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Environmental Management and Monitoring at the Øresund Fixed Link

Abstract

The relatively clean and clear water in the Øresund makes it a difficult environment in which to carry out large dredging operations. For this reason, the Øresundskonsortiet initiated an environmental monitoring and environmental management programme called "feedback monitoring" to navigate this huge and complicated construction work safely through a set of strict environmental regulations laid down by the Danish and Swedish authorities.

Environmental monitoring traditionally uses methods that need a long period of observation before one can judge with statistical certainty whether a development is a lasting change or an occasionally occurring natural variation. In connection with the construction of the Øresund Link, an environmental monitoring programme has been established which allows a much quicker evaluation of impacts, in order to make adjustments in the construction activities as observed effects follow or vary from predictions.

This so-called feedback monitoring includes selected variables that over short periods of time show quantifiable changes as a result of impacts from the construction work. The use of computer models makes it possible at an early stage to assess whether a feedback action should be taken or not, given the results of the monitoring and the future work plans.

Introduction

A fixed link between Denmark and Sweden is currently under construction. The link consists of a combination of a double-track railroad and a four-lane highway.
The link goes through a submerged tunnel under Drogden, crossing an artificial island south of Saltholm, leading to a high bridge crossing the Flinterenden to Linhamn on the Swedish coast (see Figures 1 and 2).
An environmental monitoring and environmental management programme called "feedback monitoring" has been initiated by Øresundskonsortiet to navigate the huge and complicated construction work safely through a set of strict environmental regulations laid down by the Danish and Swedish authorities.
The feedback monitoring programme is designed and carried out by the Feedback Monitoring Centre, which has been set-up and run by a co-operation between VKI in partnership with Toxicon A/B and Danish Hydraulic Institute (DHI) in joint venture with LIC Engineering (LIC).

The Feedback Monitoring Centre

The scope of work for the Feedback Monitoring Centre is to implement, maintain, run and manage Øresundskonsortiet's feedback monitoring programme.
The backbone of the environmental control and management during the construction phase is the environmental information system, EAGLE. The Feed-

Figure 1. Map of Denmark and location of Øresund.

back Monitoring Centre is one of the major suppliers of environmental data and model results to EAGLE and at the same time acts as Øresundskonsortiet's feedback advisor and manager. Feedback management and advice is based on the EAGLE system.

Furthermore, the Feedback Monitoring Centre is Øresundskonsortiet's environmental monitoring and supervision unit, which means that a certain level of readiness is implemented by the Feedback Monitoring Centre to monitor unforeseen events, e.g. oil spills, or to react to and evaluate other environmental effects, which third parties postulate are caused by the construction activities. The Feedback Monitoring Centre is run by experienced experts in biology, sedimentology and numerical modelling to secure that the Feedback Monitoring Centre can deal with all possible environmental problems which may arise during the construction phase. Furthermore, the Feedback Monitoring Centre may draw from the comprehensive base of knowledge shared by the partners involved.

Large construction activities in the marine environment will unavoidably cause some temporary and permanent changes or even damages to the environment.
The permanent effects of the fixed link between Denmark and Sweden, including changes in water flow, morphology, landscape, and such, have been minimised through a careful, costly and environmentally optimised design of the fixed link. The permanent effects, which will be small compared to the temporary effects, have been described in "The Øresund Link: Supplementary Assessment of the Impacts on the Marine Environment of the Øresund Link, Øresundskonsortiet 1995".

In the case of the Øresund Link, the temporary environmental impacts caused by the construction activities are closely related to the spill of sediment (soil particles) from the marine dredging and landfill operations.

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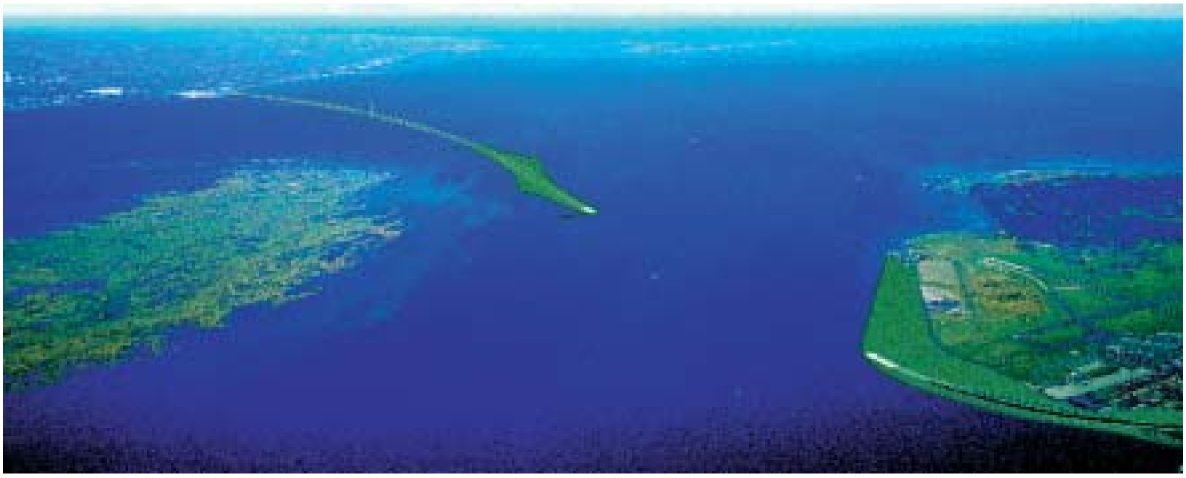
Dredging and handling of large quantities of soil in the marine environment unavoidably lead to the spill of a larger or smaller fraction of the finest particles.
The spilled sediment is carried away by currents or waves and can, even though it consists of unpolluted material, have an undesirable negative impact on the ecosystems in the sea. High concentrations of sediment in the water column can reduce or even completely switch off the life supporting light coming down to the seabed, where light-dependent plants such as eelgrass form large sheltered areas for e.g. schools of

