Historic extreme floods as input to dam safety analyses

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Abstract In a case study of the Vinstra River, a tributary of the River Gudbrandsdalslågen in Norway, hydrological data from the extreme floods in 1789 and 1938 have been collected, as well as descriptions of the consequences, in order to create reliable flood scenarios for emergency action planning for dams. HBV models (named after the abbreviation of Hydrologiska Byråns Vattenbalansavdelning/Hydrological Bureau Water Balance Section, at the Swedish Meteorological and Hydrological Institute) for several of the River Gudbrandsdalslågen sub-basins have been adapted to extreme flood simulations and data from the 1938 flood have been used for calibration. The calibrated HBV models have been used in an effort to reconstruct the 1789 flood and some preliminary results are presented.

Key words dam safety; flood scenario; historic floods; extreme flood simulation; HBV model; Norway

INTRODUCTION

Dam owners must be prepared to cope with unusual and unwanted events, which may threaten the safety of the dam construction. In order to do so, emergency action plans must be established (NVE, 1986). The objective is to document which actions to take and who is responsible for these actions in an emergency situation. In a research project at the Norwegian University of Science and Technology (NTNU) a general analysis method suitable for emergency action planning will be developed and the effects of extreme floods on the overall safety of dams will be emphasized in particular. Development of a general analysis method will probably be based on the CRIOP method, a scenario method developed for analysing risks in control centres at offshore installations (Ingstad & Bodsberg, 1990).

The Vinstra River in Oppland County, southern Norway, was chosen as a case study. The most severe flood on the regulated Vinstra River (after 1956) was a flood in October 1987, which affected most of southern and eastern Norway. Problems with flood diversion and damage to dams were reported from many dam owners for this flood (Svendsen, 1989). The estimated return period on the Vinstra River was 30 years and the maximum discharge downstream of Olstappen was 230 m³ s⁻¹. The 1987 flood was combined with a strong wind, which also caused periodic interruptions in telecommunication lines, electricity supply and road connections. On the Vinstra River
this caused problems in operating the spillway gates, monitoring reservoir water levels etc. The dam owner, Glommen's and Laagen's Water Management Association (GLB) has used the experience of the flood in 1987 as a foundation for a preliminary analysis for emergency action planning. In the NTNU project the more extreme floods in 1938 and 1789 will also be used to form scenarios for a more comprehensive analysis for emergency action planning.

VINSTRA RIVER BASIN

The Vinstra River is a tributary to the River Gudbrandsdalslågen (Lågen) with six reservoirs from Bygdin (1057 m a.s.l.) to Olstappen (668 m a.s.l.). Most of the reservoirs are situated on a mountain plateau surrounded by high peaks and glaciers to the west/north rising to about 2300 m a.s.l., except for Olstappen, which is surrounded by forest. The main dams in the Vinstra River basin have gated spillways, some in combination with a free overflow crest. The design floods ($Q_{1000}$) are $144 \text{ m}^3 \text{s}^{-1}$ at Bygdin Dam and $658 \text{ m}^3 \text{s}^{-1}$ at Olstappen Dam (Krokli, 1989). However, recent reassessment of the flood calculations indicates that the design inflows should be adjusted downward. The river reach from Olstappen Dam to the confluence with Lågen at Vinstra (225 m a.s.l.), has an average gradient of 1:60. Most of the settlements and the main road along the river are on the north side of the river valley, at a presumed safe height (200–300 m) above the river itself. The valley-sides are steep and vulnerable to landslides, though.

