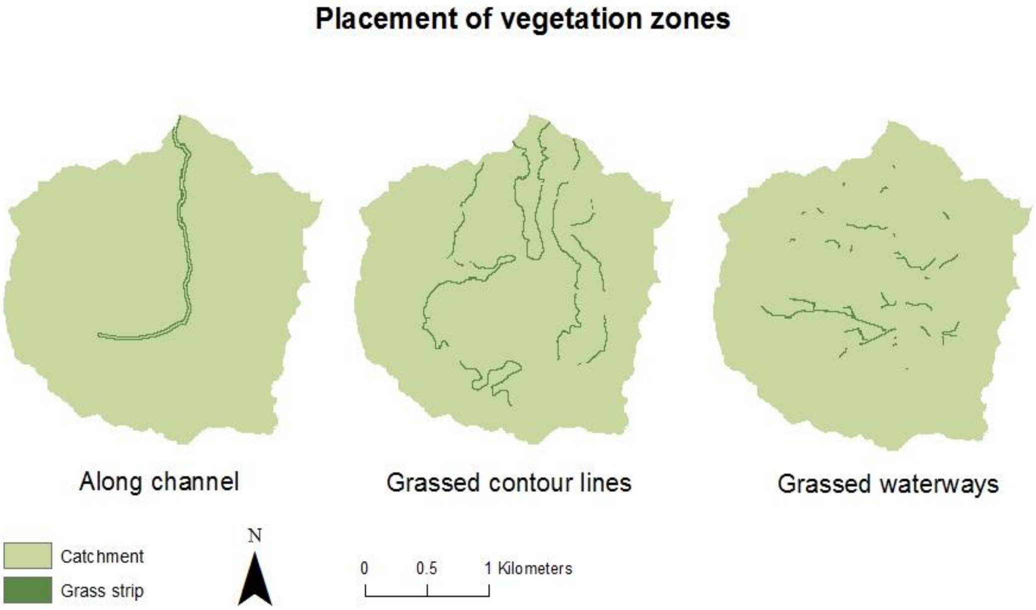

Figure 3.3 Placement of vegetative zones

The maps show the placement of the various vegetation measures within the Skuterud catchment.

3.2.3 Model considerations

In addition to general model constraints (see chapter 1.3.3) there are several specific considerations that should be underlined when using the LISEM model. Regarding the conceptual aspect of the model it should be noted that it was originally developed for the conditions of South Limburg in the Netherlands, and has mainly been calibrated and validated in regions with similar physical characteristics, such as the Skuterud area. Although the basics of the model are transferable to other areas it is not certain that the model is the accurate method of presenting the data for other areas, if physical conditions and landscape processes differ considerably. Further, there are aspects that may disguise aspects of the source data when it is implemented into the model. Each cell can only drain to another single cell, meaning that it is not possible to include local depressions within the catchment. Therefore, in a local drainage direction map confined depressions are removed to create a continuous drainage direction, concealing features that exist in the real landscape. The effect of a raster based input should also be recognized, as the spatial data is subdivided into smaller units which are assumed to be homogeneous. The pixel size may especially be influential when modeling measures. For example, a resolution of 10m*10m is suitable to model larger measures that cover a considerable area, however for smaller measures such as local drainage ditches the modeling approach is less appropriate. The output of the simulation will depend on both the grid cell size and time step length. The grid cell size will mainly depend on the spatial resolution of the data available, but factors such as hard-disk space and calculation time may also be taken into consideration (Hessel 2005).

3.3 SOURCES OF ERROR

3.3.1 Data source

The basic data for this study was provided by Bioforsk based on previous studies of the Skuterud catchment by Kværnø (2011) and Kværnø and Stolte (2012). Any sources of error in the data collection, editing or representation in previous work will therefor persist in this study. As underlined by Kværnø & Stolte (2012) some of the main factor for uncertainty around the data is the assumption of K_s values and the use of PTF’s to calculate properties of matric potential and soil water content. Although the source of the input parameters is based on abundant research in the area, the parameter values are based on point sample which are assumed to represent the immediate surroundings. These approximations can give inaccurate estimates of input values for unsampled locations.

3.3.2. Map projection and conversion

The basic maps that have been applied for this research are projected in a NGO 1948 projection. The map for erosion prone gullies has been derived from a satellite image and catchment shape based on a UTM zone 33 projection. After conversion to the same coordinate system, the shapes of the catchments still deviated slightly due to distinct sources. The maps were manually adjusted to best fit, yet small inaccuracies in the overlay can remain. The maps have been edited in PCRaster and ArcMap 10.1. Multiple conversions between formats and programs can lead to minor transformations and changes within the raster dataset.

4 RESULTS

The LISEM model calculates the discharge as a function of the precipitation, and a total of three precipitation events of various magnitude were simulated for the Skuterud catchment. The discharge is calculated for two points, one mid-channel measuring point located midstream in the channel and at the main outlet of the catchment. The 13.08.10 rain event generates the least amount of precipitation with 24.07 mm after 800 min. The total discharge in the catchment without measures was 75 m^3, with a peak discharge of 8 l/s as shown in **Table 4.2**. The peak time of discharge occurred after 553 min. A larger precipitation event from 19.08.08 was simulated, in which the total precipitation accumulated to 46.6 mm after 800 min. Without implemented measures, total discharge of this event accumulated to 7022 m^3 and 470 l/s (**Table 4.3**). In addition a hypothetical rain event which magnified the 2010 event times 3, was simulated to display a scenario of extreme rainfall. For the intensified event the total amount of precipitation was 72.21 mm after 800 min. The results from the simulation are displayed in **Table 4.4**, and for the background state of the catchment the total discharge was 75 467 m^3 and the peak discharge was 8 174 l/s. The peak time of discharge occurred after 538 min.

When measures where include in the catchment they were modeled as part of the arable land, with various spatial extent. The total areas of the measures and the percentage of arable land are presented in table 4.1.

Table 4.1 Area and percentage of land use measure

	Area of measure	**% of arable land**
Grass strip along channel	7.8 ha	2.9 %
Grassed contour line	19.9 ha	4.8 %
Grassed waterway	6.4 ha	2.4 %

Based on meteorological data from the measuring station at Rustadskogen, which is located within the catchment, return periods (years) have been calculated based on events from 1974 – 2002 (Noreng et al. 2012) (see Appendix A). The return period is an estimate of the time period between rain events of a certain magnitude. The precipitation data is based on total amount of rainfall after a given time interval. For the three simulated rain events the majority of the rainfall occurred within a time span of 360 min although the simulation time was 800 min. In this regard the 2010 rain event is equivalent to a 2- year frequency event, the 2008 rain to a 50 year frequency event and the hypothetical rain event surpasses the rain amount equivalent to a 100 year frequency.

4.1 CATCHMENT DISCHARGE

4.1.1 Total discharge

Table 4.2 displays the simulated discharge and surface runoff for a catchment without measures and when the various measures are incorporated under condition of the 13.08.10 rain event. Although the total discharge is relatively small, some variations between the model approaches are visible. For simulations where grass zones are added the interception is slightly reduced for all measures. The total infiltration increases to a small degree, and there is little variation between the simulations. There is no water stored in runoff and channel at the end of the runs as an adequate amount of time has passed since significant rainfall. The highest total discharge at the outlet is registered for the simulation of the catchment where no measures are modeled, and the discharge is only slightly less for the grassed contour lines (73 m^3 / -3.4 %) and grassed waterways (72 m^3/ - 4.5 %). The total discharge is considerably reduced for the simulated grass strip along channel at 61 m^3, which is a decrease of 18.7 % from the background conditions. The most noticeable variations are in the peak discharge (l/s), where the simulation without measures has a peak value of 8 l/s, whilst for grassed contour lines and grassed waterways it is reduced to 7.5 l/s and 7 l/s respectively. The results for the peak discharge with the grass strip along channel are notably lower at 5 l/s, which is a reduction of 41.2 %. Peak time of discharge varies within a range of a couple of min.

