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Interaction between the Salhus Floating Bridge and the Environment

Interaction entre le pont flottant de Salhus et l'environnement

Wechelwirkungen zwischen der Salhus-Schwimmbrücke und der Umwelt

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SUMMARY

A 1200 m long floating bridge is planned to be built across the Salhus fjord located close to Bergen, Norway. The bridge is shaped as a continuous arch, penetrating approximately 3 - 4 m below the sea surface. The local fish farming industry fears that the presence of the bridge will form a deeper and more brackish water layer which might be harmful to their industry. This conflict has delayed for years the decision to build the actual floating bridge. The paper explains some of the measures that have been taken in order to resolve the conflict.

Interaction entre le pont flottant de Salhus et l'environnement

Résumé

Un pont flottant de 1200 m est prévu sur le fjord de Salhus, près de Bergen, Norvège. Le pont en arc est continu et pénètre d'environ 3 - 4 m sous le niveau de la mer. L'industrie locale de la pêche craint que la présence du pont ne crée une couche d'eau saumâtre en profondeur, laquelle pourrait avoir des conséquences néfastes sur leur industrie. Ce conflit a repoussé pendant des années la décision de construction du pont flottant. L'article explique les mesures prises afin de résoudre ce conflit.

Wechselwirkungen zwischen der Salhus-Schwimmbrücke und der Umwelt

Zusammenfassung

Der Bau einer 1200 Meter langen Schwimmbrücke über den Salhus-Fjord nahe Bergen, Norwegen, ist geplant. Die Brücke ist als kontinuierlicher Bogen geformt, der ungefähr 3-4 Meter in das Meer eintaucht. Die lokale Fischfarmindustrie fürchtet, dass die Anwesenheit der Brücke eine tiefere und mehr brackwasserhaltige Schicht bilden wird, die schädlich für ihre Industrie sein könnte. Dieser Konflikt hat den Baubeschluss um Jahre verzögert. Der Artikel erläutert einige der Massnahmen, die unternommen wurden, um den Konflikt zu lösen.

1. INTRODUCTION

The planning of the Salhus floating bridge has continued for more than 20 years. One of the reasons for its delay is not the lack of technology for constructing such a bridge, similar bridges are built elsewhere. The main reason turns out to be a long lasting conflict with other interests in the area, basically the local fish farming industry. They fear that the presence of the floating bridge will influence on the brackish water conditions in the fjord in such a way that they will suffer from severe economic losses. Accumulated over a time period of 25 years, losses have been estimated by governmental authorities to be of order 100 - 500 mill NOK. These figures are so large that they approach the cost of the bridge itself. This fact has motivated the Road Authorities to apply more advanced hydrodynamic models to investigate the expected impacts on the brackish water masses from the bridge more carefully.

2. THE SALHUS FLOATING BRIDGE CASE

The Salhus floating bridge is planned to cross an approx. 1350 m wide fjord in the area north of Bergen (see map on Fig. 2.1). On the Bergen side, ship traffic will be allowed to pass through an entrance which is approx. 170 m wide. On the northern side, the bulk of the ship traffic will be allowed to pass through an entrance named Hagelsundet, which is approx. 200 m wide.

The fjord area inside the floating bridge is of order 150 km^2. A number of rivers enters the area, causing a brackish layer to be formed inside the Salhus site. The western coast of Norway is exposed to westerly winds, which cause the precipitation in the area to be severe. During the spring season, the melting of the snow in the mountains gives rise to a brackish water formation within the whole area under consideration. A similar situation occurs in the autumn, before the precipitation enters as snow in the winter time.

Within the same area, a large number of fish farming industry plants have been established during the last 10 - 15 years. Of these, approximately 15 plants are based on the selling of market-sized salmon. These are growing in floating and transparent cages exposed to the brackish water masses. However, the salmon is sensitive to the presence of the brackish layer when trapped in the cages. Today, losses are sometimes experienced in the cages due to natural changes in the brackish water conditions. The fish farming industry is therefore concerned about possible "trapping" of the brackish waters inside the floating bridge in such a way that a deeper and an even more brackish layer is formed. They fear that their losses will then increase considerably.

