Sustainable methods for peak flow control in boreal headwaters affected by peatland drainage

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Summary
Peatland drainage for forestry, agriculture and peat harvesting has affected our nation's valuable headwaters. While silvicultural drainages in particular have resulted in a remarkable increase of forest resources, also negative environmental effects are evident, including changes in runoffs, eutrophication, erosion, siltation and changes in stream bed conditions. Since 60 % of Finnish peatlands have been drained for forestry, the amount of the streams and watersheds in need of partial restoration is extensive. Traditional methods for controlling sediment loads in maintenance of ditch networks have been sedimentation ponds, overland flow fields, wetlands, ditch blockings etc. However, these protection measures appear inefficient during peak flow periods, when the majority of the suspended solid loads are generated. Sustainable methods for erosion and transport control would be to integrate peak flow control and water protection. This includes controlled flooding in peatland ditches and flood plains. Effective watershed management contains also restoration of previously disturbed headwater stream channel networks. The effects of these methods on stream flow or sediment transport locally or at catchment scale are currently studied. The oral presentation will present methods, research and preliminary results projects from Northern and Central Finland.

Key index words: hydraulics, peatland, peak flows, sediment transport, watershed and stream restoration

Introduction
Peatlands are an integral part of Finnish landscape. They function as a transition zone between upland and aquatic systems, storing and attenuating waters between these zones, and affecting waters passing through them. Peatlands have been subject to artificial drainage for centuries. In Finland, peatlands and small headwater brooks have been strongly altered by human actions, mainly due to intensive forestry, peat harvesting and agriculture. Land drainage or land reclamation has often been carried out on peatlands that compose 33 % of the Finnish landcover. The drainage has resulted in a remarkable increase of forest resources but also negative environmental effects, including changes in runoffs, eutrophication, erosion, siltation and changes in stream bed conditions. In many cases the erosion is increased due to the elevated peak runoffs resulting from improved drainage.

The mitigation of sediment from peatland drainage waters has become an important issue because ditch network maintenance work is carried out in extensive areas annually. Negative effects have been somewhat reduced by developing and implementing new practices for preventing sediment erosion from peatland drainage. These methods include sedimentation ponds, ditch breaks and overland flow fields. However, load reduction effects of these structures have been found to be insufficient, especially during extreme events (Vuori and Joensuu, 1996; Liljaniemi *et al.*, 2004). It is well known that large peak flows can transport a major part of the total suspended solids (SS) load per annum. Therefore, sustainable methods for erosion and transport control would be to integrate peak flow control and water protection.

Recently, new methods based on peak runoff control have been developed for the peatland drainage water protection (Kløve, 1997, 2000; Marttila, 2004). Structures controlling peak runoff are considered as useful and cost-effective method also in forest drainage areas (Juha Jämsen, 2006, per. comm.). These structures store storm runoff

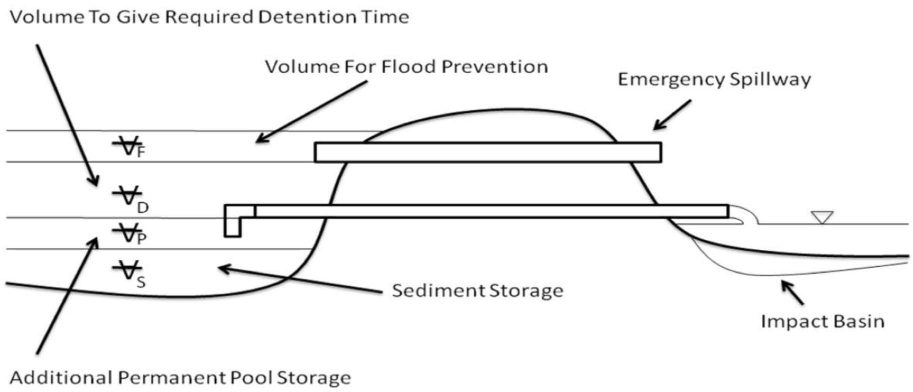

Figure 1. Illustration of studied peak runoff control dam with sediment storage, control spillway and emergency spillway. The base structure of dam is build with local material at the same time with ditch maintenance procedures to ensure cost-effective of the structure.

waters temporally to the ditch system and provide retention time for eroded sediment to settle back to the ditch bed (Fig. 1). As the peak flows are diminished, these structures may also provide better purification processes for other the water protection methods. A similar method has been successfully used in peat harvesting sites (Kløve, 1997; Kløve, 2000; Marttila, 2004; Marttila and Kløve, 2008) and in peat forest drainage in temperate environment (Amatya *et al.*, 2003); its applicability to boreal peatland forestry however needs more research evidence. Besides efficient water protection, the peak runoff control may also reduce floods and responds to the requirements of the EU Flood Directive.