Table 4.2 Simulation results – 13.08.10 rain event

	Background values, catchment without measures	Grass strip (10m) along channel	% of change from background conditions	Grass strips (10m) along 15 m contour lines	% of change from background conditions	Grassed waterways (10m)	% of change from background conditions
Total rainfall (mm)	24.07	24.07	-	24.07	-	24.07	-
Total interception (mm)	1.65	1.63	-0.7%	1.62	-1.3%	1.64	-0.6%
Total infiltration (mm)	22.41	22.42	0.1%	22.43	0.1%	22.42	0.0%
Water in runoff + channel (mm)	0	0	0%	0	0%	0	0%
Total discharge (m^3)	75	61	-18.7%	73	-3.4%	72	-4.5%
Peak discharge (l/s)	8	5	-41.2%	7.5	-8.8%	7	-10.1%
Peak time discharge (min)	553	555	-	553	-	554	-

Simulation results for 2010 rain event for the various measures and percentage of change from the background conditions of the catchment

Table 4.3 Simulation results - 19.08.08 rain event

	Background values, catchment without measures	Grass strip (10m) along channel	% of change from background conditions	Grass strips (10m) along 15m contour lines	% of change from background conditions	Grassed waterways (10m)	% of change from background conditions
Total rainfall (mm)	46.6	46.6	-	46.6	-	46.6	-
Total interception (mm)	1.9	1.9	0%	1.9	0%	1.9	0%
Total infiltration (mm)	42.95	43.29	0.8%	43.25	0.7%	43.21	0.6%
Water in runoff + channel (mm)	0.18	0.19	1.6%	0.18	-3.7%	0.15	-16.3%
Total discharge (m3)	7022	5463	-22.2%	5668	-19.3%	5951	-15.3%
Peak discharge (l/s)	470	377	-19.7%	383	-18.4%	386	-17.8%
Peak time discharge (min)	398	409	-	405	-	406	-

Simulation results for the 2008 rain event for the various measures and percentage of change from background conditions of the catchment

For the 2008 rain event the total interception was the same for all runs, whilst the infiltration improved with less than one percent for all simulations with measures. The total water in runoff and channel is relatively small, although there are some variations between the measures. Whereas the simulated grass strip along channel increases water in runoff, this feature is reduced with 3.7 % for grassed contour lines and as much as 16.3 % for the grassed waterways. All simulated measures effectively reduce the total discharge. Modeled grass strip along channel is the most efficient and decreases the total amount with 22.2. %, whilst grassed waterways show the least reduction, with -15.3 %. The reduction of discharge compared to background conditions (469 l/s) is also clear, as all simulated measures decrease this value with approximately 20 %. The time of peak discharge occurs at 398 min for the catchment without measures, and all runs delay the peak time with between 7 and 11 min.

The simulated discharge features under the intensified rain event are provided in **Table 4.4**. The results show that the interception and infiltration increases only slightly when measures are included in the catchment, although more than for the previous rain scenarios. There is some variation in outputs regarding water in runoff and channel, with grassed waterways having the highest increase of this quantity (+5.9 %) compared to background state. The total discharge is reduced for all simulations with measures with a similar volume, reduction ranging from 4.0 to 4.6 % from the catchment without measures. The simulation with grassed contour lines is the most effective in reducing peak discharge (l/s), diminishing the peak with 465 (l/s) and 5.7 %. Peak time of discharge is alike for all simulations with measures (544 min), which is a 6 min delay from background conditions.

Table 4.4 Simulation results- Intensified rain event

	Background values, catchment without measures	Grass strip (10m) along channel	% of change from background conditions	Grass strips (10m) along 15 m contour lines	% of change from background conditions	Grassed waterways (10m)	% of change from background conditions
Total rainfall (mm):,	72.2	72.2	-	72.2	-	72.2	-
Total interception (mm):,	2.06	2.07	0.4%	2.08	0.7%	2.07	0.4%
Total infiltration (mm):,	50.2	50.8	1.2%	50.9	1.4%	50.7	1.0%
Water in runoff + channel (mm):,	2.9	3.01	4.0%	2.93	1.1%	3.07	5.9%
Total discharge (m3):,	75 467	72 219	-4.3%	72 005	-4.6%	72 465	-4.0%
Peak discharge (l/s):,	8174	7865	-3.8%	7710	-5.7%	7820	-4.3%
Peak time discharge (min)	538	544	-	544	-	544	-

Simulation results for the intensified rain event for the various measures and percentage of change from background conditions of the catchment

Comparing the three rain scenarios there are some noticeable differences in the responses to the events. For the 2010 event there is a large variation among the simulations with measures regarding reduction of the total discharge and the peak discharge, where it is evident that modeled grass strips along channel provide the most significant reduction. Although the volume is influenced, the peak time of discharge shows little variation between the runs. The outputs of the 2008 rain event display that a large portion of the precipitation has infiltrated and there is little variation among the runs regarding infiltration volume. For this event the total amount of water in runoff and channel is reduced when including measures, however the absolute variations between the approaches are small. For the 2008 rain event the simulated measures overall reduce both total and peak discharge with a relatively high percentage. The hypothetical intensified rain event demonstrates a positive increase of the interception values when implementing grass zones, in contrast to the two other events, although the increase is marginal. In general, a smaller portion of the total rainfall is infiltrated into the soil and runs with measures increase the infiltration only slightly. The measures were overall not as effective in reducing total and peak discharge (l/s), and there is less variation between the effects of the modeled measures. It can also be noted that although the average precipitation intensity was merely 3 times larger for the intensified event than for the 2010 rain event, the total discharge that was approximately 1000 times larger.

4.1.2 Discharge hydrographs

Figure 4.1 displays the variation in discharge over time at the mid-channel measuring point and at the main outlet for the simulations based on the 2010 rain event. At the mid-channel measuring point discharge begins after the maximum intensity of rainfall, which occurs at 417 min. Discharge reaches a minor plateau at around 460 min, after which the simulations without measures, grassed contour lines and grassed waterways have a more rapid increase than grass strip along channel. All simulations peak at around 500 min, with grass strip along channels having the lowest discharge at this point. The hydrographs recede rapidly, reaching another break at approximately 550 min, from which all scenarios show similar behavior. At the main outlet, discharge for the simulations increase gradually from 400 min at an equal pace, before attaining the same plateau as displayed by the hydrographs at the mid – channel measuring point at 460 min. The discharge has two main peaks in all runs which appear at around 525 min and 555 min, although the peaks are lower and less distinct for the simulation with grass strip along channel. At the main outlet the absolute discharge values are higher than for the mid-channel measuring point, and the grass strip along channel clearly has the lowest peak discharge and an overall more even hydrograph. The early recession happens fast for the remaining simulations, before slowing down and after 600 minutes all runs appear to have an equal response

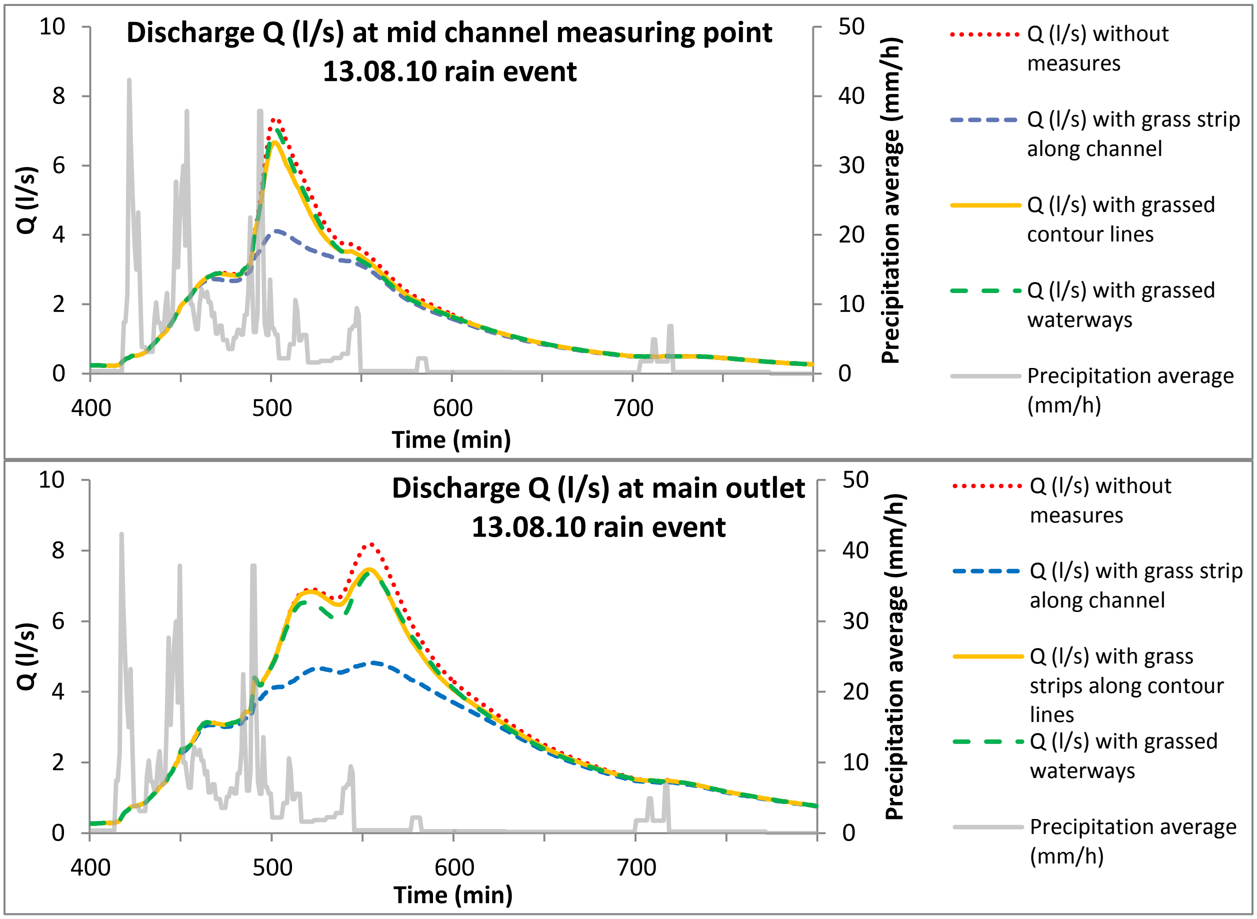

Figure 4.1 Discharge hydrographs 13.08.10 rain event

Discharge at the mid-channel measuring point and main outlet (l/s), and the precipitation average (mm/h)