The governmental authorities have asked for a quantification of the possible additional losses due to the presence of the floating bridge. A relatively simple hydrodynamic model was built in order to predict the changes in the brackish water depth and salinity due to the presence of the bridge. Results from the calculations were resented by Gjerp et. al. (1986). The model predicted average changes in the salinity and the depth of the brackish layer inside, given an average wind velocity, average fresh water inflow and bridge geometry.

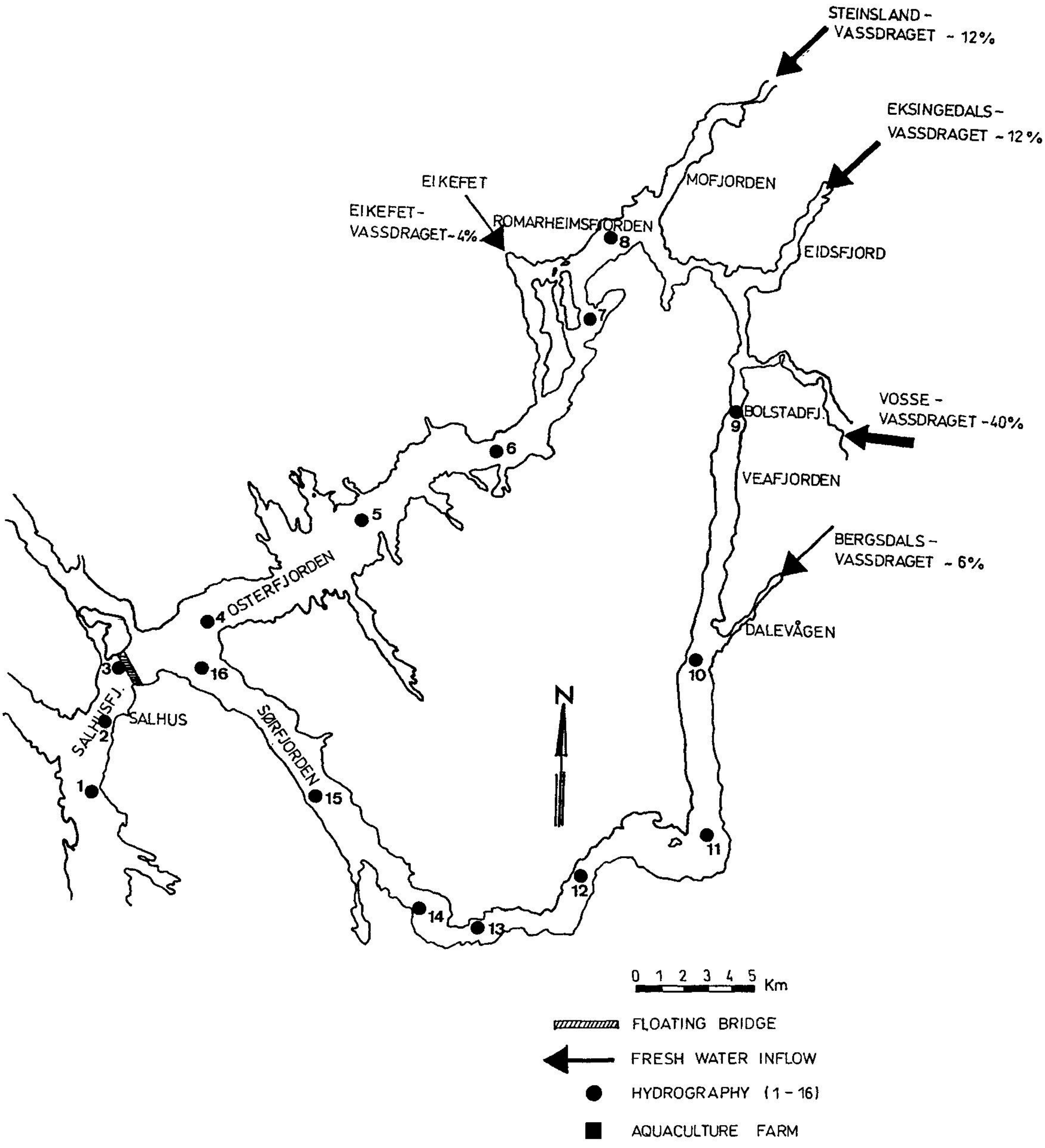


Fig. 2.1. Map of the fjord areas inside the bridge location. Main sources of the fresh water inflow are shown. Locations of the hydrographic stations, numbered 1 - 16, are shown (circles). The locations of the 5 fish farming sites are shown (squares). The city of Bergen is located close to the down left corner of the figure.