Figure 2. View over the fixed link across the Øresund.



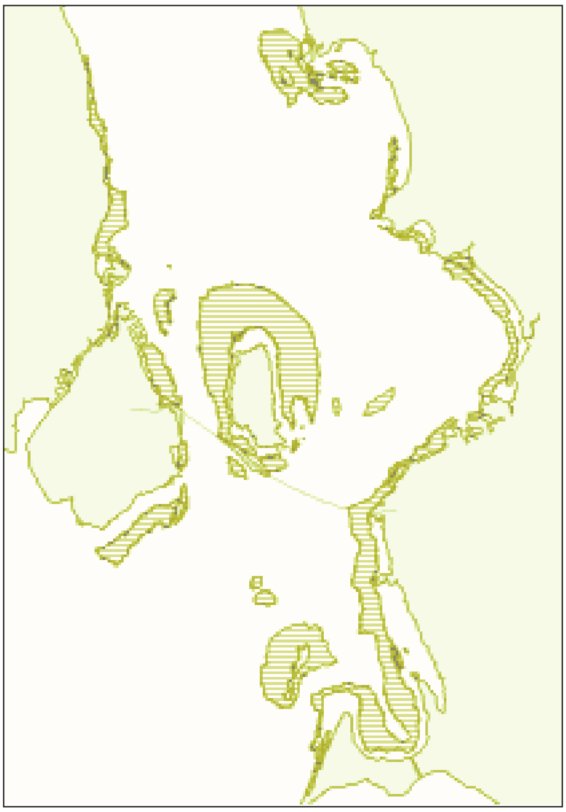


*Figure 3. Distribution of eelgrass (*Zostera Marina*).*

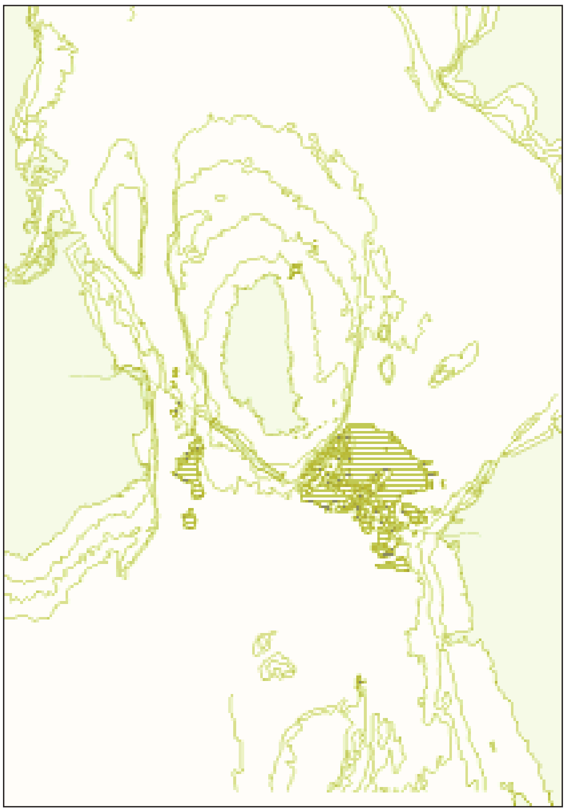


*Figure 4. Distribution of common mussels (*Mytilus edulis*) in the Øresund.*

fish. High sedimentation rates can lead to the burial and extinction of mussels living in large colonies around Saltholm.

The Danish and Swedish authorities have laid down an overall maximum limit of 5% of the sediment spill from the construction activities. In order to meet the other environmental restrictions laid down by the authorities, the Owner has imposed maximum daily and weekly spill rates. These limitations have been assessed by numerical modelling of the effect on e.g. eelgrass caused by various dredging scenarios.