Despite all water protection efforts, many headwater brooks have been altered due to intensive peatland drainage (Fig. 2). Many of these have a significant hydrological and ecological value and they receive their waters directly from the peatlands above. They are crucial in rivers and watershed areas as collectors of surface waters and retention sites of sediment and nutrient loading from the catchment area. The patterns and dynamics of sediment transport in small headwater streams also affect the status of their recipient water bodies. Thus, effective watershed management should contain also restoration of previously disturbed headwater watercourses. This includes prevention of erosion from the watershed and restoration of disturbed channel networks, providing of essential large woody debris into the channel and removal of the excess sediment material. With management of water pathways and discharges, especially peak flows can effectively influence sediment transport mechanism and retention. The overall goal in watercourse restoration research is to obtain enough knowledge so that the benefit of different structures and water protection methods can be assessed and the systems efficiently designed.

The objective of this paper is to introduce methods used to study the effect of peak flow retention on discharge and sediment transport in drained peatland forest watersheds and watercourses. The hypothesis, some preliminary results, and application of results are presented.

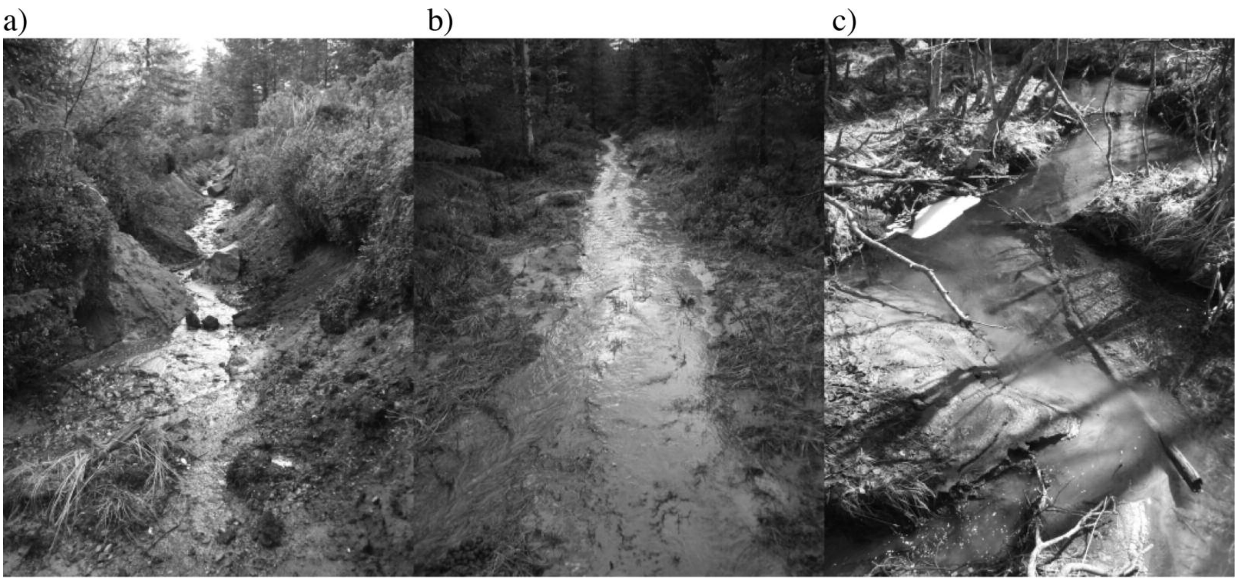

Figure 2. Uncontrolled erosion (a) from in the catchment of Nokipuro –brook. (b) Extensive silt and sand transport flows over buffer zone during storm flow period and (c) sediment are deposited to nearby Nokipuro –brook.

Materials and methods

Experimental sites

Management of peak flows and sediment load with peak runoff control in peatland forests watersheds are studied in several locations across Finland. Changes in runoff and loads are observed in Viitasaari, Central Finland. Two adjacent similar study areas with and without peak runoff control (Virkorinne and Virkosuo, 2006-2008) are compared. Moreover, five additional locations are used to further demonstrate the effect of watershed area, ditch volume, slope and other characteristics effecting design and function of the peak runoff method. Measurements in the areas started in year 2006. The watershed area varies from 10130 ha and are dominated by Scots pine (*Pinus sylvestris*) stands. The sites have been drained for forestry 2-30 years ago and ditched again in 2002-2006.