In the *Figure 4.2* the discharge for the mid-channel measuring point and the main outlet during the 2008 rain event are displayed. This event has roughly the double amount of precipitation compared to the 2010 rain event, thought the rainfall has a different temporal distribution. For the mid-channel measuring point it appears that significant discharge begins after 200 min for all runs, grass strip along channel displaying the slowest escalation, before discharge diminishes for a period. At around 350 min the flux increases for all simulated runs with the background conditions showing the highest discharge values and peaking at around 390 min. The runs with measures appear to peak shortly after and all runs adapt a similar recession limb from 450 min. At the main outlet the overall discharge values are higher, and the flux shows two main peaks. During the first peak there are visible differences in the response of the various runs, with grass strip along channel having the lowest discharge and catchment without measures having the highest, the difference being some 200 l/s. For the second peak, catchment with background conditions still shows the highest values, whilst the differences between runs with measures are less distinct.

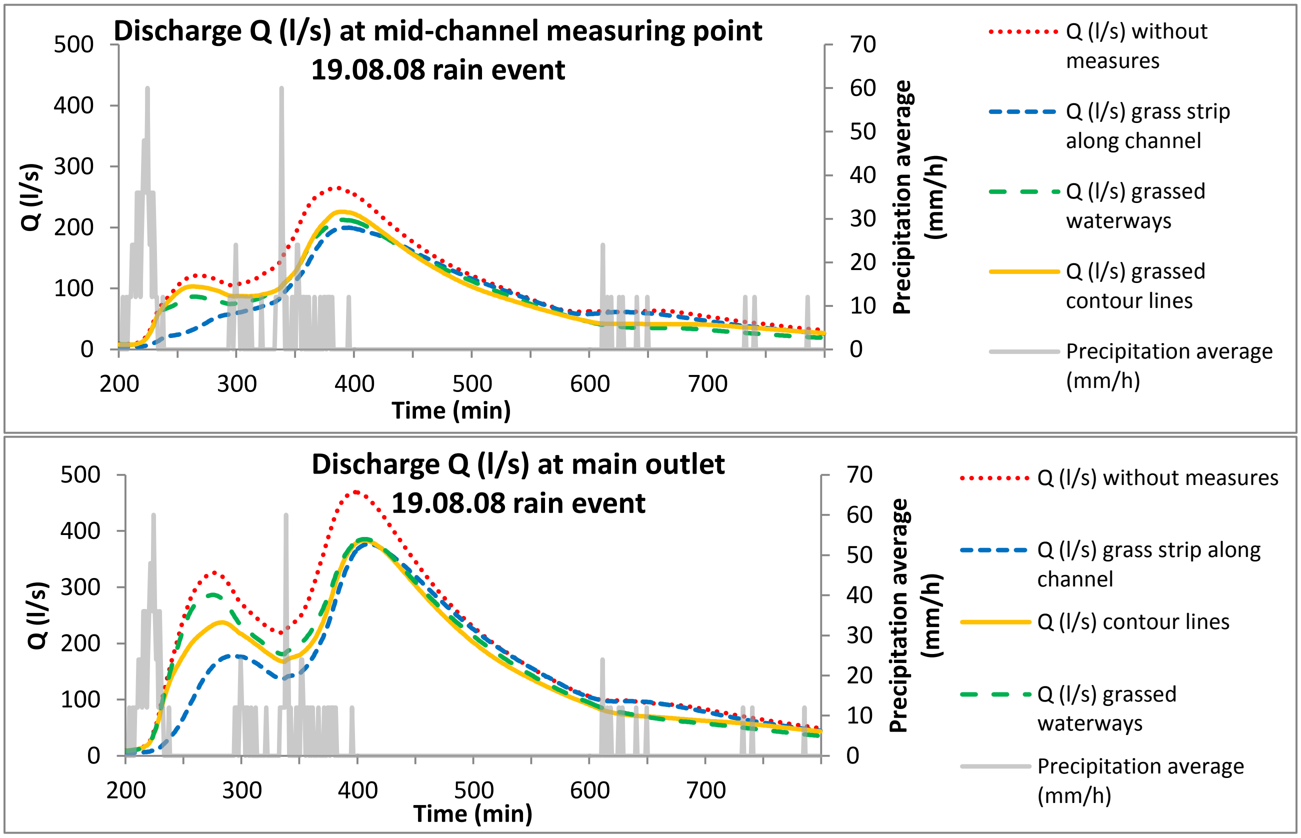

Figure 4.2 Discharge hydrographs 19.08.08 rain event

Discharge at mid-channel measuring point and main outlet (l/s), and the precipitation average (mm/h)

Generally, for simulations under conditions of the intensified rain event the variations between the runs are less distinct and all hydrographs have a similar character with a single peak and without plateaus as displayed in *Figure 4.3* At the mid-channel measuring point significant discharge appears at around 450 min after the beginning of the simulation, increasing steadily until peak is reached shortly after 500 min. From this point discharge decreases slowly at an even pace for all runs, the simulation with grassed waterways showing a slightly quicker runoff recession. The discharge hydrographs derived from the main outlet show that the discharge increases at a rapid and steady rate from 450 min until reaching peak discharge. The simulation of the catchment without implemented measures peaks first, whilst the remaining runs peak quickly afterwards with some variation in absolute discharge volume. Recession occurs after the majority of the precipitation has taken place, at an even pace. For the simulation of the grassed waterways early recession occurs slightly faster than for the remaining measures, before all hydrographs adapt a similar character.