All results from the feedback monitoring programme are presented to Øresundskonsortiet and the authorities through the advanced environmental information system EAGLE. EAGLE is based on a geographical information system and contains all environmental data related to the fixed link across Øresund. The data is supplied not only by the work of Feedback Monitoring Centre, but also by the authorities' general monitoring programme and the Contractor's spill monitoring programme.

The Øresund

The Øresund is the easternmost of the three straits connecting the Baltic Sea with the North Sea.

The Øresund region is densely populated and Øresund itself and its shores are popular recreation areas. Through the last 25 years the local communities surrounding the Øresund have invested large sums in waste water treatment plants and other environmental improvements, so that the water quality in the Øresund today has reached a very high standard. A visibility in the water of more than 10 m is not uncommon, and eelgrass can grow at water depths greater than 6 m.

The relatively clean and clear water in the Øresund is a difficult environment in which to carry out large dredging operations. Even minor sediment plumes are clearly visible and the relatively strong currents transport the spill from dredging operations over long distances.

Hydrography

The currents in the Øresund are like the currents in the two other Danish straits mainly governed by the meteorological conditions over the Baltic Sea and the North Sea. In periods where westerly winds prevail, inflow to the Baltic Sea takes place causing south-going currents in the Øresund. In periods with easterly winds the current in the Øresund is north-going allowing the Baltic Sea water to flow out. Current velocities over two nautical miles per hour are not rare in the Øresund, whereas wave action is limited owing to the lack of large free stretches.

The brackish water of the Baltic Sea is much lighter than the salty water of the North Sea coming through Kattegat. This difference in density gives rise to the formation of two or even three water layers in the Øresund. From time to time the salt water underlying the brackish surface water will flow from the north into the Baltic Sea carrying fresh supplies of oxygen-rich water to the deeper parts of the Baltic Sea. Such inflows are important for the environment in the Baltic Sea and great care has been taken to achieve a so-called zero solution for the Great Belt Link and the Øresund Link.

In order to compensate for the unavoidable reduction of the currents in the two straits caused by bridge piers and other construction elements, compensation dredging is included in the two projects. By increasing the water depth in the link area by dredging it is possible, through careful planning and design, to maintain the natural exchange of water between the Baltic Sea and the North Sea after the construction of the fixed links.

Geology and sediments

The seabed in the Øresund is formed by the currents and, in the shallow areas, also by the waves. In the area close to the link the seabed typically consists of coarse material such as sand and gravel with occasional stones and boulders. This type of seabed has developed where the currents have eroded the finer particles from the underlying glacial till leaving the coarser material behind as a protective carpet. Beneath the glacial till, which in general is less than 10 m thick, limestone is found. Skeletons of microscopic animals living in a sea more than 60 million years ago form the limestone.

In the deeper parts of the Øresund north and south of the link area the seabed has been built up through thousands of years of deposition of fine particles. 10 to 20 m of mud have been deposited in these areas since the end of the ice age. This process is still active and today between 30,000 and 100,000 tonnes of mud are deposited each year corresponding to an average layer of around 2 mm. Most of the sediment accumulating here comes from the Kattegat and the North Sea, whereas very little comes from the Baltic Sea.

The yearly gross transport of fine-grained sediment through the Øresund has been estimated to be around 200,000 tonnes/year. Fine-grained sediment comes from rivers and local shore erosion as well as sedimentation of algae living in the free waters of the Øresund. Especially after the spring and autumn blooms the sedimentation of dead algae can often be seen as white layers in the transition zone between the two water bodies.

As discussed before, the natural content of particles (sediment) in the Øresund is very low, generally below 2 mg of dry matter per litre sea water (mg/l), but locally, in front of wave exposed shores, the sediment concentration can reach 20 mg/l. During calm winter periods the concentration of particles in the water is close to zero and during such periods the seabed is visible down to 20 metres below the sea surface.

Eelgrass meadows

Beds of the marine flowering plant eelgrass (*Zostera marina*) cover extensive parts of Danish coastal areas. The vegetation surrounding the link is characterised by a few, but dominating, species and here the most important one is also eelgrass. Eelgrass is found on sandy seabeds in shallow waters, in general between 1 and 6 m (see Figure 3). The dense meadows of the shoots with the long, band-shaped leaves act as important feeding and breeding grounds for many animal species, also important commercial fish species. Eelgrass is an important food source for the mute swan.

Filamentous algae (in Danish *FedtMøg*) grow in the eelgrass meadows, which also act as a trap for freely drifting mats of living, dead or decaying algae, in the same way as current and wave action are reduced owing to the plant cover. Around Saltholm, eelgrass beds cover an area of approximately 60 km^2.
Along the coast of Amager eelgrass covers an area of about 28 km^2 and along the Swedish coast the area where eelgrass meadows are found covers at least 48 km^2.

