The ExFlood project: Dealing with extreme weather in small catchments

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Sammendrag

"The ExFlood project: Håndtering av ekstremvær i små nedbørfelt." Flomhendelsene på Østlandet i mai i år minner oss om nødvendigheten av å bedre forståelsen av dynamikken til vanntilførselen fra små bekker til de store elvesystemene. Hovedproblemstillingen i det nylig oppstartede Exflood prosjektet er å kartlegge og analysere virkningen av tiltak for å redusere negative konsekvenser av ekstremvær på infrastruktur i små nedbørfelt. Disse tiltakene skal videre implementeres i et arealplanleggingsverktøy. Ulike arealbruk; skog, landbruk og urbanområder, samt infrastruktur innenfor disse områdene krever ulike tiltak for å redusere negative konsekvenser. I Exflood prosjektet vil vi finne metoder som reduserer og forsinker flomtoppen slik at skader på infrastruktur unngås. Tre kommuner fra ulike klimasoner i Norge deltar i prosjektet, der skal bl.a. det nye planleggingsverktøyet testes. Et mindre nedbørfelt, der det gjøres en rekke detaljerte målinger, brukes for å studere de dynamiske prosessene som fører til flom.

Summary

The recent flooding episode in Norway from May this year shows the necessity of understanding the processes of water discharge from small tributaries feeding the larger river systems. The major objective of the recently started ExFlood project is to define and analyze measures to combat negative impact of extreme weather events on infrastructure in small watershed areas in Norway and to incorporate this in a land use planning tool. Urban, agriculture, nature, and forest areas and infrastructure elements demands different approaches concerning impacts of and opportunities for extreme

weather events. The approach of the ExFlood project is to reduce the peak flow and delay the peak time to avoid damages on infrastructure. Three municipalities from different climate regions in Norway contribute to the project where the planning tool will be tested, and an experimental catchment site is selected to conduct in depth process studies.

Introduction

The recent flooding episode in Norway from May this year shows the necessity of understanding the processes of water discharge from small tributaries feeding the larger river systems. Measures to reduce peak flow can be identified and a catchment management plan can be defined, taken all land use systems into account. Recently, the Norwegian Research Council funded project 'ExFlood' has started, focusing on a new method for flood protection caused by extreme weather in these small, tributary catchments. The major objective of the ExFlood project is to define and analyze measures to combat negative impact of extreme weather events on infrastructure in small watershed areas in Norway. The measures and their expected effects on flooding reduction will be incorporated in a land use planning tool, whereby use will be made of modeling techniques to quantify discharge from multi-functional catchments (i.e. urban, agriculture, nature, infrastructure elements etc.). In order to guarantee a successful result of the project, a strong input of stakeholders is foreseen.

Fragmented research exists within catchment scale hydrology. Urban area and peri-urban area hydrology has been subject to several researches, where measures likes swales, rain gardens, green roof tops etc. are developed to deal with rain and rain excess water. Urban risk areas for flooding and how to protect these areas have been studied (Lindholm et al., 2008). Protective measures taking flood frequencies into account include dimensioning guidelines for various types of infrastructure designs (e.g. bridges, culverts etc.). The challenge with climate change is that these frequencies will change and we don't know exactly how. Evans et al. (2004) show that effects of increasing rain intensities due to climate change are bigger than the rain intensity increase itself. They found that a 40% increase of the rain intensity increases flood volume with 100%, damage to buildings with 130% and financial damage to 200%. Boyer et al., (2010) concluded that for a Canadian tributary, projected climate changes will induce important modifications of the hydrological regime with a gradual shifting from snow to rain regime. The Norwegian flood forecasting system (NVE) is based on the combined use of river discharge measurements and the HBV model. Online measurements of discharge are used to update the parameters of the model. This method has so far been effective for predicting flooding situation in the large rivers of Norway. Since the model is not physically based and works on relatively large gridcells, it may not be applicable to predict or forecast floods in small catchments. In most cases the extreme precipitation events are very local and will not be captured by the national weather monitoring programme which is used as boundary condition in the HBV model. The runoff situation during snowmelt is highly affected by ground frost, situations with rain on melting snow with frozen ground has produced several flooding events (e.g. Holmqvist and Petterson, 2008).

Damages for several million Norwegian kroner each year caused by extreme storm events have been reported (FNH, 2009). Based on the vulnerability of infrastructures to extreme weather events today, it is anticipated that the damages to infrastructure increases due to climate change and higher frequency of extreme events. Several ongoing projects aim at dealing with the consequences of extreme weather events. Especially municipalities, the road authorities and insurance companies in Norway are active in finding solutions in urban and peri-urban areas (Leivestad et al., 2008). A number of measures are identified and tested for urban areas (Lindholm et al., 2008). An example of mitigation measures in an agricultural area in Belgium (12 ha grassed waterway and a retention dam in the thalweg) implemented after an extreme event in 2002 showed alleviation of the flooding risk in the area. Model simulations gave a peak discharge and a runoff volume reduction of more than 40% (Evrard et al, 2007). Hauge (2006) has documented similar measures in Norway.