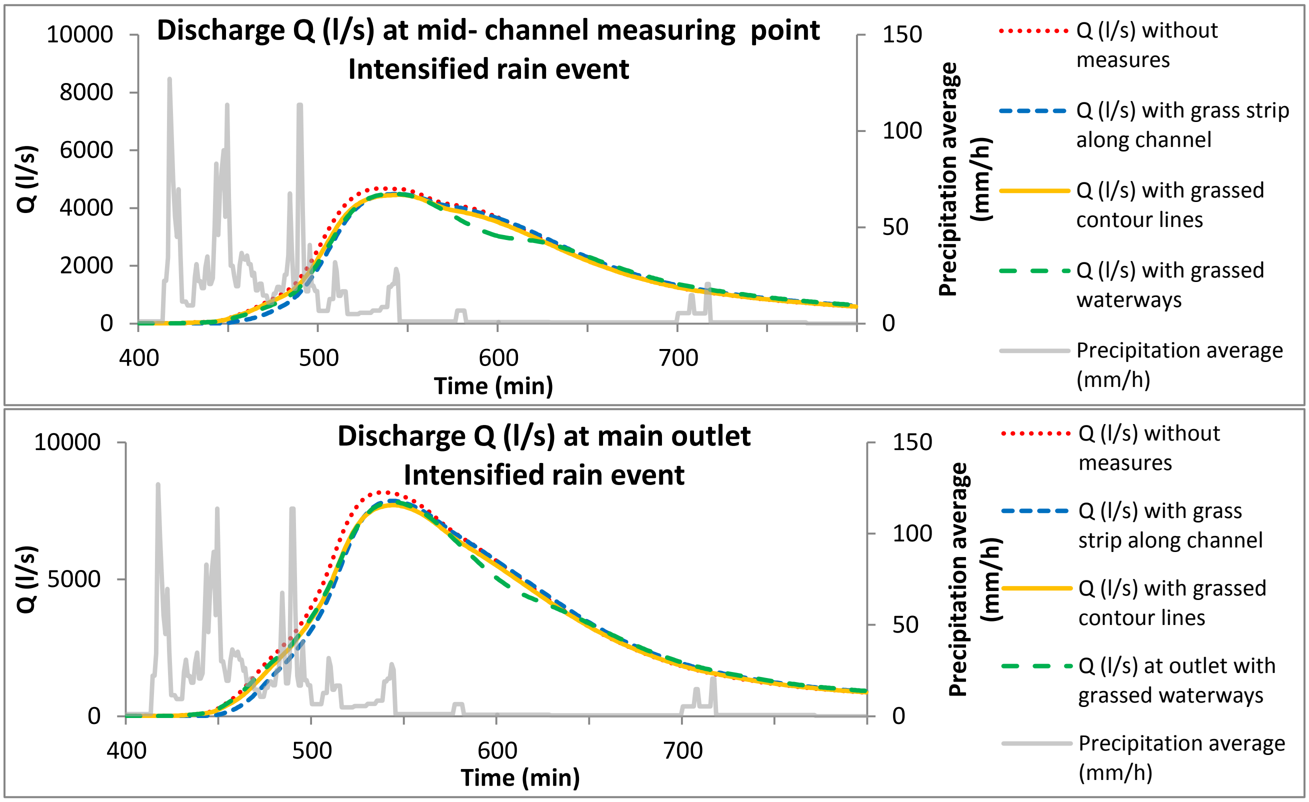

Figure 4.3 Discharge hydrographs intensified rain event

Discharge at the mid-channel measuring point and main outlet (l/s), and precipitation average (mm/h).

4.2 SOIL LOSS

The simulated soil loss and deposition are highly dependent on velocity of overland flow and stream power, and as such are expected to reflect the flow characteristics of the catchment. Detachment and deposition patterns thus indicate the spatial variation of flow in the modeled terrain.

4.2.1 Total soil loss

The total simulated soil loss for the 2010 rain event was minor due to small total runoff and will therefore not presented or discussed further. LISEM simulates erosion by rainfall and detachment by overland flow and flow in the channel. **Table 4.5** displays the soil loss features of the 2008 rain event. The simulated measures reduce the splash detachment only slightly, showing little variation in the effect between the different approaches. The differences in flow detachment among the simulated measures are especially evident. Whilst the simulation with grass strip along channel does not reduce the detachment by flow on land, the grassed waterways reduces the detachment with 9.8% and the grassed contour lines with as much as 27.5% (about 9 ton) compared to the catchment without measures. These two measures are also modeled as the most efficient in reducing deposition, although the relative reduction is smaller. Suspended sediment on land increases for all simulations with measures, though to a small degree. The soil loss features of the channel are given by the flow detachment, deposition and suspended sediment in channel and the simulated grass strip along channel is the most effective in reducing flow detachment and deposition. Grassed waterways appears to be the most effective in reducing suspended material within the channel, however the absolute values of the suspended material are relatively small, therefore significant change in fraction may be an actual small proportion. The total soil loss is displayed in the *Figure 4.4*. From the figure it can be noted that the total soil loss is quite little and that the comparative differences are small in absolute amounts.

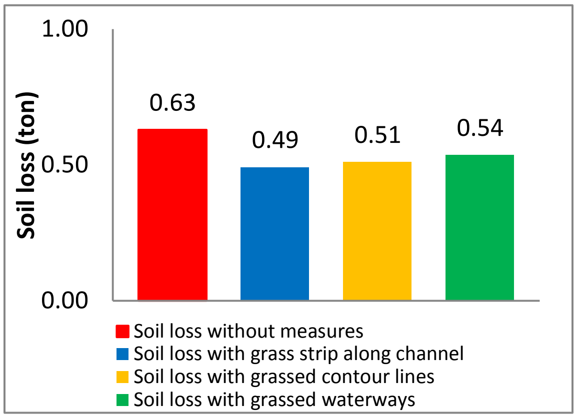

Figure 4.4 Total simulated soil loss 19.08.08 rain event

Table 4.5 Simulated soil loss -19.08.08 rain event

	Background values , catchment without measures	Grass strip (10m) along channel	% of change from background conditions	Grass strips (10m) along 15 m contour lines	% of change from background conditions	Grassed waterways (10m)	% of change from background conditions
Splash detachment on land (ton)	151	149	-1.3%	148	-2.2%	149	-1.1%
Flow detachment on land (ton)	32	32	0.0%	23	-27.5%	29	-9.8%
Deposition on land (ton)	-176	-174	-1.1%	-164	-6.9%	-172	-2.8%
Suspended sediment on land (ton)	6.2	6.2	1.4%	6.3	2.5%	6.2	1.2%
Flow detachment in channel (ton)	2.5	2.3	-11.4%	2.4	-7.5%	2.3	-7.9%
Deposition in channel (ton)	-1.9	-1.8	-8.0%	-1.8	-3.9%	-1.8	-5.7%
Suspended sediment in channel (ton)	0.01	0.01	-3.0%	0.01	-2.8%	0.01	-15.6%
Total soil loss (ton)	0.63	0.49	-21.8%	0.51	-18.8%	0.54	-14.7%
Average soil loss (kg/ha)	1.4	1.1	-21.8%	1.1	-18.8%	1.2	-14.7%

The table displays the simulated soil loss for the 2008 rain event for the various measures and the percentage of change from background conditions. Deposition is given in negative value

Table 4.6 presents the simulated soil loss features for the intensified rain event. Splash detachment on land is almost unaffected when including simulated measures, indicating that the implemented vegetation zones have little influence on this feature. Both flow detachment and deposition on land display variations between the simulated runs, with the grassed contour lines expressing the most significant reduction in detachment from the original catchment. As grassed contour lines show the least soil detachment on land, this measure also generates the lowest deposition. The suspended sediment (erosion minus the deposition), is almost unchanged when simulating with measures, denoting that including measures has little impact on this property. Regarding the channel properties, the simulation of grass strip along channel shows the largest reduction of flow detachment, deposition and suspended sediment from the background conditions. For this run the deposition of sediment in channel is reduced by as much as 27.4 %. Total soil loss is reduced for all simulations with measures, and the reduction varies from 24 ton to 31 ton, grass strip along channel having the highest reduction with 26.7% and grassed waterways having the lowest with 7. 2 %. In general, the soil loss for this precipitation event is high, therefore the differences between the measures is considerable in absolute values.

Table 4.6 Simulated soil loss - Intensified rain event

	Background values, catchment without measures	Grass strip (10m) along channel	% of change from background conditions	Grass strips (10m) along 15 m contour lines	% of change from background conditions	Grassed waterways (10m)	% of change from background conditions
Splash detachment on land (ton)	509	507	-0.4%	505	-0.7%	507	-0.4%
Flow detachment on land (ton)	1803	1773	-1.7%	1679	-6.8%	1743	-3.3%
Deposition on land (ton)	-2262	-2242	-0.9%	-2141	-5.3%	-2203	-2.6%
Suspended sediment on land (ton)	9.28	9.30	0.3%	9.25	-0.3%	9.30	0.3%
Flow detachment in channel (ton)	5.4	5.2	-3.7%	5.3	-1.8%	5.3	-1.5%
Deposition in channel (ton)	-12	-9	-27.4%	-11	-10.4%	-11	-8.1%
Suspended sediment in channel (ton)	0.05	0.04	-7.9%	0.05	-2.8%	0.05	-1.0%
Total soil loss (ton)	33	24	-26.7%	28	-14.9%	31	-7.3%
Average soil loss (kg/ha)	74	54	-26.7%	63	-14.9%	68	-7.3%

The table displays the simulated soil loss for the intensified rain event for the various measures and the percentage of change from background conditions. Deposition is given in negative value

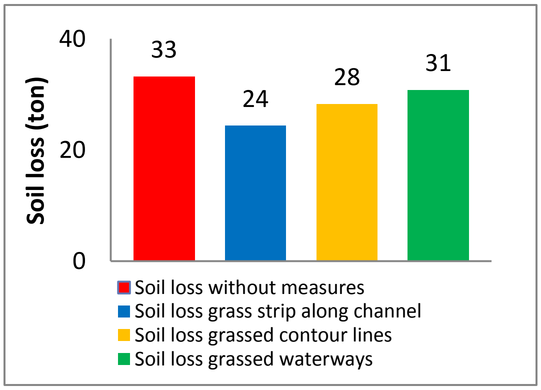

Figure 4.5 Total simulated soil loss intensified rain event

Comparing the soil loss characteristics for the two rain scenarios there are some differences in the simulated responses. For the 2008 rainfall the simulated measures have a higher impact on splash detachment and suspended sediment in comparison to when the rainfall intensifies. However, the effect of the measures on these features is relatively small for both rain scenarios. Regarding the flow detachment on land and in the channel, there is a substantial variation in the response of the runs with measures for the 2008 rain event, and although there is still some variation for the intensified rain event, the distinctions are definitely less. In contrast, the effect of the measures on deposition on land and in the channel does not appear to diminish when the total precipitation increases. For the intensified rain event the deposition in the channel is e.g. reduced with 27.4 % when grass strip along channel is modeled, whilst for the 2008 event the simulated reduction with the same measure was 8%. For both rain scenarios the effect of measures on reducing soil loss varies to some extent, though the most effective measure is grass strip along channel, whilst the least effective is grassed waterways. In general, the generated soil loss for the intensified event results in high quantities with a significant difference in the absolute difference between the measures.