Mussel beds

Large parts of the seabed surrounding the Øresund Link are dominated by hard bottom and places exist where even the limestone rock is exposed. Such areas form brilliant places for the common mussel (*Mytilus edulis*). The mussel attaches itself to hard substrates, the rocky seabed, stones, shells of dead mussels or even living mussels, with a bundle of thin threads produced by the mussel itself. Mussels may form thick layers of dead and live mussels. Whenever the mussels cover more than 40% of the seabed it is characterised as a mussel bed. Dense populations of mussels are present in the vicinity of the alignment and on mixed seabed types in deeper water north-west of Saltholm. The distribution of mussels in the Øresund is shown in Figure 4.

The area of mussel beds in the Drogden Channel and in the vicinity of the alignment is approximately 46 km^2. Thirty per cent of the mussel beds are located at depths of less than 6 metres. The weight of the living mussels including their shells is estimated to be around 92 thousand metric tonnes. Twenty per cent of the mussel beds are found in shallow waters, i.e. at depths less than 6 m. The mussels in the Øresund are consumed by eider ducks in the spring and by tufted ducks and golden-eyes during the winter. They are not important as a food supply for fish.

Dredging and Reclamation Work

During construction of the fixed link approximately 7 million m³ of material has to be dredged from the seabed. The dredging is necessary both for construction purposes and to compensate for the reduction in water flow.

The dredged material is utilised for construction of the artificial island south of Saltholm (Pebberholm) and for the peninsula located east of Kastrup Airport (see Figure 2). These landfill operations take place behind closed bunds made of gravel dikes with a protective outer layer of stones.

The major dredging operations will be carried out using different types of dredging equipment. Most of the dredging of construction channels, work harbours and other elements will be done using the mechanical dipper dredger *Chicago* (see Figure 5) and dredging of the tunnel trench will be carried out by a hydraulic cutter suction dredger *Castor* (Figure 6). A number of smaller backhoes will be used for the dredging of pier fundaments and such.

Figure 5. The dipper dredger Chicago.

This mechanical dredger works with a bucket which unloads on barges moored alongside the dredger.
The filled barges are transported to the landfill areas by tugs, and here the material is unloaded by dozers and mechanical dredgers.

Seabed material which has broken loose is sucked and pumped through a pipeline to the landfill area. The water surplus is drained off through sedimentation basins where the fine material has time to settle before the water is returned to the Øresund. Both types of equipment lose some of the dredged material to the surroundings. This material is defined as spill if it is transported away from the work zones or the landfill areas by currents and waves.

Spill limitations

The spill of fine sediment from dredging and land reclamation operations causes the major impact on the marine environment during the construction of the link. Most of the monitoring variables included in the feedback and general monitoring programmes are strongly dependent on the amount of spill and the dispersal pattern of the spilled sediment.

An overall spill limit of 5% of the total masses of material handled inside the work area has been established by the Swedish and Danish authorities. Moreover, the spill of sediment must not hinder fulfilment of the environmental criteria laid down for the Øresund by the Danish and Swedish authorities. In order to comply with those criteria weekly and daily restrictions on maximum spillage rates have been calculated for the various parts of the work area. A weekly maximum spill rate has been established based on numerical modelling of the impact on eelgrass. The maximum weekly spill rate is imposed during the growth season for the eelgrass, which is from 1/3 to 1/11.
A daily maximum spill rate has been established based

Figure 6. The cutter suction dredger Castor.

Figure 7. The spill monitoring vessel Coastal Flyer.

Figure 8. Right, The Feedback Monitoring Centre's research vessel Maritina.

on numerical modelling of the sediment dispersal with respect to fish migration, water quality, the burial and settling of mussels and the feeding of eiders and swans. The maximum daily spill rate is imposed throughout the whole year.
The maximum weekly and daily spill rates may be increased or decreased during the construction period depending on the observed impact on the biological variables. This will, however, not have any influence on the overall 5% spill limit, which is in force in any case.

Spill monitoring programme
Sediment spill from the dredging and land reclamation operations occurs at a number of different locations simultaneously, and therefore a highly mobile ship-based monitoring system is required. Clouds of suspended sediment or plumes develop both at the site of dredging operations and at outlets from deposition areas (landfill areas) or sedimentation basins.

The monitoring programme is designed to provide real time and depth/space integrated information about the actual spill rates from all spill sources. The sediment concentration and the flux of spilled sediment are known to vary considerably over space and time depending on the dredging and deposition activities, the character of the dredged material and the current and wave conditions. It is therefore important that the distribution of the spilled sediment is measured and/or calculated as space and time integrated values.

Monitoring of the dredging operations is carried out from a mobile survey vessel, which follows the various dredging activities, while monitoring of the outlets from the deposition areas and sedimentation basins is based on a combination of fixed automatic measuring stations and the mobile station. Figure 7 shows one of the spill monitoring vessels operating in the Øresund.