In Connecticut (USA) multiple use of pluvial measures in an urban catchment reduced the flood peak with 78 % compared to a traditional developed area (Hood et.al, 2006). Hessel et al. (2003) illustrate the possibilities for estimating changes in erosion and flooding patterns due to land-use change by using modeling. The NorKlima funded ClimRunoff project (Stolte et al., 2009) aims at quantifying peak discharge towards road crossings to reduce flooding and road body damages. Within the Norwegian Road Authorities, the Transport og Klima program identifies the impact of climate change on infrastructure elements like bridges, road drainage systems and slope stability (Petkovic, 2008). For land use planners, these projects deliver valuable tools to plan areas for dealing with extreme weather events. The MOUSE tool calculates urban area hydrology (DHI, 2000) and is widely used in municipality land use planning projects.

In the Netherlands, the LISEM model is used to dimension and situate measures to decrease negative effects of extreme summer storms (Stolte et al., 1999). The Norwegian flood forecasting system (NVE) is based on the combined use of river discharge measurements and the HBV model (Beldring et al., 2006; Bergström, 1992). The potential for using modeling results to assess economic impact of implemented measures in a catchment has also been shown by several (e.g. Stolte et al., 2005). The tools mentioned here are either focusing on fragmented areas within a catchment or are applicable on a much larger (national) scale. To be able to identify effects of land use change, measures and climate change for a total catchment, an integrated tool should be used. This is one of the key objectives of the ExFlood project. With such a tool, land use planners are able to define the (economically) optimal measures to control the negative impacts of extreme weather events.

Urban, agriculture, nature, and forest areas and infrastructure elements demand different approaches concerning impacts of and opportunities for extreme weather events (Figure 1).

Figure 1. Illustration of different land use and the hydrological cycle in a small catchment (illustration: Karel Hulstein, Alterra, Wageningen, Netherlands).

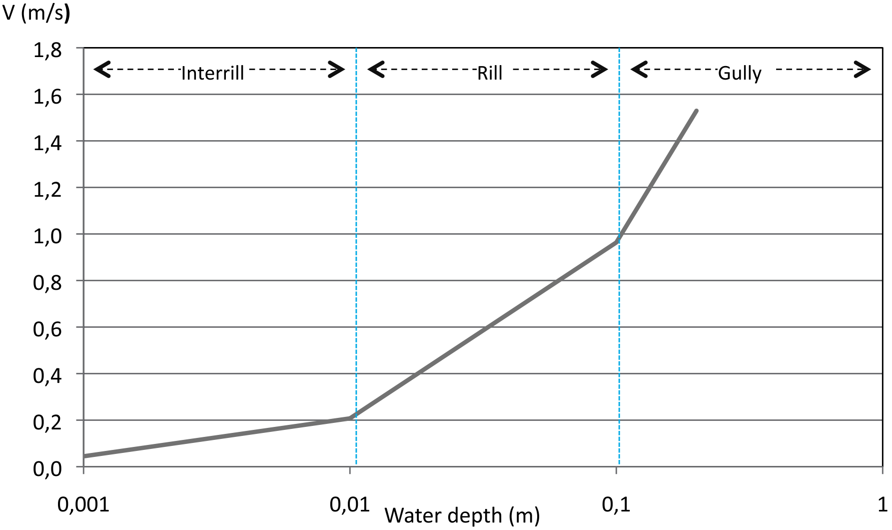

Figure 2. Flow velocities of surface water discharge for different stages in a catchment (after Van Dijck, 2000).

The approach of the ExFlood project is to reduce the peak flow to avoid flooding and with going damages on infrastructure. Flow velocity of discharge increases from a few l/s on field, to 10's of l/s from a field to 1000's l/s at catchment scale (e.g. Van Dijck, 2000) as is illustrated in Figure 2.

By applying measures at the 'low-flow' areas, flooding problems downstream will be reduced. The hypothesis is that upstream measures are more efficient in terms of reducing peak flow, and more economical, than traditional downstream flooding protective measures such as constructions near the built infrastructures. The anticipated effect of reducing peak flow on the total hydrograph using upstream measures is shown in Figure 3. As can be seen from Figure 3, the effect of the implemented measures will be (i) decreasing the peak flow amount ($Q_{max}B < Q_{max}A$) and (ii) delaying the maximum peak time (tA and tB).

