EXTREME FRAZIL AND BOTTOM ICE FORMATION CAUSING ICE PROBLEMS IN A REGULATED RIVER

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Abstract

The watershed of Otta river is regulated for power production, with corresponding increase in winter discharge. The town Otta is located at the confluence of the tributary Otta river and the main river Lagen.

In cold winter periods there may be extreme frazil and bottom ice formation in the Otta river. Some years the ice conditions stabilizes, and there are no ice problems in the river.
Other years there is extreme frazil production followed by increased water stage in the river, causing increased ground water stage, and sometimes flooding of basements and sewage systems in Otta center. Occasionally there are also ice runs that aggravates the situation even more.

The frazil accumulates both in the tributary Otta and in the main river Lagen. There are three main parameters influencing the ice situation in the area:

- Weather conditions,
- discharge in the river,
- river bed geography.

The measure so far used to reduce the problem is to reduce the discharge. Due to long water travel distances between the reservoirs and the problem area, the reduction must be done some time in advance to be effective. In order to minimize the duration and the number of discharge reductions, and consequent power loss, knowledge of weather conditions and good weather forecasts is of vital importance.

The river bed topography undergoes natural changes with time. In addition, there has been man-made changes done that are believed to have had negative influence on the ice conditions, specifically the capacity for transporting frazil down the river. Changes are now being made in the river bed to improve the topography, and hopefully this will reduce the extent of discharge reductions.

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INTRODUCTION

Otta river, a tributary to Lagen, drains mountainous areas east of the main watershed in Norway. Before regulation the ice conditions in the river Otta were usually stabilized every winter. The lakes Breiddalsvatn and Rauddalsvatn are now regulated, and supply increase winter discharge for power generation downstream. Two contributary rivers from Aursjoen and Tesse are also developed, and cause additional increase in winter discharge. In total the winter discharge downstream Vagamo has increased from about 10 m^3/s to about 40 m^3/s by management of the reservoirs. Otta river from Eidefoss to Otta center has a fairly steep slope with whitewater most of the way. Fig. 1 gives an overall view of the Otta water course.

The water temperature at Eidefoss is, both after regulation and as before, very close to 0°C all winter. Every winter there is frazil production, large bottom ice formation, and building up of ice dams from Eidefoss to the outskirts of the town Otta. The river is not stabilized every year, and ice runs may occur. The present winter discharge is very close to the maximum acceptable for this river. Lagen has a more gentle slope and get ice covered long before Otta.

The last 2 km before the confluence with Lagen there may be ice-jamming in Otta. The frazil accumulates in the rivers Otta and Lagen in the are of the town Otta, and cause increased water levels. This in turn causes increased ground water levels, occasionally so high that basements in the area are flooded. Also in Lagen frazil accumulate and cause increased water level.

To avoid problems it has been necessary to reduce the discharge flow from the reservoirs, causing a loss of generation for the downstream power stations. There has also been changes in the river bed, both natural and man-made, which are believed to have influenced the ice situation.

The paper summarizes briefly results of measurements and experiences from this area, focused on finding measures to cope with the ice situation in the best possible way, both as regards the local community, and the potential for power generation.

PROBLEMS EXPERIENCED

The weather conditions is of major importance for the ice conditions. As there in this region may occasionally be large variations in weather between years, there may also be occasionally large variations in the ice conditions. Although the last increase in reservoir capacity took place in 1965, the first winter with major problems was that of 1980-81. After a period with temperatures above freezing at the end of January water was overflowing the ice in Lagen, causing thickening of the river ice in the following freezing period. Frazil accumulations

