Stormwater runoff under partially frozen conditions.

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1. Abstract

The transport infrastructure is a vital part of the society, with high capital investments. Proper management and design of this system is therefore very important. Climate changes will increase the frequency of extreme precipitation events, floods and snow melt periods experienced by the infrastructure. According to initial analysis by the Norwegian transport sector these changes will affect road maintenance, emergency planning, design of new roads and infrastructure. Increased frequency of floods is expected to cause more closed roads because of insufficient and badly maintained drainage systems. More ground frost is expected to affect the road quality and lifetime. Increased ground frost and ice formation on ground surface may also cause large increases in surface runoff during snowmelt. The ClimRunoff project recently started in Norway and couples the state of the art downscaled climatic scenarios with historic data, local hydrology models and geology. The objective is to quantify the run-off amount near roads and the applicability of current road design standards for different scenarios. Together with a risk analysis of the vulnerability of the transport infrastructure a model will be used to create guidelines for road construction with respect to run-off and drainage that can account for changes in climate. The model has been calibrated so far for a rain event in January 2008 for a study area in Norway. Preliminary results show that the LISEM model is potentially capable of dealing with discharge measurement from small agricultural catchments in Norway, but that a number of adaptations to the model have to be done.

2. Introduction

The transport infrastructure is a vital part of the society, with high capital investments, proper management and design of this system is therefore very important. Climate changes will increase the frequency of extreme precipitation events, floods and snow melt periods experienced by the infrastructure. Expected climate changes in Norway according to the Norwegian research project RegClim (e.g. Benestad and Førland, 2004) include:

- Increased temperatures, largest increases during autumn and winter
- Increased precipitation, largest increases in autumn and winter on the west coast
- Increased frequency of extreme events such as intensive rain episodes, and freeze/thaw incidents, and change in the timing of freezing and snowfall.
- Less effect on summer conditions

According to initial analysis by the Norwegian transport sector (Nasjonal Transportplan 2006- 2015, Anonymous, 2002) these changes will affect, road maintenance, emergency planning, design of new roads and infrastructure. Increased frequency of floods is expected to cause more closed roads because of insufficient and badly maintained drainage systems. More erosion on areas next to the roads is expected because of higher groundwater levels, which may cause instability of road fundaments, and also clog existing drainage systems. More ground frost is expected to affect the road quality and lifetime. Increased ground frost and ice formation on ground surface may also cause large increases in surface runoff during snowmelt (Johnsson and Lundin, 1991).
Changes in winter climatic conditions will have large effects on hydrology in general and subsequently influence the local hydrology near roads, runways and buildings causing changes in:

- Water and energy balance, which determines when liquid water is available, hence it strongly affects the melt water management at a particular location.
- Pollution risk, as the amounts and distribution of water and diffuse pollutants on the surface determine the potential for retention (degradation, adsorption and uptake by vegetation) of pollutants before melt water reaches groundwater or surface waters.

Physical processes in the soil occurring at cm^3 and m^3 scale near the surface, are important controls of the flow of meltwater and can also affect the hydrology at a catchment scale (e.g., the response time). According to e.g. Baker and Spaans (1997); French and van der Zee, (1999); Johnsson and Lundin (1991); French and Binely (2004), infiltration during snowmelt often occurs as focused recharge in local depressions on the surface. This may cause higher velocities through the unsaturated zone than during evenly distributed infiltration on the surface, hence causing less than optimal conditions for degradation of pollutants. The redistribution of meltwater can also cause extreme runoff in areas where there is normally high infiltration capacity. Hence it is important to take the dynamics of infiltration capacity into account in estimates of produced runoff from catchment areas draining towards roads. Damages for several million Norwegian kroner, have been caused by extreme storm events.

In 2007, the Bioforsk started the CLIMRUNOFF project. The project is carried out in close cooperation with Luleå University of Technology, Sweden the University of Minnesota, USA. The project is financed by the Norwegian Research Council. Main objectives of the project are to:

- Classify regions of Norway with respect to the vulnerability of road infrastructures to extreme run-off situations, with special focus on winter and spring conditions.
- Improve modeling tools for improved prediction of run-off situations near roads.
- Improve construction and dimensioning guidelines for road construction, maintenance and drainage considering possible consequences of climate change.

This paper describes the work carried out so far with emphasis on the study area, model choice, initial model results and limitations.