This model does not take into account the geographic variation of the brackish water conditions within the area under consideration. Nor does the model include a description of the time and geographic variation in the wind conditions and the fresh water inflow. The model assumes "stationary" conditions. The residence time of the water masses inside may run up to 14 days, which makes the assumptions in the model not realistic. The results from applying the model described by Gjerp et. al. (1986) can therefore be characterized as a first approximation to the description of the brackish water changes inside the floating bridge.

In 1988 the governmental bodies finally agreed to build a floating bridge across the Salhus fjord, on the following terms:

* Alternative solutions for the lay-out of the floating bridge which would allow the brackish water to pass through should be considered.

* A monitoring programme should be conducted to determine the impacts from the floating bridge.

In addition, the Road Authorities decided to apply a more advanced hydrodynamic model to improve on the description of the brackish water changes. The motivation for this was to be able to improve on the calculation of losses imposed on the fish farming industry by the bridge.

The bridge is at present sceduled to be installed on site at the turn of the year 1993/94.

3. THE MONITORING PROGRAMME

The monitoring programme includes hydrographic measurements of the brackish water masses, a number of surveys for observing possible biological changes in the area, and fish physiological laboratory investigations in order to determine the response of salmon to brackish water stresses. The duration of the programme is expected to last for 3 years before and 3 years after the installation of the bridge.

The hydrographic measurements are partly carried out on 5 different fish farming plants in the area, including daily measurements of temperaure and salinity down to 10 m depth. These measurements reveal the time variations of the brackisk water on actual fish farm locations. In addition, hydrographic surveys are carried out every fortnight in the area. These cruises reveal the geographic variations of the brackish water conditions. The locations for the 5 fish farming industry plants as well as the stations for the hydrographic surveys (numbered 1 - 16) are shown in Fig. 2.1.

Fig. 3.1 shows one example of brackish water changes recorded during the measurement program. The figure shows the salt water changes at the location Trengereid during February, 1990. Note the rapid thange in salinity conditions at February 7 and February 21-24. Such changes are expected to be harmful to the fish farming industry. However, no losses were experienced during these two cases.

Fig. 3.2 shows the results from the survey carried out at April 9, 1990. This figure illustrates the geographic variations in the salinity conditions which are sometimes experienced in the area. Salinity are shown for increasing station numbers from left to right. Note the rapid change in the salinity in the Vaksdal area (see the map in Fig. 2.1).

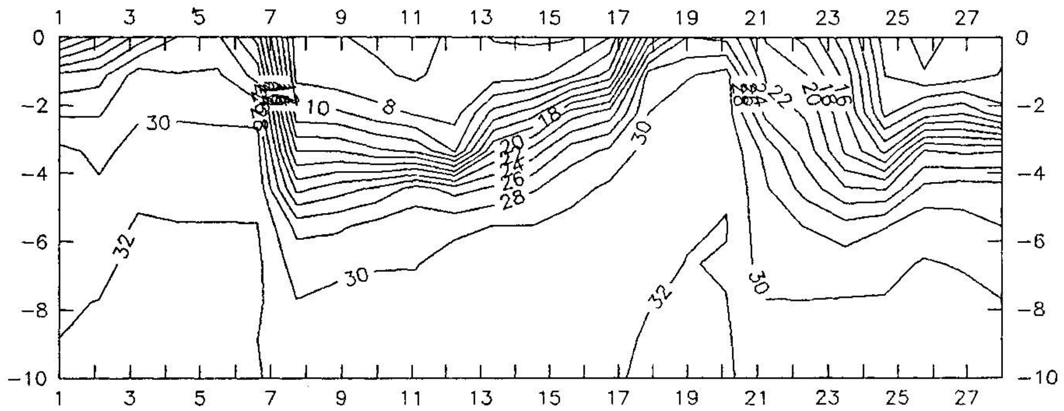


Fig. 3.1. Plots of the salinity (°/oo) measured at Trengereid in February 1990. Horizontal axis: Date. Vertical axis: Depth in m.