Data from the fixed monitoring stations and the mobile station are sent on-line to a central computer where the actual spillage from the various sources is calculated. The system including the mobile station is manned continuously during periods with intensive dredging activities or when new dredging operations or dredging equipment are started up.
The daily spill rate reported to Øresundskonsortiet is used to model and evaluate the results of the other monitoring variables. The spill measuring programme is operated by the contractors under close supervision by Øresundskonsortiet and the authorities.

Feedback Monitoring Programme

Environmental monitoring traditionally uses methods that need a long period of observation before one can judge with statistical certainty whether a development is a lasting change or an occasionally occurring natural variation. In connection with the construction of the Øresund Link an environmental monitoring programme has been established which allows a much quicker evaluation of impacts, in order that adjustments can be made in construction activities as observed effects follow or vary from predictions. This has been named feedback monitoring.

Øresundskonsortiet has implemented the Feedback Monitoring Centre to conduct their Feedback Monitoring Programme for the Øresund Link Project in order to be able to have detailed information on potential impacts arising from the construction works and to be able to react quickly in case threshold values are exceeded. The Feedback Monitoring Centre operates several vessels and one samples biological samples of either eelgrass or mussels every week to follow the development of the ecological conditions in the Øresund (Figure 8).

Feedback monitoring is used by Øresundskonsortiet to monitor and model selected variables, which over a short time show quantifiable changes owing to chan-

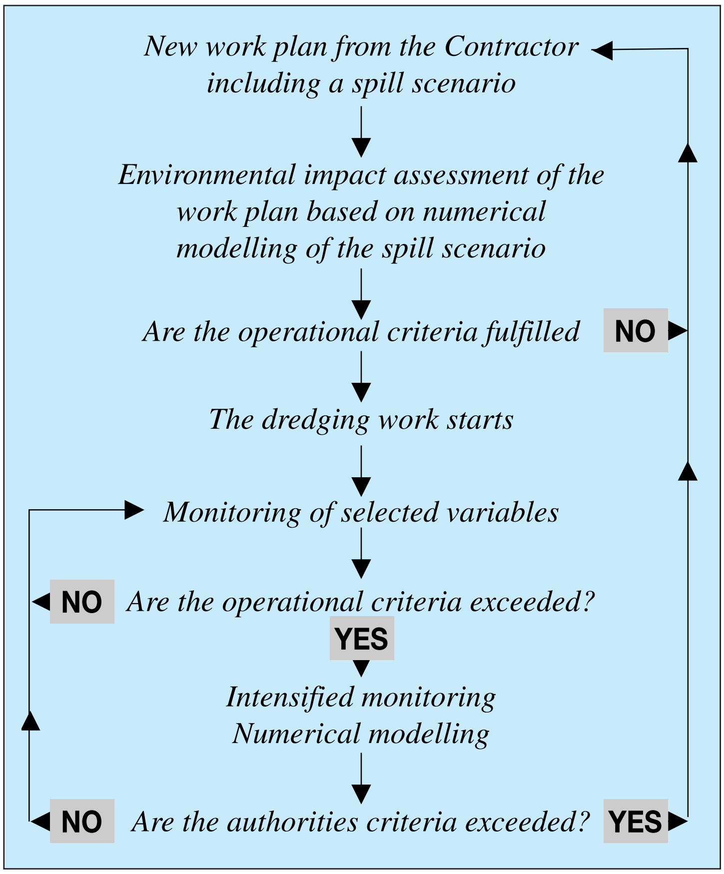


Figure 9. Principals of feedback monitoring.

ges in the environmental conditions. The planning and environmental approval of dredging activities is seen as the primary tool to ensure compliance with environmental requirements. The combination of measured conditions of the environmental variables, with predictions based on numerical modelling of the response of the variables to the actual work plans, is the key factor for making decisions concerning feedback action at the construction site.

In the monitoring programme the use of numerical models is integrated in the feedback system.
The models are applied partly to hindcast the condition of the variables based on measured hydrographics and spill emissions and partly to forecast future impact based on the actual work plans and representative hydrographic scenarios. The model results are frequently compared with measured conditions to evaluate the performance of the models and to assess factors other than the construction works, which might influence the variables.

Strategies
The environmental impact assessment has shown that the largest impacts will result from the dispersal of spilled sediment. Consequently, great effort has been put into organising the environmental monitoring to secure that the criteria on the emissions will be met.

Two major tools have been introduced to ensure that the spill is kept below the limits fulfilling the objectives/criteria for all variables:
1. The Contractor is made responsible through his contract for keeping the spill below specified limits varying in time and space, taking into consideration the environmentally sensitive periods and areas.
2. A feedback monitoring programme is implemented covering sediment spill, the dispersal hereof and biological key variables representing the important influenced ecosystems.