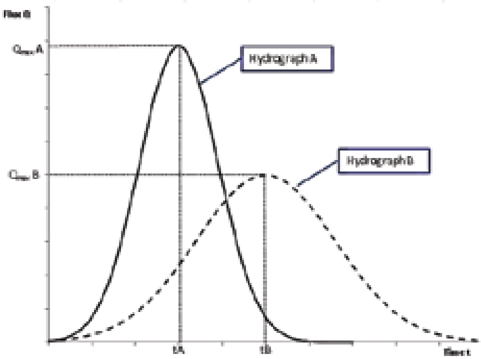

Figure 3. Hydrograph from a catchment with common land use (A) and anticipated with the use of measures to delay and decrease peak discharge (B).

Study area

For testing the approach, study areas are selected based on (i) data accessibility, (ii) existing research, (iii) reported problems with flooding and damages to infrastructure and (iv) difference in climatic regions. Three areas in Norway are selected: Fredrikstad, Sandnes and Trondheim. The areas are municipalities located near Norway's coastal areas and represent three different climatic zones according to the Norwegian institute of meteorology. A fourth catchment (Skuterud area in Ås municipality) is selected for testing modeling approaches and to study processes in detail, because of its data availability and ongoing research, Figure 4.

Figure 4. Localization of the study areas of the ExFlood project.

Fredrikstad has 72.000 inhabitants and covers an area of 283 km². It is located in southeastern Norway near the outlet of the largest river in Norway, Glomma. Hence it is prone to flooding by both river floods and flooding during extreme rain events. Marine clays in the area have given several incidents of landslides due to the presence of quick clays (Leivestad et al., 2008). An intensive rain event in September 2002 caused flooding damage to 250 buildings. Water entered the buildings from the flooded municipal sewage network. The precipitation during one day was higher than the 50 year reoccurrence – which is the dimensioning criteria for municipal drain and sewage pipes.

Sandnes municipality (62.000 inhabitants) is located in southwestern Norway. Different land use (forest, agriculture, urban and peri-urban areas) are represented and the main river through the area is Storåen. In most cases agriculture and forest areas are found upstream from urban areas and road infrastructure. Sandnes has been working in close collaboration with SINTEF and NVE on modeling of storm water runoff and evaluation of the major flooding event in 1995. A new urban area for 50.000 inhabitants is presently being planned, and the new guidelines for local handling of storm water under climate change (Veiledning i klimatilpasset overvannshåndtering, LOD, local overvannsdisponering) have been integrated in these plans (Odd A. Vagle pers. communication).

Trondheim, located in central Norway, is the 3rd largest town in Norway and the entire municipality has about 166.000 inhabitants. In 1997 local flooding was caused by 2 days of rain plus snow melting on frozen ground. During the summer of 2007 a high intensity rain event lasting 8 minutes overloaded the local sewerage network and basements were flooded (Olav Nilssen, pers. com.). A main challenge in the area is that population is expected to grow with the following increase of impermeable surface areas which also affects flooding risk. Hence both land use changes and climate change will be important for future situation in this region.

The project consortium consists of Bioforsk Soil and Environment, UMB and NVE. A reference group consists of the communities Sandnes, Trondheim and Frederikstad, Finance Norway (FNO) and the Norwegian Public Roads Administration. Furthermore, an expert group is formed consisting of researchers from KTH Stockholm, Minnesota University and NTNU Trondheim.

Measures

So far, a number of potentially interesting measures have been identified. In general, the focus is on measures that delay the peak discharge. In forested areas this can be achieved by increasing the surface roughness and/or construction of retention areas (Fig. 5).

On agricultural areas, a number of measures are available. Here as well, the focus is on increasing the surface roughness and delaying the peak time. Use can be made of grass strips, grassed waterways, buffer areas, vegetated riparian zones, wetlands restoration, re-opening of small streams etc., Figure 6.

For urban areas, measures can be used conform the three-stages approach:

Figure 5. Retention area in a forest in Norway (picture by Atle Hauge, Bioforsk).