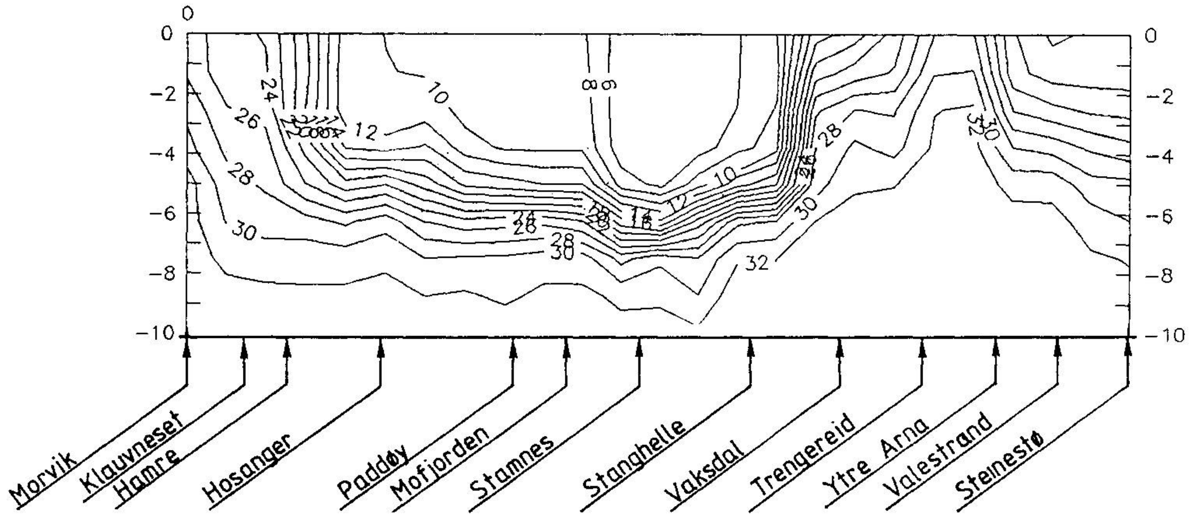


Fig. 3.2. Plots of the salinity (°/oo) measured at April 9, 1990. Horizontal axis: Location of measuring site, se map in Fig. 2.1. Numbers are running 1 - 16 from left to right. Vertical axis: Depth in m.

Due to the large time- and geographic variations of the hydrographic conditions in the area, it will be difficult to separate the natural variations of the brackish water conditions from the imposed variations caused by the floating bridge. To do this, the model "MIKE-12" was applied, as explained in the next chapter.

4. THE DHI HYDRODYNAMIC MODEL "MIKE-12"

Bjerknes has pointed out (Bjerknes, 1985) that actual values of salinity within the brackish layer may not be the crucial parameter for the fish stresses rather than rapid time changes in the brackish water conditions. Such changes cannot be described by