4.2.2 Soil loss and deposition distribution

The soil loss and deposition distribution in the catchment is fundamentally the same for both the 2008 and the intensified rain event, though the quantities where significantly higher when the precipitation and runoff increased. In figure 4.6 the spatial distribution for these features are shown for the various measures after 800 min under the intensified rain event, where the maps display the soil loss (red) or a negative value for deposition (blue) per cell. It is evident that all runs show similar patterns and that there are only minor variations when the catchment is simulated with measures. The maps demonstrate that most areas of erosion have an adjacent deposition area downstream, suggesting that a significant portion of what is detached is deposited in immediate surroundings. The largest soil loss and deposition is calculated where water flow accumulates in the terrain in addition to the main channel. Further, loss and deposition seem to be more evident in the eastern part of the catchment where the slopes are steeper and shorter. High values for the immediate surroundings of the peat area in the southern part of the catchment are also evident. The simulation with grassed contour lines appears to have slightly reduced detachment and deposition values in the eastern part of the catchment and in some sections of the main channel.

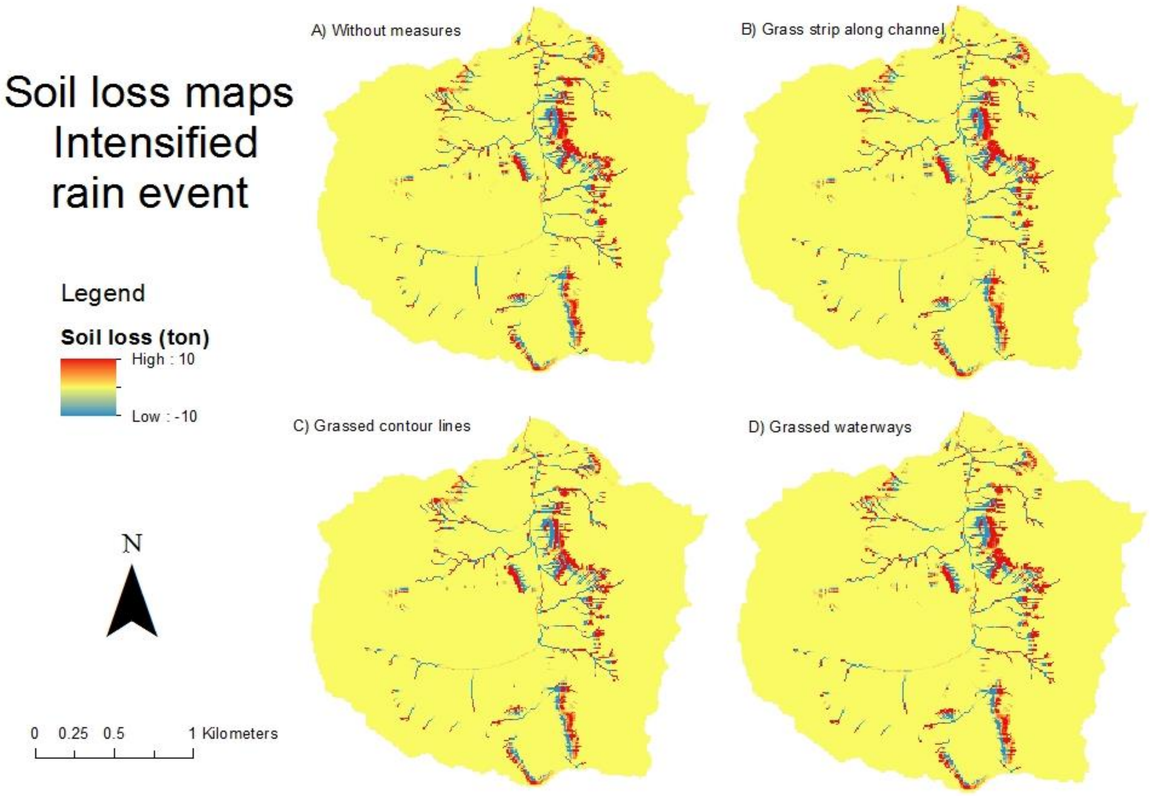

Figure 4.6 Soil loss distribution – Intensified rain event.

The maps show the soil detachment and deposition for the catchment with the various simulated measures. Areas of high soil loss are marked in red, whilst deposition is given as a negative value, indicated by blue.

4.3 FLOW VELOCITY

The LISEM model produces maps which display the average velocity of each cell per time step. For the rain events the highest velocities in the Skuterud catchment are simulated on arable land, with prominent velocity occurring in the eastern part of the catchment and towards the center, close to the main water channel. Similar to the soil loss maps, the simulations for all rain scenarios show only minor variations in velocity between the runs where vegetation zones have been introduced and then primarily in the areas of the modeled measure. Here, examples of two different time steps for the 2010 and intensified rain event are displayed to present the velocity patterns. *Figure 4.7* shows the velocity in the catchment area without measures and when a measure (grassed contour lines) is implemented for the 2010 event. Spatial variation in the flow appears at approximately 492 min, 80 min after peak rainfall. For this scenario overall velocity is generally low, although there are some indications of a higher flow rate in sections of the arable land. At 510 min the velocity is receding, though still eminent in several detached areas throughout the catchment, which seem to coincide with areas of silt loam if compared to the soil map of the catchment in *Figure 3.1*. The water velocity in the catchment with a simulated measure, here grassed contour lines, is similar although it appears that the flow rate is reduced throughout. Also, the areas of additional vegetation are apparent with a lower velocity.

Flow velocity for the simulated intensified rain event for the catchment without measures and grassed contour lines is shown in *Figure 4.8*. Overall the velocity is considerably higher. In the simulated catchment without measures a high flow rate is evident in the majority of the catchment after 492 min. Velocity appears to accumulate in natural rills and flow net defined by local drain direction, whilst the flow rate is less in the modeled peat area in comparison to the surroundings. At 510 min the velocity remains high and is not significantly reduced as was the case for the same time step in the 2010 rain event. For the simulation with grassed contour lines, the velocity appears to be somewhat reduced at 492 min in comparison to the background conditions. The vegetation zones are not as well defined as for the 2010 event, and only vaguely visible, indicating that the excess rainfall is too large for the vegetation to substantially reduce the velocity. After 510 min the velocity is not significantly reduced.

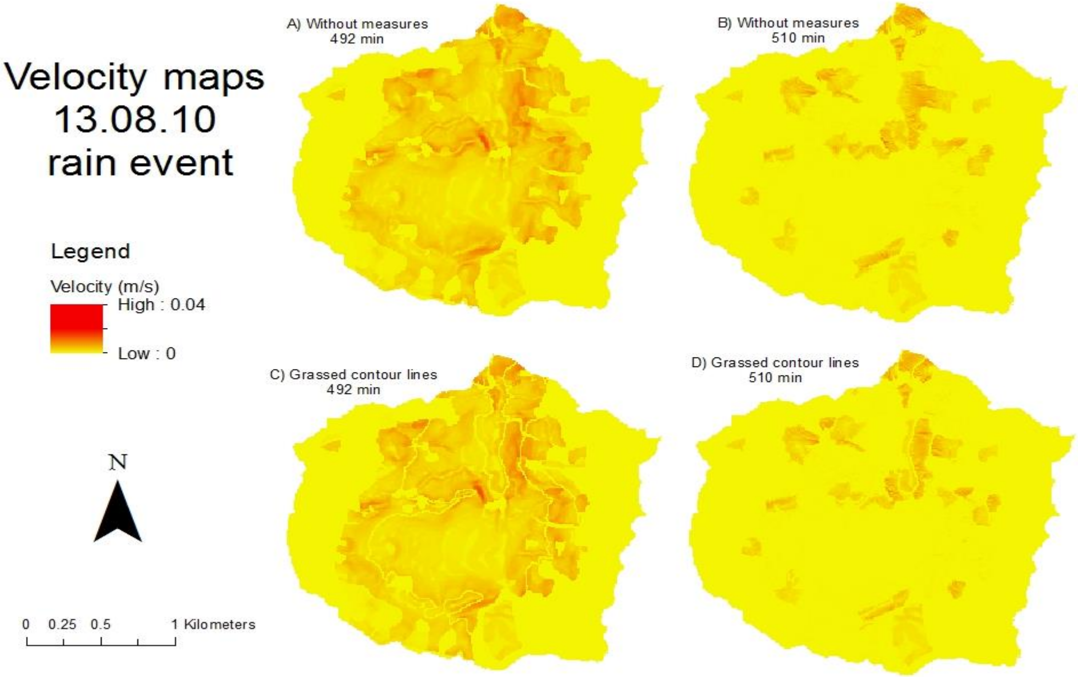

Figure 4.7 Flow velocity 2010 rain event

The maps show the flow velocity (m/s) for the catchment at two different time steps for the 13.08.10 rain event