3. Methods

Modelling

For modelling discharge from small catchments, a number of models are available. A quick investigation has been done for a number of models. The models considered are: WATER, LISEM, SUTRA, WEPP, SWAT and COUP. None of the described models meet all defined criteria. The WATER model is capable of calculating infiltration using several methods, but the spatial scale is limited. LISEM calculates infiltration and soil loss and nutrient losses on catchment scale. The timescale is event based. However, LISEM is not capable in calculating sub-surface flow and snowmelt input. SUTRA is not able to calculate overland flow and sediment transport. WEPP is able to calculate effects of frozen soils and snowmelt. However, catchment scale is generalized by uniform hill slopes, leaving no option for field heterogeneity. The same goes for the SWAT model, where HRU's are defined, considered homogeneous. Besides this, the SWAT model is not capable in calculating rainfall events, but generalizes results on a daily basis. In the SWAT model, infiltration is based on the curve number method or Green-Ampt equation. Overland flow in the WEPP model is calculated as Hortonian flow, and sediment transport based on USLE-like empirical assumptions. A study on Norwegian catchments (Grønsten and Lundekvam, 2006) showed that the WEPP model did not produce satisfactory estimates of surface runoff and soil loss.

Given this very brief analysis and given the experience gathered with the models, first focus of the ClimRunoff project is on using the LISEM model. Assumptions are:

- flooding is event based
- no effect of subsurface flow on total discharge during an event

Consequences are that the model should be extended with (i) a snowmelt routine (ii) infiltration in freezing soils (iii) effects of drainage system should be quantified.

The LISEM model uses the Richards' equation to calculate the infiltration. A soil profile of 1 m depth is assumed, with an estimated 25 cm thick frozen layer forming the upper layer of the soil profile. The majority of the input parameters are gathered from Deelstra et al. (2005).

Study area

The model performance is initially being tested on an agricultural catchment close to Ås: the Skuterud area. The catchment is 4.5 km^2 in size, dominated by agricultural land. Part of the catchment is urban area and forest. The outlet of the area crosses the E18 near Holstad. The Skuterud area is part of the JOVA program, which for more than 10 years monitors discharge, sediment load, water quality and agricultural practices in several catchment in Norway (Bechmann et al., 1999).

Calibration

An event on January 10 2008 is used to calculate the hydrograph. This event took place after a long period of frost, resulting is a frozen top layer of the soil. Calibration of model results have been performed on measured peak discharge optimizing the saturated conductivity value of the frozen layer. The calibrated saturated conductivity value has been used to calculate the rain event from 13-16 January 2008 for validation. A view of the overland flow processes during the event on January 16, 2008 is shown in Figure 1.

Figure 1 Overland flow in the Skuterud area during the rain event on January 16, 2008.

4. Results

The event of January 10 had a total rainfall of 13 mm with a maximum rainfall intensity of about 8 mm/h. The event from 13-18 January produced 80.6 mm total rainfall, and a maximum intensity of about 15 mm/h. Results of calculations of both events are shown in Figures 2 and 3. Fig. 2 shows the calibration, where 3 different values for the saturated conductivity value are used.