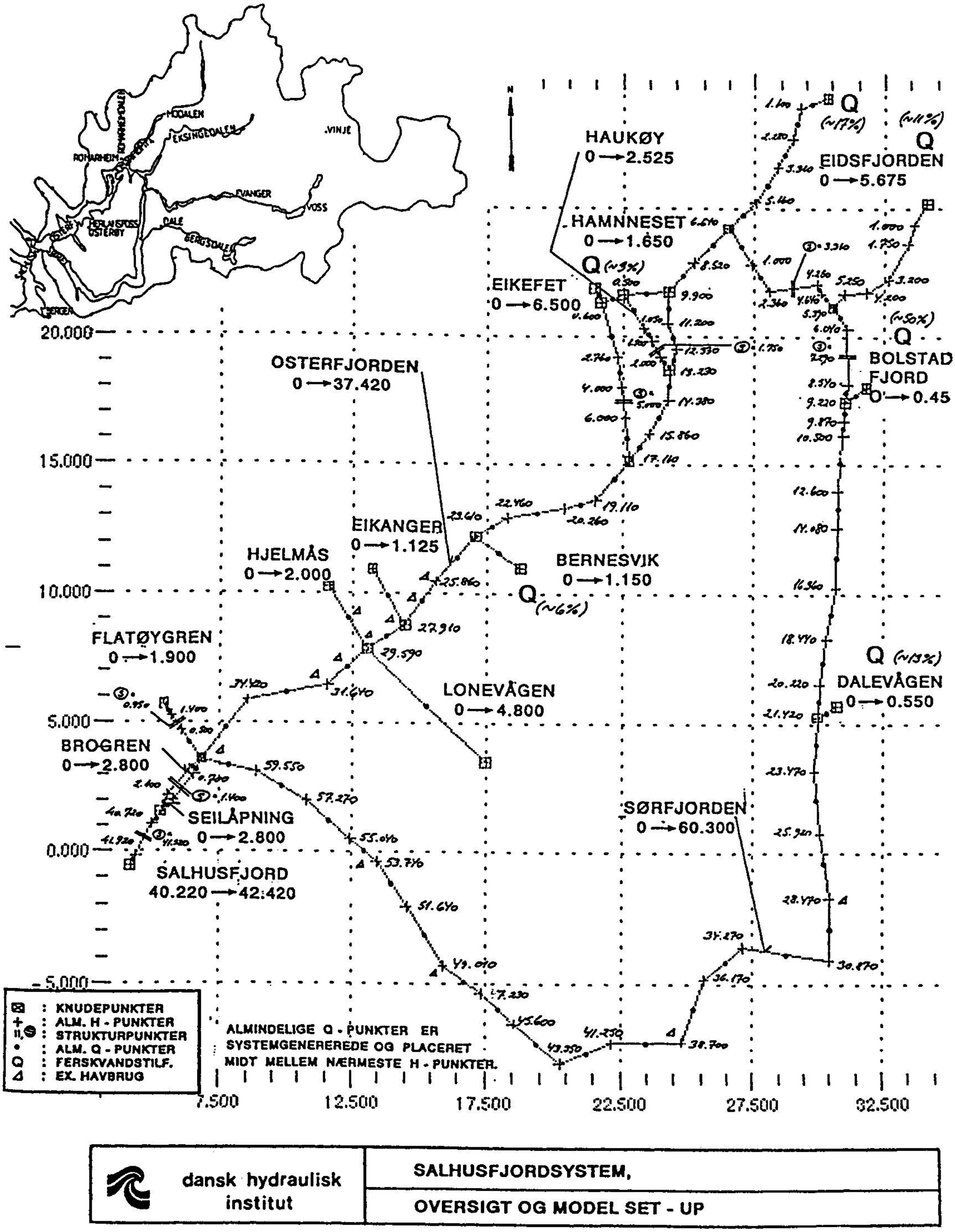


Fig. 4.1. Structural lay-out of the DHI hydrodynamic model "MIKE-12". Open boundaries are located at Salhusfjord (point no. 42.420) and at Flatøygren (point no. 1.900). Locations for fresh water inflow are denoted Q (6 locations). Location of the floating bridge is close to "SEILÅPNING".

means of a "stationary" type brackish layer model. The DHI model "MIKE-12" has the ability to describe such time changes as well as geographic variations in the brackish layer. This model was therefore chosen for the the more advanced description of the brackish layer conditions.

The model is based on a two-layer description where the hydrodynamic equations are applied to each layer. Acceleration terms as well as diffusion terms and sink/source terms within each layer are included. The model resolves the brackish water properties in time and along the main fjord axis, as shown in Fig. 4.1. All physical properties are integrated laterally (normal to the main fjord axis) and within each of the two layers. Forcing factors are fresh water inflow (which enters the model area at 6 different locations), tides and wind. The tides are specified on the border, while the wind is specified at the surface. Both wind direction and strength are allowed to vary, both in time and space, within the model area.