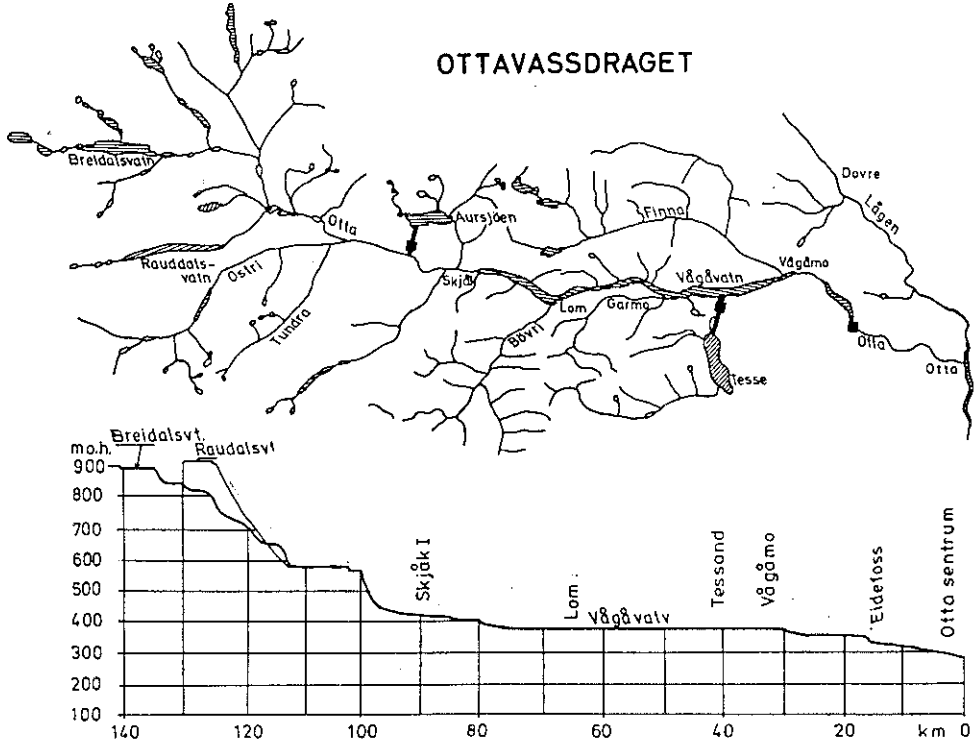

Fig. 1. Sketch of the Otta river system. Below a profile of the slope of the river.

prevented water passage under the ice. In late February the water level increased even more, due to large masses of frazil in the river, and local basements were flooded.

The discharge from the reservoirs was immediately from 42 to 28 m^3/s when this happened, but even with this substantial reduction the water level kept on rising. The water depth in some basements were 50-70 cm, and water was also flooding the fields. Most serious, however, was that the sewage system became inoperative because of ground water entrainment. At this point the regulated winter discharge was reduced was reduced further, and was in early March down to 12 m^3/s. Finally the water level reacted on the reduced discharge, and gradually receded. The discharge was then gradually increased again. One week later most basements were dry, and in April the ice started to melt.

When the problems occurred one started to investigate the ice situation, and it was found that large masses of frazil had accumulated under the river ice more than 5 km downstream Otta center. It was very hard to localize the water that seemed to flow in thin layers fairly close to the bottom.

This year the frazil formation in the river Otta was usually large, as no stable ice cover was formed. Periods with thawing might also have increased the ice accumulation downstream, by supplying loosened bottom ice and marginal ice cover. The meteorological conditions were however not very different from other years when these problems did no occur. The winter release of water had been of a slightly different pattern than previous years, with a lower release in the first part of the winter and then increasing. But this slightly different pattern is not considered to be a fully satisfactory explanation of this years problems.

Attention was also focused on recent changes in the river bed. The sewage system had recently been changed. New main sewage pipes were crossing the river some 2 km downstream the town center. The pipes were however located somewhat shallow, and to protect them a thresholdlike configuration had been established across the river. Further had some gravel excavation taken place, which possibly also had changed the river bed. These changes ere however considered to be of minor importance. It was also clear that these problems would hardly have been experienced with no winter regulation, and no increase in winter discharge.

It was therefore decided to perform further investigations to try to find the reasons for these problems, and to find better solutions. At this point the only effective measure had been to decrease the winter discharge, which for the power owner is an expensive one.

Fig. 2 indicates the main areas of ice jamming, flooding, sewer pipe crossings, and frazil accumulation.