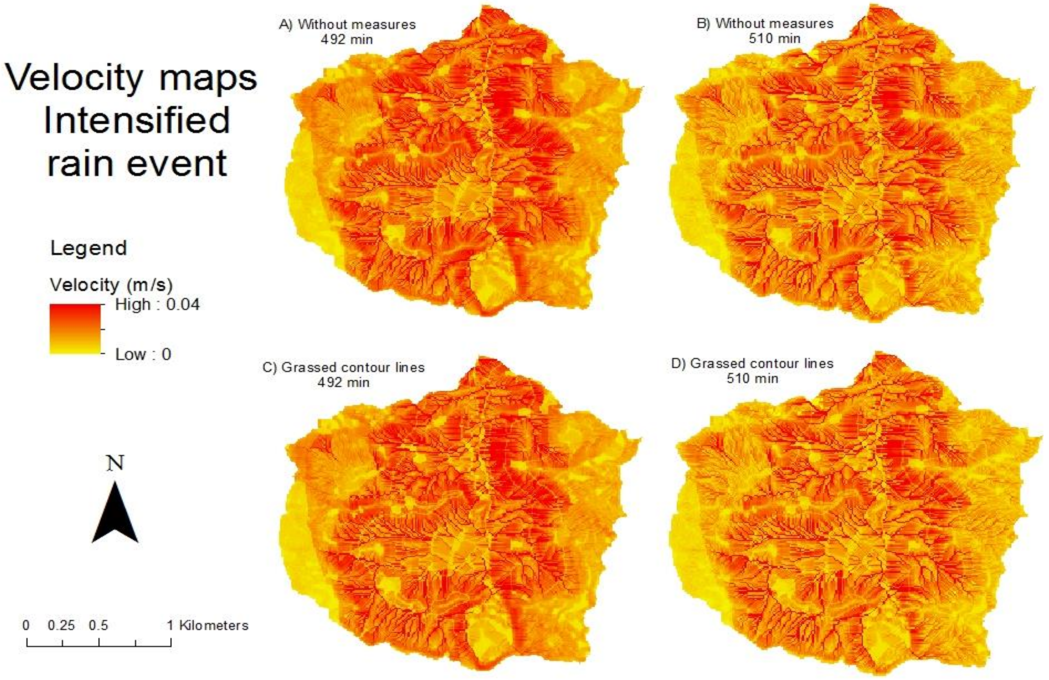

Figure 4.8 Flow velocity intensified rain event

The maps show the flow velocity (m/s) for the catchment at two different time steps for the intensified rain event

5 DISCUSSION

In this section the outcome of the model simulations will be discussed. In the first part of the chapter (section 5.1. and 5.2) the specific research questions will be in focus. The effect of the altered input parameters and spatial extent of the measures will be examined. Further (in section 5.3 and 5.4), the applicability of the model to the natural catchment and future perspectives for the model are highlighted.

5.1 EFFECT OF CHANGE IN INPUT PARAMETERS

5.1.1 Vegetation

The change in vegetation parameters can potentially affect the calculated interception and the splash erosion in the model. For all simulations with measures vegetation was altered so that grass zones obtained values that enhanced the water storage capacity of the canopy. For the 2010 rain event, the interception was slightly reduced for all runs with measures, diminishing the most for the grassed contour lines. For the 2008 event the interception appears the same for all simulations, whilst it increases slightly for runs with measures under conditions of intensified rain.

In the model, the cumulative interception can be influenced by altering the LAI value and/or the percentage of vegetation cover. The percentage of cover for arable land is from the background conditions estimated to be 100%, and therefore it can be assumed that the difference in interception is a result only of the altered LAI in the vegetation zone. Based on the theoretical framework it is expected that a higher LAI will increase the overall interception values, however for two of the simulated rain events this does not occur. It therefore appears that the calculation of interception is sensitive to the rain intensity values. As the total interception increases with a higher rainfall, it is likely that the modeled vegetation in the Skuterud catchment has a considerable maximum storage capacity which is not reached during simulation of smaller precipitation amounts. However, the total absolute increase of interception is at the greatest only 0.02 mm for grassed contour lines which encompass an area twice as large as the two remaining simulated measures. Thus, it seems that the effect of change in the LAI does not have a great influence on the canopy storage capacity of the given area even under extreme rain conditions.

For the simulated vegetation zones the crop height of grass is set to 0.2 m, whilst the average crop height of the arable land is estimated to be 0.7 m. For the LISEM model crop height is used to calculate the rainfall kinetic energy and hence the splash erosion. Looking at the simulated soil loss from the 2008 and intensified rain event, the splash detachment is reduced to a certain degree when measures are included. It appears that the implemented measures have a higher relative impact on splash detachment when the rainfall is moderate, though the absolute reduced values are alike for both events. The splash detachment is calculated from the aggregate stability of the soil, rainfall kinetic energy and the depth of the surface water (equation V). As the aggregate stability is constant, the reduction in splash erosion by simulated measures is caused by change in kinetic energy and depth of the surface water layer. The kinetic energy is calculated from the rainfall intensity, which is likely to cause some difference between the two rain events. The depth of surface water in a cell is based on preceding water which has been estimated in the area, which again depends on the infiltration and the flow velocity. As such, several calculations may influence the splash detachment, and it is therefore probable that the variations in splash detachment are not a result of the change in crop height alone.

5.1.2 Surface properties

Manning's N and Random Roughness input parameters where modified in the areas of the vegetation zones and influence the surface resistance to overland flow and the flow velocity. The surface flow can be assessed based on the velocity time series maps (shown in *Figure 4.7* and *Figure 4.8*). It appears that the increase in Manning's N in the vegetation zones reduces the velocity in the vegetated area itself and potentially in the cells downstream of the measure. For simulations with grass strips along the channel the velocity can only be reduced close to the main waterway where the measure is modeled, thus the upstream velocity in the catchment is the same as for background condition. When rain intensity increases the reduced velocity in the areas of grass strips seem to be less distinct, and there is overall a high velocity in the entire area. According to the calculation for velocity (equation IV) the flow should be faster in areas where the slopes are steep. However, it appears that when the rain intensity is high there is little distinction in velocity based on terrain features. This is most likely because the wetted parameter of the area is substantial, which diminishes the influence of the slope angel. All though the simulations with measures reduce velocity, none of the simulations seem to influence the estimated time of peak discharge to large degree, which can then be assumed to be less responsive to the flow velocity in the catchment. Previous studies of LISEM show that a change in Manning's N parameter has significant influence on the result and the model is sensitive to a change in this value (Nearing et al. 2005). This can explain why a relatively small change in Manning's N has an effect on simulated velocity for all rain scenarios. At the same time it should be noted that the Manning's N often needs considerable adjustment after calibration (Fathi-Moghadam 2007; Kværnø 2011; Nearing et al. 2005), and values should therefore be applied with caution.

5.1.3 Soil properties

Infiltration: It is expected that infiltration is increased in vegetation zones due to a higher soil stability, reduced velocity and water absorption by plants and root systems (Klimakommune.no 2008; Syversen 2002; Van Dijk et al. 1996). To reflect this in the model the topsoil layer (top 25cm) of the grass zones were defined with hydraulic conductivity and soil water retention of sandy soils rather than clay, which provides a higher K_s value in grass zones. For the 2010 event the modeled soil surface has the capacity to infiltrate the majority of the rainfall, even without measures, and the total infiltration increased with only 0.01 – 0.02 mm when measures where added. For the intensified rain event a smaller share of the total rainfall is infiltrated, in comparison to the 2010 and 2008 event for all runs. For all three rain scenarios the grassed contour lines does not have a significantly higher infiltration despite the fact that the measure has almost twice the spatial extent of for grass strip along channel and grassed contour line. At the same time it is evident that the increased infiltration provided by measures is relatively small under any condition.