In theory the Contractors' fulfilment of the criteria of maximum spillage alone should reduce the impacts to acceptable levels. However, because of the unpredictability of the hydrographical and meteorological regime and natural variations in the ecosystem, the actual state of the environment during the construction works must be monitored to ensure the fulfilment of the general environmental criteria.

Feedback principles
Feedback monitoring includes selected variables that over short periods of time show quantifiable changes owing to impacts from the construction work.
These variables are measured continuously or with a high intensity and constitute the main instrument for fast regulations of the construction works.
To ensure fulfilment of the environmental objectives and criteria, procedures have been established that specify the actions to be taken on the construction work, where criteria are in danger of being exceeded.
The feedback monitoring serves as an integral part of the environmental management system and will impose changes/restrictions in the marine works which may lead to increased costs. The feedback procedures include:
– assessment and approval of equipment, work plans and so on, prior to the initiation of operations;
– application of threshold criteria and feedback loops with an agreed code of action; and
– a clear definition of responsibilities of the involved parties.

The planning and environmental approval of dredging activities are seen as the primary way to ensure compliance with environmental requirements. This means that the key factors for making decisions on actions changing the construction works are the measurements of the environmental variables, combined with forecasts of the future conditions.

In the monitoring programme the use of computer models is integrated in the feedback system.
The models are applied in the planning of the dredging and reclamation operations. They are used to forecast the sediment dispersion and sedimentation, and the impact on water quality and the eelgrass beds. The use of the models makes it possible at an early stage to

assess whether a feedback action should be taken or not, given the results of the monitoring and the future work plans. The principles of the overall feedback procedure are illustrated in Figure 9.

The general environmental criteria set by the authorities in connection with the construction of the Øresund Link have been transformed into operational and measurable criteria for the feedback monitoring. The operational criteria relate to organisms or communities that are representative for the ecosystem.
In the Øresund, eelgrass meadows and mussel banks dominate the plant and animal communities, as can be seen on the map, and these have therefore been chosen as the most suitable organisms for feedback monitoring in the Øresund.

In feedback monitoring it is essential that the variable chosen for measurement meets certain basic demands:

– It must have an unambiguous, easily measurable relationship to the feedback organism, which represents the ecosystem concerned.
– The measuring result has to be available in a short time (no more than a few days).
– Background material must be available for the determination of statistically reliable limit values and criteria for judging an exceeding of the limits.
– The impact of various conditions on the variable should be calculable in advance, that is, some kind of model of the relationship between cause and effect has to be available.

Given these demands, the following variables were selected for monitoring of the feedback organism eelgrass: shoot density, leaf and root biomass, and carbohydrates dissolved in the rhizomes. The selected variables in the mussel monitoring are distribution and biomass.

Feedback Monitoring and Actions

The active monitoring procedures of the feedback programme are described below in the sections covering sediment and turbidity, eelgrass and mussel monitoring. Prior to all activities, the effects of the expected spills from the planned dredging and reclamation activities are assessed. A spill scenario is produced on the basis of the work plans. This scenario is modelled and shading, sediment transport, sedimentation and effects on the eelgrass community are forecasted. The model calculations are based on expected weather situations, light, currents, waves, and so on. A full year of comprehensive hydrographic measurements in the Øresund (1992-1993) is utilised as the hydrodynamic scenario for the forecast simulations that are used for environmental impact assessments. If it is anticipated that a work plan does not comply with the operational criteria, a new work plan has to be elaborated before the work can be initiated.
In reality the light, wind, currents, waves, and such do not end up as anticipated in the forecast modelling. The summer may be extraordinarily windy or the like.

Figure 10. Diver at work in the eelgrass community.