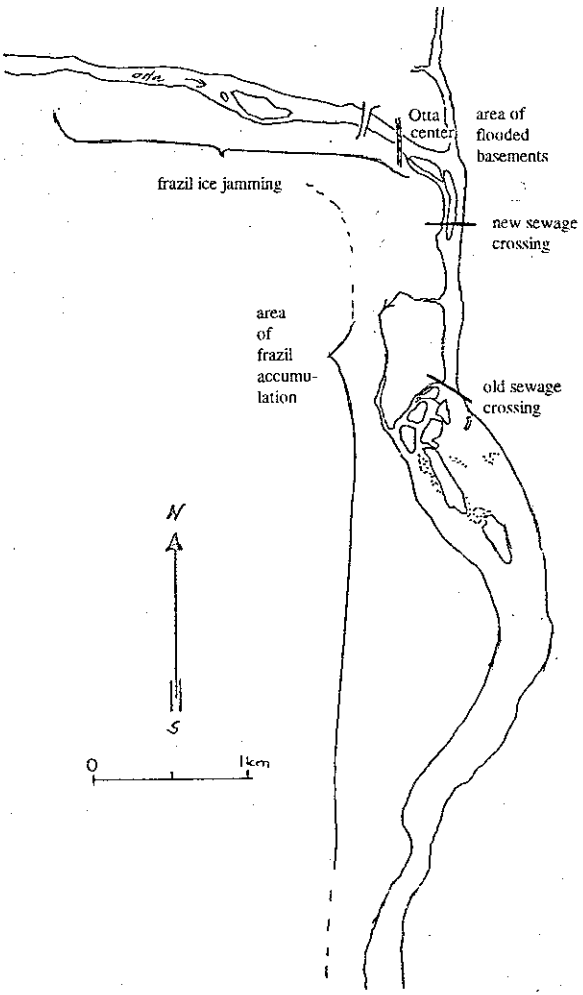

Fig 2. Sketch of the confluence area of the rivers Otta and Lågen. The slope in Lågen is fairly gentle, and the ice formation starts in this river with surface ice cover. Somewhat later an ice cover of frozen frazil will normally develop in Otta. Close to the confluence with Lågen the slope in Otta is less than higher up, but steeper than in Lågen. Throughout the winter frazil will accumulate under the ice cover both in Lågen and Otta.

INVESTIGATIONS IN THE AREA AND FURTHER DEVELOPMENT

Water discharge and water temperature had already been measured regularly before. In addition, measurements of water stages and ice observations were started when the problems occurred. It was at that time decided to focus on the following:

- Water stages for a number of places along the frazil accumulation area,
- ice profiles in the same area,
- ice observations,
- water temperature,
- discharge,
- air temperature,
- ground water level.

These measurements and observations have more or less been continually performed since then.

It became obvious that there was a close relation between rise in water level, in air temperature, and in winter discharge. As long as the river upstream was not ice covered the frazil formation increased in cold periods, and the water level could easily rise. Occasionally there was ice runs in the river, but the ice runs stop and the ice masses accumulate before they reach the town Otta.

Mild weather periods following situations when ice masses had been stored upstream, as in 1981, generally seemed to be a high risk condition for critical situations to develop. When things started to happen the water level could increase very rapidly, often more than one m in less than a day or night. Fig. 3 illustrates this very clearly. Such conditions have therefore been watched very closely, and immediate measures in the way of reducing the discharge flow have been taken when such a rapid increase in water level could be expected.

Some years the ice situation have been more critical than others, but no serious damage was caused for a long period. On December 25, 1995 there again was a sudden increase in water stage, and on January 1, water was overflowing the ice on Lagen, downstream Otta center. The situation was very similar to what happened in 1981. The discharge had been reduced already at the end of the mild period and before the rise in water level. It was then decreased further until the water level decreased and then stabilized. One was afraid that a slight unfavorable change in the meteorological situation would initiate another increase of the water stage that could then easily pass the level of damage. The water level remained generally high until the end of the ice forming session (fig. 3).

The measurements of water stages were intensified, and the ice profiles measured throughout the winter. The results of earlier measurements were compared with the situation this year. The ice cover in Lagen was very thick, and there were large masses of frazil stored under the ice, as indicated by the measured increase in water stage in this area.