For all simulations aggregate stability, soil and root cohesion and initial pressure head where kept constant and where the same for the entire catchment. The soil parameters that influence the outcome, are the change hydraulic conductivity and soil water retention curve given by the hydraulic tables. Several studies of the model have concluded that the K_s is one of the parameters to which the model is most sensitive (Hessel 2002; Kværnø & Stolte 2012; Nearing et al. 2005). However, the increased infiltration provided by the change in K_s values was generally small for all rain events. It appears that the effect of the altered topsoil is greater when rainfall intensity increases, in other words the rainfall has to be considerable for the measures to show enhanced infiltration. As such it appears that the volume of water and perhaps the intensity of the precipitation influence the infiltration rate in the top soil layer. It also seems that the increased infiltration is not reflected in reduction of total and peak discharge as these properties show a significantly higher variation among the runs.

Detachment and deposition: The alterations in the input data can also indirectly influence the estimated erosion and deposition. Considering the simulated soil loss from both the 2008 and intensified rain event, grassed contour lines were the most effective in reducing flow detachment on land, followed by grassed waterways. The effect of the measures was largest when the rain intensity was moderate. Grass strips along channel provided the least reduction in flow detachment. The reduced velocity in the vegetation zones can influence the simulated capacity of detachment and deposition by flow. Grassed contour lines and grassed waterways are placed higher up in the catchment which can also reduce the velocity and flow detachment of the lower lying cells. Of the two, grassed contour lines have the largest effect, which may indicate that when the vegetation zones are spread in the catchment the size impacts the quantity of flow detachment on land. For all runs the deposition of soil on land will to a large degree depend on the detachment, as more suspended particles will allow a higher deposition.

Regarding the simulated flow properties of the channel, grass strip along channel is the most effective in reducing detachment and deposition for both rain events. Generally, runs with measures appear to have a higher effect on flow detachment for when rainfall is moderate (2008 rain event).

For the 2008 event it can be assumed that the differences in the simulated velocity upstream in the catchment influences the flow and total amount of water in the channel (and hence the wetted parameter), which presents variation in the response among the measures. Overall, detachment in the channel is reduced more than deposition, indicating that for this rain event a higher amount of the sediment is deposited in the channel itself when measures are modeled. The precipitation amount of the intensified rain event can be assumed to be sufficiently large so that the wetted parameter of the flow equals the cross sectional area of the channel for all model approaches. This may explain why the measures have little impact on flow detachment. For this precipitation event the variation among the approaches is larger when it comes to the deposition of sediment in the channel. Here grass strips along channel show a significant reduction in channel deposition, which should indicate more suspended sediment or a higher soil loss. However, the total suspended sediment is little and this is the approach that reduces the soil loss the most among the three measures. Therefore it can be assumed that the simulation computes a smaller amount of sediment that enters the channel to begin with.

It should also be considered that the variation in responses can be a result of the rainfalls differing in character. The 2008 rainfall has a more even distribution with rainfall throughout the entire simulation period, whilst substantial rainfall for the 2010 and intensified event is not registered before after 400 min. Previous studies show that runoff and erosion quantities can vary greatly depending on the character of the rain event (Hessel & Tenge 2008; Nearing et al. 2005). According to Nearing et al. (2005) the soil detachment is closely related to not only the total amount of precipitation, but also the intensity of rainfall. Increased rainfall intensity is likely to have a larger effect on soil loss, than a higher quantity of rainfall alone (Nearing et al. 2005).

5.2 SIZE AND PLACEMENT OF VEGETATIVE ZONES

5.2.1 Effect of vegetation zones on discharge

Size of vegetation zone: The grassed contour lines is the largest simulated measure and comprises of almost 5 % of the arable land, whilst the grass strip along channel and grassed waterway cover 2.9 % and 2.4 %, respectively. For the 2010 and 2008 simulated rain events, the most effective reduction of both total and peak discharge was presented by the smallest measure, grass strips along the channel. For the 2010 event it was in fact the most sizeable measure which performed the weakest in reducing total discharge.

As grassed contour lines constitute a considerable spatial distribution, it is expected that this measure should display the largest effects on increased infiltration and a lower total discharge for all simulated rain events. However, based on the results it appears that the effectiveness does not depend on size of the measure. Therefore it is likely that the calculation of flow function and drain direction are important factors that influence the effectiveness of the measures. For the intensified rain event there was little variation in the effectiveness among the measures, this is most likely because the total amount of precipitation and surface runoff is too large for the storage capacity of the measures to delay the water quantity. Overall it can be assumed that size has little influence on the simulated quantity and peak time of discharge for this catchment.

Placement of vegetation zones: Based on all runs it appears that placement rather than size is the most relevant factor when it comes to the effects of the implemented measures. As grass strips along channel is placed in the downstream area of the catchment, the majority of the catchment will have the same velocity and depth of surface water as the simulation without measures, and any influence on the runoff and sediment must occur in the area of the implemented measure. However, this measure appears to have a great effect on the reduction of discharge for both the 2010 and 2008 rain event. For these events it can appear that the quantity of water that gathers higher up in the catchment is essential for the function of the measures. For this placement, all upstream runoff will pass through grass strip cells, which is likely to contribute to the high estimated efficiency. Based on the hydrographs from the 2010 event it seems that the grass strips along channel has a higher capacity to delay surface runoff from an early stage in the simulation. For the 2008 rain event the heightened buffering capacity of the grass strip along channel diminishes after about 400 min and is then similar to the remaining measures. This presumably reflects that the initial high capacity for this measure is reached.

Both grassed contour lines and grassed waterways are placed upstream in the area and can influence the flow in a larger section of the catchment. For the 2010 rain event the grassed contour lines had the lowest relative effect on reducing both the total discharge and the peak discharge. For this approach it emerges that not all upslope runoff passes through vegetation zone grid cells, which might influence the ability of this measure to influence the outcome. Looking at the hydrographs for the 2008 rain event, it appears that there is some difference in response at the mid - channel measuring point and the main outlet, and grassed contour lines are more effective in influencing discharge at the main outlet than at the mid channel measuring point. This is most likely because the measure is spatially concentrated close to the main outlet, which can cause this effect. Here the grassed contour lines also display a higher effectiveness early on in the rain event, with possible higher available buffering capacity before rain intensity accumulates. During intensified rain conditions, the grassed contour lines have the highest effect on peak discharge of the three measures, though only slightly. The grassed waterways perform relatively similar to the grassed contour lines for all rain events, though slightly less effective. It is possible that this slight difference may be a result of the variance in spatial extent rather than placement of the measure.

Relating to the peak time of discharge, there is some, although little variation between the measures for the various runs. For the 2010 rain event there is a large variation in the quantity of peak discharge, however it appears that this does not affect the peak time greatly as a 40 % reduction in discharge only reduces the peak time with 2 min. Although the 2008 event shows some further variation this is also within a time span of only 11 min. The grass strip along channel shows the largest delay, which is likely to be related to the reduced total discharge. Here the variation in time may be linked to rainfall characteristic, as precipitation early in the event influences the water level in the catchment from an early stage. For the intensified rain event all runs give the same peak time of discharge, as the effect of the measures on discharge is similar. In general, the model shows little variation in peak time of discharge, and it appears this attribute is not highly sensitive to the change of input data under the given conditions.

5.2.2 Effect of vegetation zones on soil detachment and deposition

For the 2008 rain event there are large variations in the responses between the measures when it comes to the flow detachment. Grass strip along channel does not present any reduction in the flow detachment on land, yet it is the measure which reduces the total soil loss the most. In the simulation with grassed contour lines the flow detachment on land is reduced significantly with the measure, however the total soil loss in the catchment is higher than for the grass strip along channel.

Overall, it is expected that the simulated detachment and soil loss reflect the discharge characteristics because the competence of the detachment and deposition is highly related to the energy expended by the flow. Therefore it can be assumed that simulations which generate a higher discharge have a higher potential soil loss. However, looking at the simulated soil loss properties there are some evident variations both between the modeled measures and the intensity of the rain event. For grass strip along channel it appears that all reduction of detachment occurs in the channel, and it can therefore seem that the soil loss in the waterway is the most significant. The high effect of the grassed contour lines on the flow detachment on land is most likely because the feature disrupts the flow field and reduces accumulated velocity.