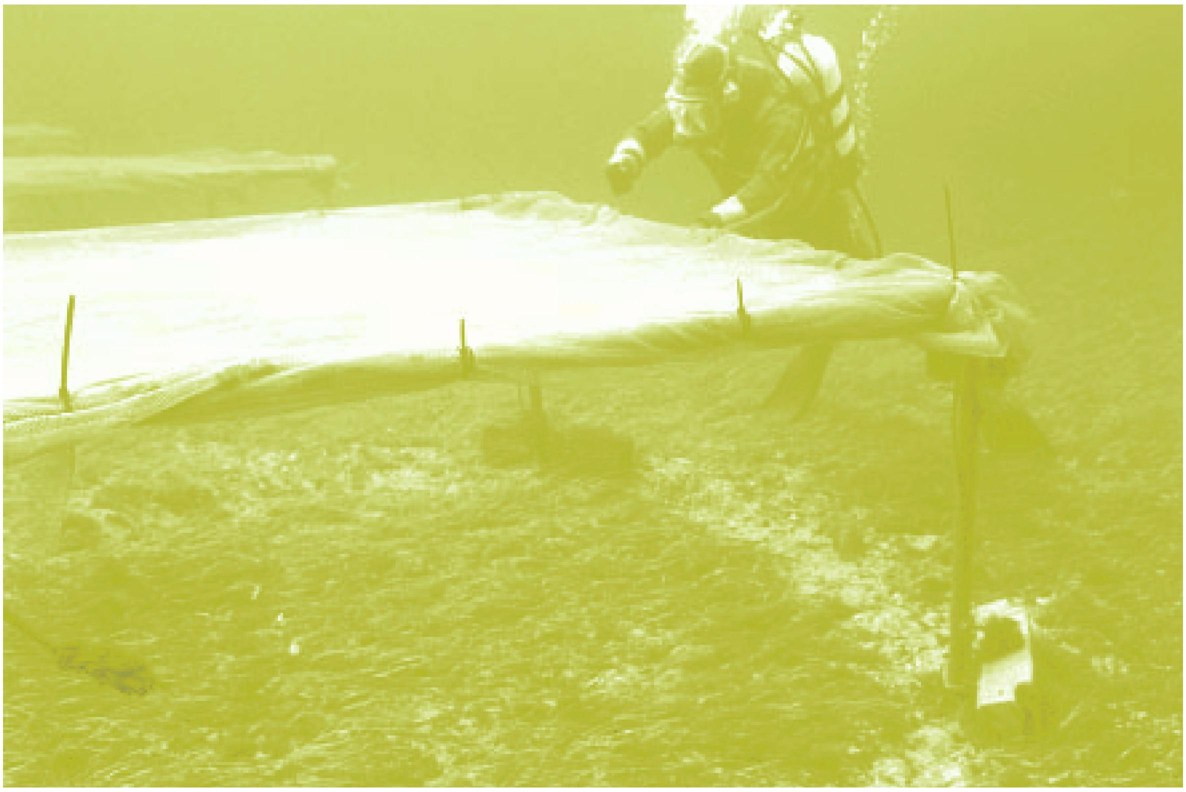


Figure 11. A photo from a mussel bed south of Saltholm.

Consequently, the effects may be somewhat different from the ones forecasted. In order to make the next forecasts more reliable, modelling of the past events is accomplished. That is, from the beginning of the construction of the link to the actual time. This modelling uses measured boundary data, measured temperature and light conditions and other conditions. It is called hindcast modelling and is carried out several times a year.

Turbidity and sedimentation

When dredging and reclamation work start, turbidity and sedimentation surveys are carried out several days a week. Turbidity is a light measurement that allows for the calculation of the concentration of sediment particles in the water.

The surveys serve two main purposes. The monitoring provides data for the tuning (calibration and verification) of the sediment model, so that it reflects the real conditions in the Øresund as correctly as possible.
Also data on turbidity and sedimentation rates are needed to control directly that the work is carried out in accordance with some of the operational criteria.
The amount of spilled sediment that is transported around in the Øresund waters may be measured in different ways: Either as turbidity measured as light attenuation or as optical back scatter. In some cases sediment plumes may be mapped using acoustic methods (Acoustic Doppler Sediment Profiler). In addition, the sediment fluxes are estimated on the basis of results obtained from sediment traps deployed at several stations in the Øresund.

The transport of sediment along the seabed and the sedimentation are further evaluated on the basis of a combination of submarine video recordings, dual frequency echosounders and sidescan sonar recordings of the seabed. Also a number of bottom markers have been put out on the seabed. Samples of the seabed are regularly taken with core and grab samplers and they are analysed for dry matter content and grain size.

The turbidity and sediment monitoring takes place in the areas most affected by the spilled sediment. The grey-white plumes of mostly small lime particles can be observed on the sea surface from the research vessel. Occasionally, satellite pictures and aerial photographs are included to support the planning of the surveys. The submarine video recording surveys are being planned according to the results of the hindcast modelling of sedimentation. They do not follow a regular pattern, but will cover areas where deposition of spill can be expected.

Turbidity monitoring may trigger feedback actions in three cases:

- If visibility in the water at the bathing beaches along the Swedish and Danish coasts in the season is less than one metre in the bathing season. This relates of course to a criterion concerning the quality of bathing water.
- If sediment plumes with concentrations above 10 mg/l occur simultaneously in the Drogden Channel and the Flinterenden for a longer period. This is introduced to comply with a set of criteria that aims at ensuring unhindered fish migration.
- If visibility in the water around Saltholm falls below one metre for a period longer than two days. The criterion is intended to allow the mute swan to graze on eelgrass relatively undisturbed.
- If the sedimentation exceeds 15 kg/m^2/month feedback action has to be taken to ensure compliance with criteria concerning mussel beds.