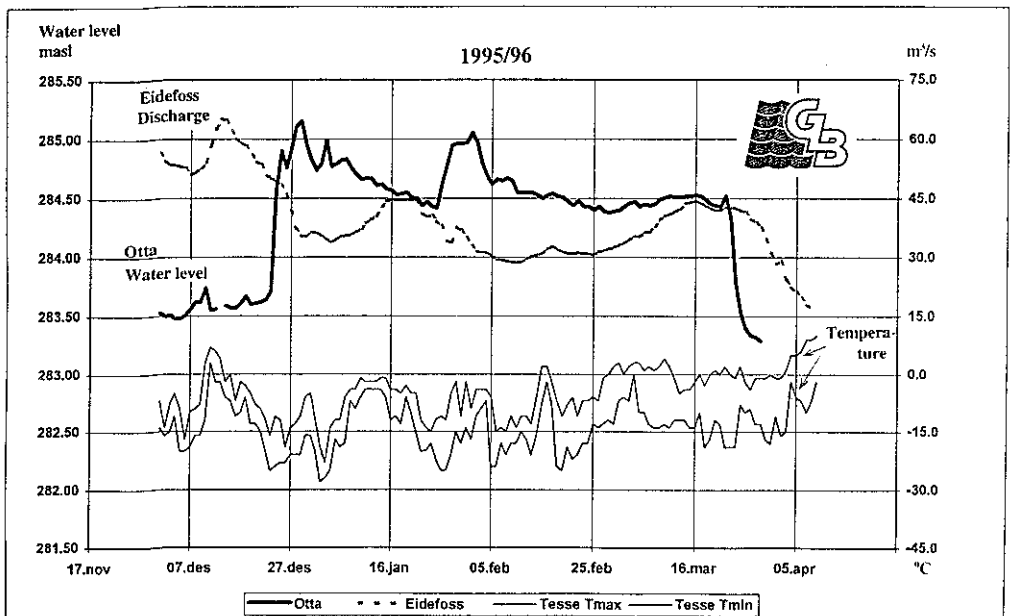

Fig 3. Water level and discharge in Otta 1995/96. Note that the water level increases very rapidly when the air temperature drops below - 15° C.

The previous fall a temporary bridge crossing that led to a narrowing of the river stream had been built in Lagen. This bridge was used for the construction of a bike- and pathway along the eastern shore of the river. The intention was to remove this before winter. When the water stage increased it was obvious that this formed an obstacle in the river, but due to the large ice masses it was impossible to remove it at this time.

FOCUSING ON THE RIVER BED

Gradually the attention was more focused on the effect of various changes in the river bed. In 1992 there had been a damage on the sewage pipe crossing the river. It was then recommended to dig the pipe deeper so that the obstacle for frazil transport at this place would be less. This was at that time however not found to be possible, and therefore not done. Instead the obstacle here became worse, as a protection for the shallow pipe was built upstream. The following winter turned out to be a critical one, with some flooded basements.

The new bike- and pathway along the river bank would partly narrow the river. A plan for maintaining the water discharge possibility, specially during floods, was developed. The possible influence on the ice situation was also considered. The major problem was assumed to be the obstacle formed by the pipe crossings. The existing pipes did prevent an major deepening of the river bed on this critical spot, but no changes for this area was included in the construction of the pathway.

In the winter 95-96 the ice situation again became critical, and very similar to the 1981-situation. This time, however, the river bed was narrowed due to the work on the pathway and the construction work had to be closed down due to the ice situation. This occurrence initiated new discussions on the possible influence of the river bed configuration on the ice situation.

It was then finally decided to both move the pipe crossing and locate it deeper so that it should be no obstacle for deepening the river bed. Unfortunately the work was not finished the following summer. The following winter, 1996-97, there were again periods with water overflowing the ice in Lagen for a period of time. There remained still obstacles in the river, as the remnants of the temporary bridge was not removed, and the pipes were still there.

The new pipes are now in place but the system is not commissioned yet. This will be done before next winter season, and the old pipes then removed. Some adjustments have been done in the river bed. The bottom topography will be mapped, and detailed ice measurements performed next winter to see the effects of the changes so far. Supplementary changes of the river bed will be done next summer. Hopefully this will give less restrictions on the discharge flow in the years to come.

CONCLUSIONS

The source of this problem is the production of frazil in the river. This is depending on the meteorological conditions and the discharge. No measure has however been found for reducing the production of frazil, except by lowering the discharge winter flow.

The configuration of the river bottom is believed to have a major influence on the risk for accumulation of frazil, and thus the risk for flooding. Proper configuration of the river bed is expected to reduce this risk.