Under the conditions of intensified rain the results display that the splash detachment and suspended sediment on land show little difference for all runs when vegetation zones are entered. In general, the measures display a variation in the responses to the remaining soil characteristics although the general amount of precipitation and runoff is high. The modeled grass strip along channel causes a reduction in the total soil loss by 26.7 % in comparison to the background catchment. Comparing this to the total discharge which was only reduced by 4.3%, it appears that the grass strip along channel reduces the velocity close to and in the channel, though the quantity of water flow remains high. The catchment with grassed contour lines shows a relatively high reduction in flow detachment and deposition on land, and has some effect on the deposition in the channel. Although the effect of this measure on the total soil loss is smaller than for the grass strip along channel, it still displays a 15 % reduction in comparison the catchment without measures. When altering the properties of the contour lines it appears that soil loss is reduced upstream in the model area, in addition to the channel. The approach with grassed waterway shows the smallest reduction in total soil loss during both rain events, though influences properties of soil detachment on both land and in the channel. The variations in soil loss characteristics among the approaches are generally high, and can possibly be explained by the complexity of the simulation process related to soil detachment and deposition. The sediment characteristics depend on the water discharge, in addition to other factors such as transport capacity, bulk density and soil cohesion. The simulation of erosion and deposition is also complex as the same sediment can be eroded and deposited several times during the simulation time.

5.3 MODEL’S APPLICABILITY TO NATURAL CONDITIONS

5.3.1 Input data

As established by numerous studies, the LISEM model requires a large amount of input data which is often challenging to measure and/or estimate (Kværnø 2011; Sheikh et al. 2010; Takken et al. 1999). Both the quality and quantity of such data is essential for the model performance, and application of input values should be reasonably evaluated in the modeling. For an area such as the Skuterud catchment extensive data collection has been carried out on soil physical properties and flow functions. Nevertheless, there are still several assumptions made for the soil and vegetation properties, especially in urban and forest areas, which are potentially inaccurate. For example the soil properties for the forest area, comprising of 33%, of the catchment, is for this study based on national soil maps rather than field investigations. Errors or inaccuracies derived from this source may greatly influence the result. Inadequate input data can affect the model performance and over or underestimate the runoff discharge and soil loss.

5.3.2 Model design

The raster based approach and the grid cell size are important factors that influence the model prediction. The processes are based on the characteristics of the individual cells, which define the totality of flow functions. Within the model it can be assumed that the runoff and sediment is uniformly distributed within the grid cells. However, given natural conditions this is rarely the case, as sediments and flow alter soil and vegetation surface and form natural accumulation and micro depressions, which guide the surface flow. The spatial variability in the field has e.g. been investigated by (Takken et al. 1999), which found that after an extreme event, clear patterns of rills, erosion and depositions were present in the field. Such natural formations can potentially cause buildup of sediment and reduce the function of the vegetation zone. Also, previous sediment deposition and accumulation which might be significant for the flow pattern is not considered as this is a single-event process based model. The grid resolution will also influence the model outcome. It defines the average slope in an area and can affect both the velocity and the time span for which infiltration can occur. As the LISEM simulation is based on a larger grid cell size (here 10*10 m) micro relief and highly local condition are not accounted for in the model, but can potentially influence the effectiveness of the real implemented vegetation zones.

5.3.3 Calibration

For hydrological models in general, calibration is important to ensure the predictive quality of the model. Calibration is commonly done using data from the catchment outlet, however attention to validation based on spatial variation within the catchment is increasing (Hessel 2002; Takken et al. 1999). The main purpose of the calibration is to adjust the estimation of the total discharge, peak discharge and time of peak. Calibration carried out on the LISEM model by Hessel (2002) for a Loess plateau in China showed that calibration gave different results depending on the input rainfall data (Hessel 2002). Other calibration of the model show that the adjustment of K_S values and

Manning’s N were necessary for improving the predictions (Hessel 2002; Kværnø 2011; Nearing et al. 2005). It should therefore be considered that the model is highly calibration-dependent in order to provide accurate estimates.

For the Skuterud catchment the model has only been calibrated for the surface runoff of the sub-catchment area for the August 2010 rain event. The parameters were assumed to be applicable to the entire catchment area (Kværnø 2011). Nevertheless, the surface runoff in the catchment is likely to be influenced by various dynamics and highly local conditions, and it is probable that measurement for the catchment as a whole would lead to different calibration factors. The design of the model challenges the calibration of the results for a real rain event in the entire catchment. The measurement of discharge at the outlet would not practically include water flow in rills and gullies, and therefore wrongly estimate the total discharge of the catchment.

5.4 USE OF THE MODEL AND FUTURE PERSPECTIVES

The uncertainty regarding the validity of the simulations to natural conditions limit the practical application for modeling land use measures at this stage. Nevertheless, the experimental modeling can provide increased understanding of model processes which creates the basis for further model development. For the model to be useful as tool in the context of land use planning there is a need for further study of the effects of various land use measures within a catchment. This requires knowledge on the estimating correct input parameters for the various measures, in addition to the validation of their effect in a catchment. A considerable amount of the research is done on the design and placement of vegetation zones in agricultural areas, focusing on sediment trapping and nutrient runoff (E.g. Al-Wadaey et al. 2012; Dosskey et al. 2006; Syversen 2002). However, in evaluating the impact of placement and size on quantity of runoff and functions during flood scenarios, the modeling approach could benefit from additional investigation. More research is needed on calibration and measurements in catchments with conservation measures in order to understand to what degree models in general, and LISEM in particular, reflect the natural circumstances in the landscape. This requires detailed monitoring and information from the catchment which can be compared with the model output. It is therefore recommended that more sites are developed for monitoring of water flow in order to calibrate and verify runoff and erosion models in Norway.

6 CONCLUSION

Hydrological and soil erosion models can be used to examine conservation approaches that reduce negative impacts from surface runoff and flooding, and are therefore potentially a valuable tool within land use planning. For this study the LISEM model has been applied to investigate the modeling of grass zones as a conservation measure in the Skuterud catchment in Norway. Three different approaches (grass strip along channel, grassed contour lines and grassed waterways) have been simulated, under the conditions of three rain events of varying magnitude. In addition to the background conditions of the catchment without measures has been presented.

The main results from the simulations show:

- For small to moderate rain events the LISEM model indicates that a single measure downstream in the catchment along the main water channel is the most effective in reducing total discharge and peak discharge
- For small to moderate rain events it appears that placement rather than size is essential for the effect of the simulated measure
- For events with high rain intensity the effect of the simulated measures is reduced, and there is less variation among the approaches
- Flow properties respond similarly for all approaches when rain intensity increases, however there are large variations in the simulated soil loss between the approaches, indicating that the grass zones influence the velocity, even when the discharge is high

The results demonstrate some of the complexities for process based modeling when quantifying the amount of runoff within a catchment. Not only where there differences among the approaches, but there were also significant variations according to the amount of rainfall and intensity. All though there is less difference in the results when rain intensity increased, the behavior of the soil loss is more complicated, most likely due to the complex calculation of soil loss. Regarding the input factors for the conservation approaches, it appears that the change in vegetation parameters gave little effect on the surface runoff, whilst the Manning’s N factor was significant for the velocity, detachment and deposition in the catchments with measures. It appears that the most significant factor regarding the effectiveness of the simulate measures was the placement within the catchment, rather than the size of the simulated measure. At the same time it is recognized that the raster based approach influences simulated flow functions, which are not necessarily reflected under natural conditions. In order for the LISEM model to be functional as a land use planning tool , more research is needed on the validity of the estimated results, calibration methods and model development which focuses on conservation approaches.

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APPENDIX A

Return period (year) , Precipitation (mm)														
17870 ÅS - RUSTADSKOGEN														
Period: 1974 - 2002														
Number of seasons: 26										1hr	1.5hr	2hr	3hr	6hr
År	1 min.	2 min.	3 min.	5 min.	10 min.	15 min.	20 min.	30 min.	45 min.	60 min.	90 min.	120 min.	180 min.	360 min.
2	1,7	3,0	4,0	5,7	8,3	10,0	11,3	12,8	14,3	15,3	17,2	18,3	19,9	24,4
5	2,1	3,8	5,2	7,5	11,6	14,1	15,8	18,0	20,2	21,7	24,9	26,3	26,8	31,5
10	2,4	4,3	6,0	8,7	13,8	16,8	18,7	21,5	24,2	26,0	30,1	31,6	31,3	36,1
20	2,7	4,9	6,7	9,8	15,9	19,4	21,6	24,8	28,1	30,1	34,9	36,6	35,7	40,6
25	2,7	5,0	6,9	10,2	16,6	20,2	22,5	25,9	29,3	31,4	36,5	38,2	37,0	42,1
50	3,0	5,5	7,6	11,3	18,6	22,7	25,3	29,1	33,0	35,4	41,3	43,2	41,4	46,4
100	3,3	6,0	8,4	12,4	20,7	25,2	28,0	32,4	36,7	39,4	46,0	48,1	45,6	50,8
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Data is valid per 28.02.2008 © met.no														