Management of sediment load and peak flows in disturbed first and second order streams were studied also in Northern Finland at Taivalkoski and Pudasjärvi areas. Three altered forest brooks (Vantunlammenoja, Nokipuro and Kylmäoja) and watershed were selected to study the effect of in-stream restoration on sediment transport mechanism and the flow regime. All stream beds were initially heavily deteriorated due to ditch erosion and sediment transport resulting in filling of the channels with sand, silt and organic sediment. Measurements in the areas started in year 2006. The sites were restored by adding wooden structures and restoring floodplains and stream bed complexity.

Measurements in the study areas

To detect the effect of peak flow control dams, the study sites contain automatic discharge, turbidity, temperature and groundwater elevation sensors. Water samples were taken every week or biweekly from the measuring stations throughout the unfrozen season. Electrical conductivity and pH are measured from the samples in the field conditions. Water samples were analyzed for suspended solids (SS), nitrate (NO_3), nitrite (NO_2), ammonium (NH_4^+), phosphate (PO_4^-), total phosphorus (Ptot) and nitrogen (Ntot) and potassium (K) in the accredited laboratory of the Environmental Research Institute of the University of Jyväskylä. The weather information provided by the nearby Finnish Meteorological Institute weather stations is used. Sediment characteristics (particle size, amount of organic material, etc.) and deposition are measured to study effect of the peak control dams on sediment transport.

Storage capacity of drainage areas was studied and measured flow values are used to calculate effect of the control dams to peak flow, sediment and nutrients retention. Simulation during different weather conditions relation to storage capacity and dam design dimensions will be modeled with *Reservoir routing* -methods and hydrological models (e.g. SWAP, GSSHA). The peak control dam structure design is studied and special attention is paid to proper sizing, durability in northern conditions and need of maintenance. Possible changes in tree growth following the construction of the peak flow control dams will be investigated with growth reconstruction methods using temporary sample plot data that will be collected in 2008.

Peatland characteristics such as saturated and unsaturated hydraulic conductivity, decomposition, etc. are measured in every study area to obtain the effect of different peat soils on function of the peak flow retention and water storage capacity of peat layers. Similar measurements are also performed from several peat forest drainage areas across Finland in cooperation with Finnish Forest Research Institute (Hökkä *et al.*, 2008) to clarify differences and effect of drainage on peat characteristics. Peat properties are needed in future modelling work.

In order to quantify the effects of watercourse restoration on discharges and sediment transport mechanism several water level sensors were installed to study sites. Sensors are placed along the brook channel to indentify effect of wooden structures on discharges and restoration of floodplains. Special attention is paid to storm events and possible retention of peak volumes. Also before/after watershed restoration situation are measured and analysed with tracer tests. Sediment sampling, analysing (particle size, amount of organic material, etc.) and bed structure measurement are performed to determinate sediment pathways and effect of restoration methods on sediment transport and brook bed structure. Watershed and brook modelling are carrying out using GSSHA and HEC-RAS -models.

Preliminary results and discussion

Preliminary results in all study sites are promising. During the two years measuring period peak flow control significantly reduced major discharge peaks and suspended solid and nutrient loads. Most effectively control dams have functioned during extreme events such as thunderstorms. Similar levels of peak flow and loading reductions have been found in previous studies (Kløve, 2000; Amatya *et al.*, 2003; Marttila, 2004). Therefore, already preliminary results indicate that the peak control dams can be used as an effective water protection method also in the peat forest drainage areas. However, the calculations are still tentative and more measurements need to be performed to study the effect of the control dams on nutrients retention, sediment settling etc. In particular measurements during snowmelt events are still needed. The control dams have not effected average peat water elevations and drainage conditions in between ditches. The studied control dam structures have been stabile and no maintenance has been needed. The structure appears to stand winter conditions. Possible effects in downstream watercourses and purification structures will appear after future modelling study.

Restoration of disturbed watercourses and its effects on erosion and sediment transport shows positive outcomes. Prevention of erosion and especially addition of wooden structures on brook channel have remarkable reformed the bed materials and structure to for a more heterogeneous bed profile. Restoration effects on flow distribution and possible peak flow retentions will unravel after modelling work. However, preliminary results indicate clearly that with restoration of flow pathways and fluvial processes cause immediately positive effects on watercourses.

Application of results

The studies will provide the necessary information on advantages of peak flow control on water protection and sediment control in drained peat forest watersheds. On these grounds information design and dimensioning recommendations will be established. Dimensioning guidelines will contain guides to build peak flow structure on different areas; according to drainage area, total watershed area, peat sediment erosion (Marttila and Kløve, 2008), slope, storage capacity, etc.

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