CONSEQUENCES OF TWO EXTREME FLOODS IN THE VINSTRA RIVER BASIN

Information about the consequences of historic extreme floods, as input to emergency action planning, is interesting even though the flood events occurred before the river was regulated. The flood of July 1789 has been reported and described in several local history books, theses, official reports and newspaper articles (e.g. Sommerfeldt, 1972) and every description tells of an incredible event. The weather conditions causing this flood have been reconstructed and described by Østmoe (1985). The prevailing weather conditions (intense rainfall combined with snowmelt and saturated soil) caused extensive landslide activity, and one landslide after another hit farmland, houses, roads and forests. Rivers and streams, eroding and partly taking new courses, sounded like roaring waterfalls and they looked like thick soup due to the debris and mud. Many people were convinced that the Day of Judgement had come. On 24 July the rain stopped and the flood soon subsided. After several months the authorities were able to get an overview of the situation. In the Vinstra River basin three people where reported dead due to landslides (of 68 fatalities in the entire county). In addition, the damage was extensive and every farm in the Vinstra River valley suffered serious losses of fields, meadows, forest and buildings. A great portion of the damage was due to landslides, erosion and flooding from small streams forcing their way down the steep valley-sides to the Vinstra River. It took many years to recover from the flood and several farms were abandoned.
In the last days of August 1938, after a period of warm and sunny days, rain combined with thunder and lightning caused a severe flood to the west and north of Gudbrandsdalen. Most descriptions of the flood damage were reported in the two neighbouring river basins to the north of Vinstra—the Sjoa and the Otta (e.g. Vågå historielag, 1988; Espelund, 1988), but there are also some references to the Vinstra River basin (e.g. Gudbrandsdalen, 1938). The main road to Olstappen was broken, telephone lines were cut and many landowners experienced damage from erosion or landslides.

**HBV SIMULATION OF THE 1789 FLOOD**

GLB has established an operational hydrological model for the entire Glomma River and Lågen River basins (41 200 km²) which is composed of several HBV models. The HBV models for the sub-basins Lalm/Otta (3195 km²), Bygdin/Vinstra (305 km²), Olstappen/Vinstra (636 km²) and Losna/Lågen (5630 km²) have been specially adapted to extreme flood simulation. Daily precipitation data from 1938 are available from several locations in the river basins as well as water level and discharge records. These data have been used for calibration of the model with good results (Fig. 1). The flood of 1938 has also been analysed in a general study of extreme floods and precipitation.
Table 1 Simulated local inflow to Lalm, Bygdin, Olstappen (Olst.) and Losna for the floods of 1789 and 1938.

<table>
<thead>
<tr>
<th>Date</th>
<th>Lalm</th>
<th>Bygdin</th>
<th>Olst.</th>
<th>Losna</th>
<th>Date</th>
<th>Lalm</th>
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</table>

(Beldring et al., 1989). In this study the return period of the 1938 flood at Lalm on the Otta River was estimated to be 100 years, even though the return period for the rainfall event was estimated to be 1000 years. The deviation is a result of the flood estimates being based on melt floods, which are much larger than rain floods in the Otta River basin.

The reconstruction of the weather conditions in 1789 (Østmoe, 1985) is qualitative and cannot be used directly to find precipitation data. Thus, probable precipitation data have been constructed and combined with snow storage from 1990, which had an extraordinary large amount of snow as was the case in 1789. Constructed precipitation distribution for the days 21–23 July 1789 are 70–75 mm, 80–100 mm and 20–25 mm, respectively. Water level registrations (carved into solid flood stones) are available as a control. At Losna the maximum flood water level recorded for the 1789 flood was 188.8 m a.s.l. corresponding to approximately 5500 m$^3$ s$^{-1}$. In comparison, the 1938 flood peaked at 184.65 m a.s.l. and 2700 m$^3$ s$^{-1}$. Table 1 shows the simulated local inflow for both years at Lalm, Bygdin, Olstappen and Losna. The estimated return period for the inflow of the 1789 flood in Vinstra River is approximately 1000 years. A flood frequency analysis based on 100 years of gauged data at Losna has resulted in a 1000-year flood discharge of approximately 3500 m$^3$ s$^{-1}$, which is in good agreement with the design flood calculations for the Vinstra River. Thus, the estimated flood discharge in 1789 of 5500 m$^3$ s$^{-1}$ corresponds to a very high return period. This may partly be explained by the extremely wet situation in the river basins in 1789 and the large areas involved, but further analysis is needed to confirm the magnitude and probability of the 1789 flood.

CONCLUSION

Reconstruction of historical floods is a challenge because of uncertain and missing data. However, by using all kinds of untraditional sources it may be possible to perform simulations of historical flood events and thus be able to create credible flood scenarios for dam safety analyses. An effort has been made to simulate the extreme flood of 1789 in the Vinstra River in Norway. Preliminary results presented in this
paper are promising. Together with the weather conditions and consequences of the 1789 flood described, these results will hopefully be a valuable contribution to future upgrading of emergency action plans for dams on the Vinstra River.

REFERENCES


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