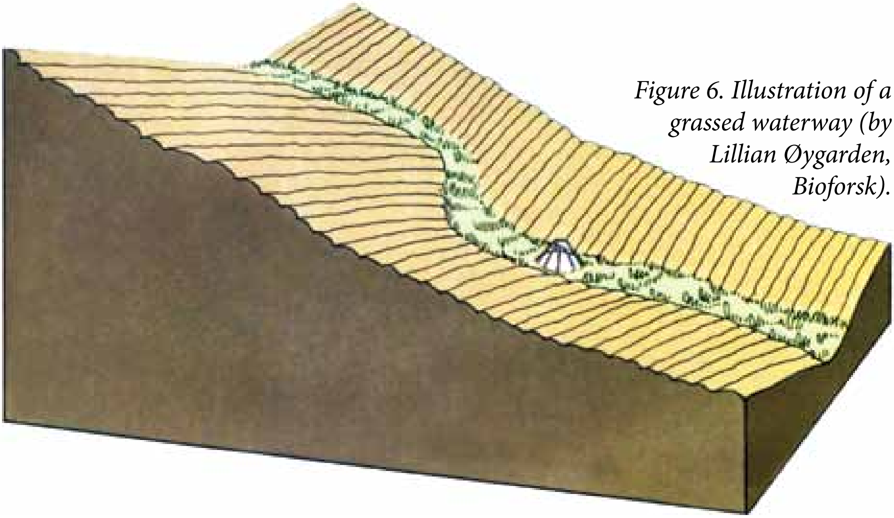

Figure 6. Illustration of a grassed waterway (by Lillian Øygarden, Bioforsk).

infiltrating small rain events locally, delay discharge from larger event and safely drain surface water access from the most extreme events. A mixture of measures is available for this, like green roofs, infiltration areas, retention buffers etc., Figure 7.

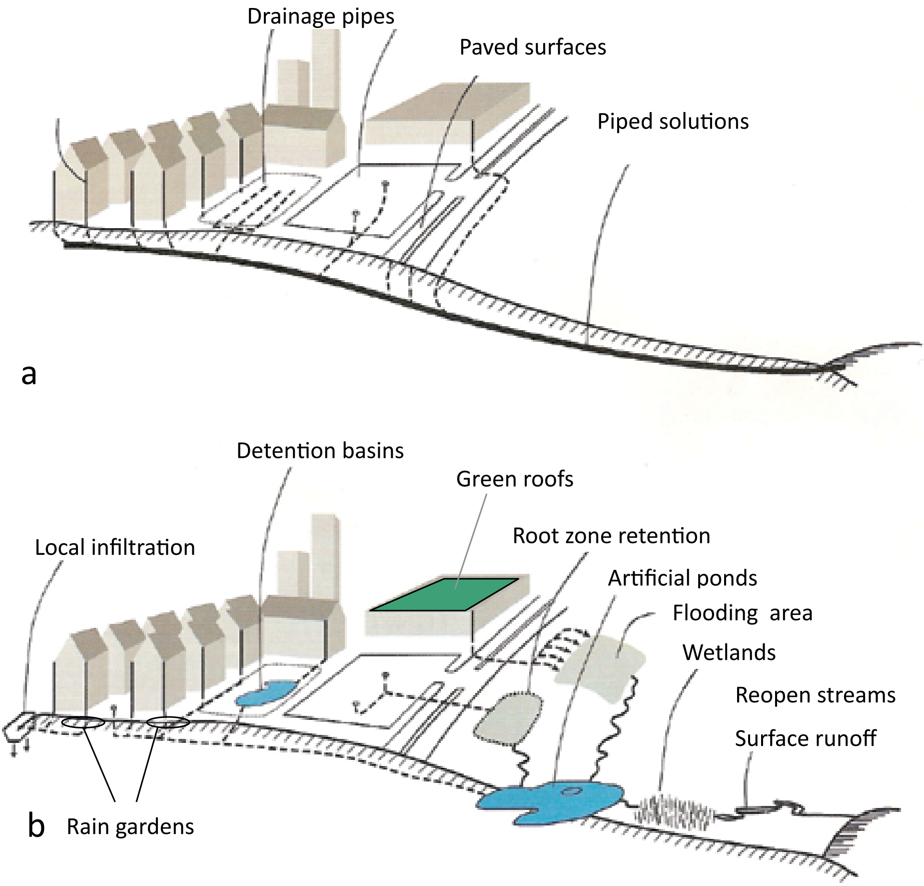

Figure 7. Overview of urban area measure: common practice (a) and alternative measures (b) (illustration by Peter Stahre, adapted by Bent Braskerud).

To analyze the effect of the total set of measures, a coupling of existing models is needed to quantify the hydrology of a catchment. Existing models for upstream urban areas (e.g. MOUSE) will be coupled with agricultural area models (e.g. LISEM) and nature and forest models (e.g. CoupModel, HBV model). The hypothesis of more effectiveness of upstream measures described above will be tested using this chain-of models approach. The complexity of this chain-of-models tool depends on the choice of basic models included. Simplification of the model will be achieved as much as possible using a sensitivity analysis. This results in a land use planning tool available for the end-users for dimensioning and localization of effective measures.

More information on the ExFlood

project is available on www.bioforsk.no/exflood.

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