The wind causes local pile-up of the brackish water masses due to surface stresses. At the same time, it generates mixing between the two layers and thus causes the salinity (or density) in the upper brackish layer to vary. Some initial mixing at the river entrances is included. The model also allows for internal hydraulic jumps and corresponding mixing at the location of the floating bridge and at narrow passages where the flow conditions become supercritical. Further details of the DHI hydrodynamic model "MIKE-12" is given in Møller et.al. (1989).

In order to account for the bridge effects, laboratory investigations were carried out with a floating bridge model installed in a water flume. The model bridge was exposed to a brackish water flow, running on top of a heavier water body below. Different geometries of the floating bridge were tested (surface roughness, width, depth and rounding of the corners) and the results parameterized for use in the mathematical model. Details are given in the reports from DHI (DHI 1989 and Møller et.al. 1989).

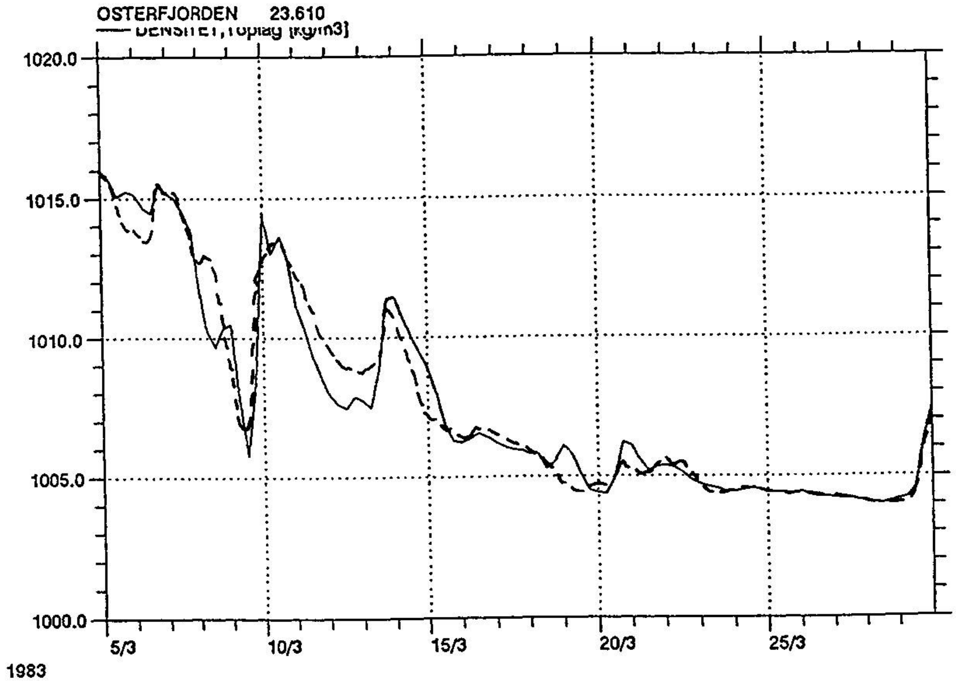
The effects imposed by the floating bridge were then determined by first computing the brackish layer behavior in the fjord system (given the actual time-varying wind conditions and the fresh water inflow as input) without the floating bridge present. Then the computations were repeated, but this time with the floating bridge present in the mathematical model. The difference in brackish layer depth and salinity (density) computed for the two runs represents the bridge effect.