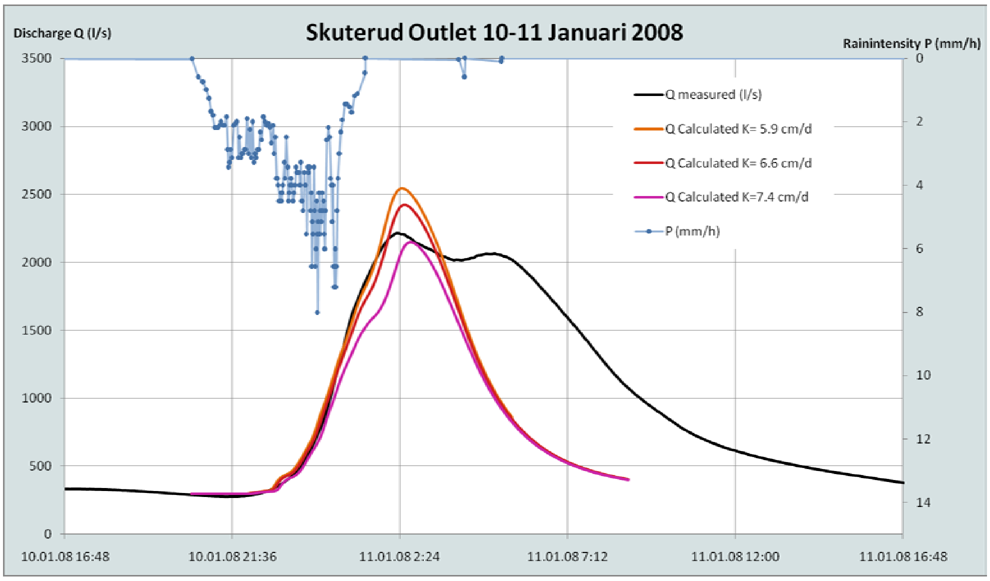

Figure 2 Measured and calculated hydrograph for the Skuterud area for a rain event on January 10, 2008. Black line is the measured hydrograph (5 min interval), calculations are done using the LISEM model for three different saturated conductivity values for the frozen top layer.

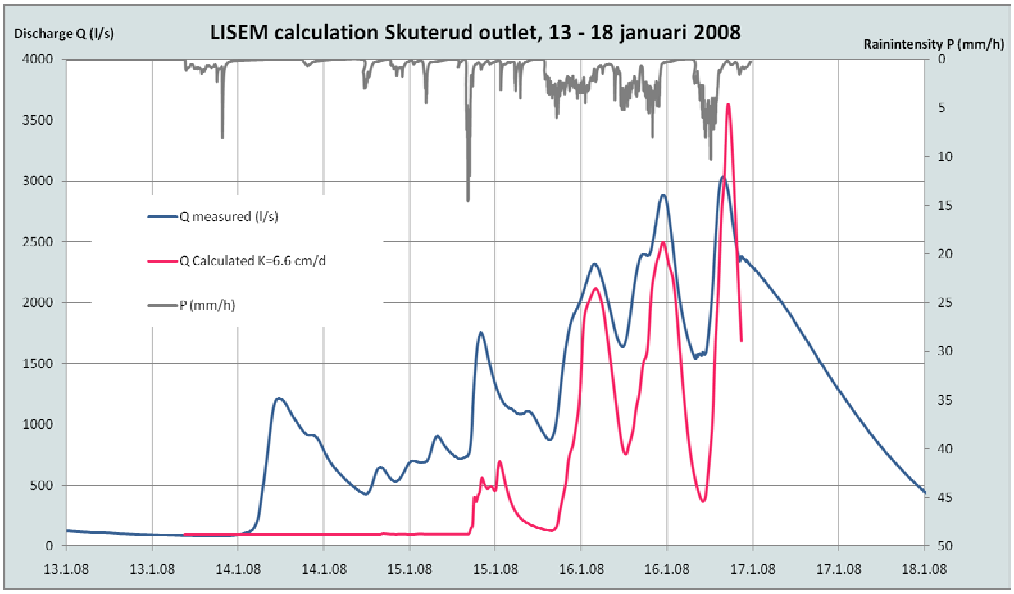

Figure 3 Measured and calculated hydrograph for the Skuterud area for a rain event on January 13-16, 2008. Blue line is the measured hydrograph (5 min interval), calculations are done using the LISEM model.

5. Conclusion and discussion

Figure 2 shows a good estimate of the peak discharge. It also shows that the model is very sensitive for the saturated conductivity, as is shown before by e.g. Stolte et al. (2003). The total amount off discharge is less accurate predicted by the model. This might be explained by the snowmelt, since the area was still partly covered by snow during the rain event. This snowmelt amount is not incorporated in the input data for the model. From Fig 3, it shows that a calibrated parameter set is able to predict other events in term of peak discharge and peak time accurately. But, the first measured discharge caused by the event is not calculated by the model. This might be caused by the sub-surface drainage system on the agricultural fields. This sub-surface drainage process is not incorporated in the model, and might be the cause of the first measured discharge peak.

Conclusion from this initial survey on modelling results is that the LISEM model is potentially capable in calculating discharge from small agricultural catchments in Norway. A number of adaptations to the model have to be done to fine-tune the model for cold climate regions. Major effort will be on the quantification of snow melt; infiltration capacity of frozen layers; quantification of water through drainage systems. These modifications will be carried out in the course of the ClimRunoff project.

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