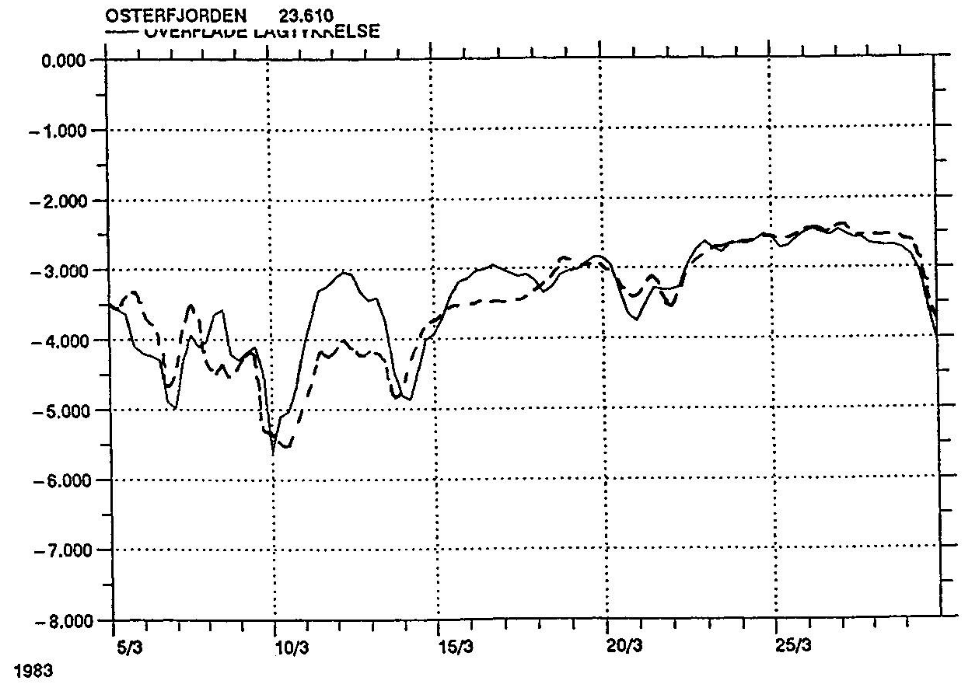
5. VALIDITATION OF THE MODEL

The hydrographic material collected provides an excellent basis for verification of the "MIKE-12" model. The model was verified to compare reasonably well with recordings of the hydrographic conditions during a time period in Aug/Sept. 1989. The comparison shows best agreement between the recorded and the simulated depth of the brackish layer. For the simulation of the salinity, the agreement is less satisfactory, although the trends are reproduced. The discrepancy is attributed to strong local variations in the wind fields which are not reproduced by the model. Further details are given in Rye (1990).

6. A CASE STUDY; MARCH 1983

During March 1983, losses were experienced on many fish farming locations within the Osterfjorden area. The cause of the losses has been attributed to a fresh water episode which started in the beginning of March 1983.





Figs. 6.1 and 6.2. Density (upper figure) and brackish layer thickness (lower figure) for the Osterfjorden location computed for March 1983. Full line: Without bridge present.
Broken line: Bridge included.

Fig. 6.1 shows the computed density in the brackish layer during the time period of March 5 - 30, 1983, for one location in Osterfjorden (Point No. 23.610). Fig. 6.2 shows the similar results for the brackish layer depth during the same time period. The full lines in Figs. 6.1 and 6.2 show the results from computations without the floating bridge present, while the broken line shows the results with the floating bridge included.

It turns out that in this particular case, the differences are small. The density reduction is almost not present, in fact, the density changes are both positive and negative. The increase in the brackish layer thickness is rather modest. In addition, there seems to be a bridge effect present which tends to decrease the oscillations induced by the wind.

The mathematical model has been applied to simulate other time periods as well. The general trend is that the bridge effect is largest when the fresh water inflow is large combined with the absence of the wind. In such a case, the increase in the brackish layer thickness may exceed 1 m in the areas closest to the bridge (Møller et.al. 1989). The amplitude of the changes decays somewhat with an increasing distance from the bridge. Such conditions occur frequently in the springtime when the snow melting in the mountains takes place.

7. SUMMARY

The revised computations as well as the monitoring programme have brought about a better understanding of the mechanisms involved when salmon is exposed to brackish water stresses. However, the governmental bodies have shown some reluctancy to include this new information into their loss estimates. This could be harmful for the aquaculture industry in particular, because some of the losses which are experienced in the past are probably <u>not</u> originating from brackish water stresses, but have other causes. This is at present not fully recognized by the fish farming industry. It is therefore a risk that the fish farming industry may experience additional losses because their true origin is not fully recognized.

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