Whenever feedback is initiated the project manager reports to the Project Director, the Environment and Authorities of Øresundskonsortiet and action is taken to change the harmful activities. This can for example be in the form of a dredger being moved to another area in the Øresund.

The eelgrass programme

Every second week during the eelgrass-growing season (March to November) samples of eelgrass are taken in the area around the Øresund Link. The density of the eelgrass meadows, the weight of the live parts of the plants and the storage of energy in the underground parts are recorded. Samples are taken by scuba divers at ten locations. The locations are chosen according to the ongoing dredging and reclamation work and on the basis of the hindcast modelling (Figure 10).

Some other items are also monitored to supplement the eelgrass programme. At two sites in the Øresund light sensors and data loggers are placed permanently on poles which allows for the calculation of light reduction. They are visited weekly. Light reduction is also estimated indirectly from measurements of the growth of discs of the sea lettuce (*Ulva*), which are exposed in Plexiglas cages on buoys in the Øresund. The area distribution of eelgrass is assessed using aerial photographs, which are taken every autumn.

The results of a monitoring cruise are compared with results obtained before the construction of the link (baseline). If no important change is observed, monitoring continues as planned. If an important change in the variables chosen in the hindcast and forecast modelling occurs then an assessment must be made as to whether the criteria will be violated. If the project management resolves that the change is owing to activities in connection with the Øresund Link construction, feedback action is taken in the same way as previously described.

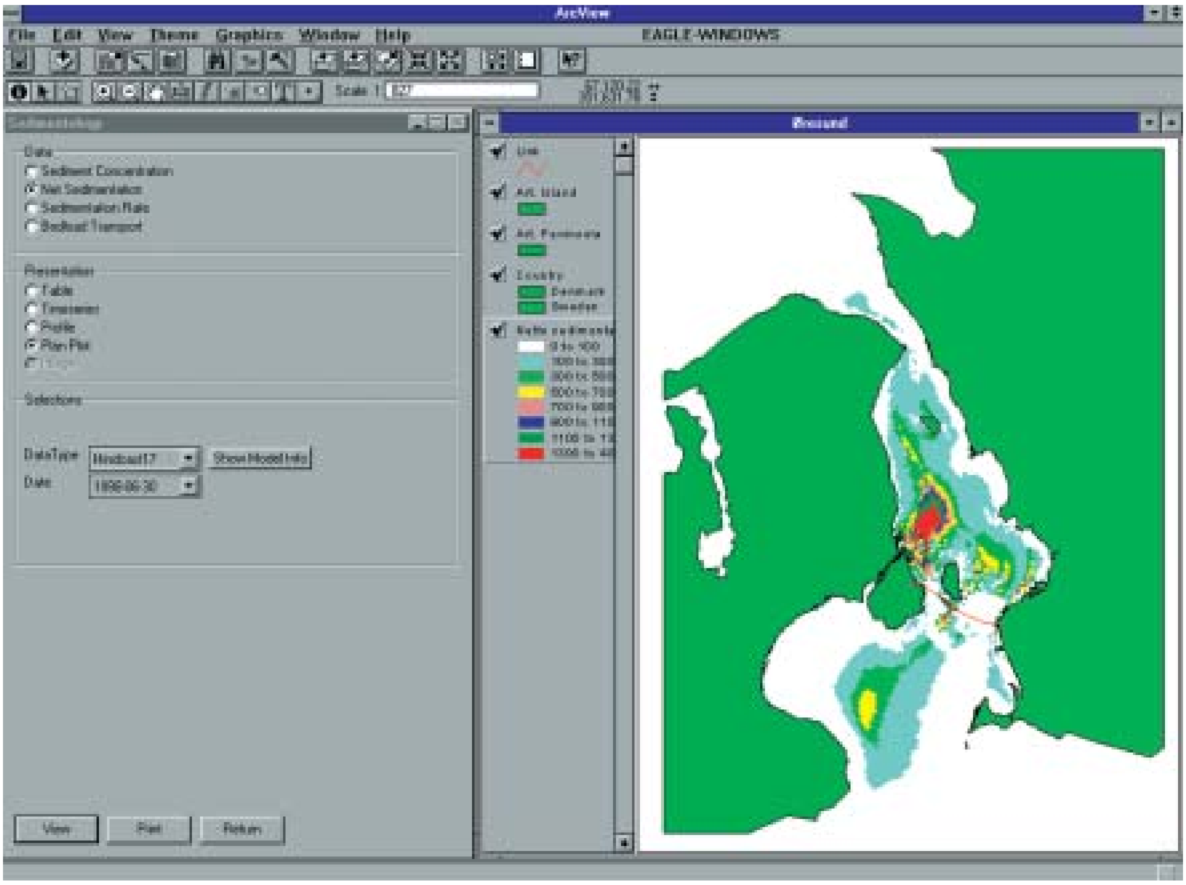
The mussel programme

The mussel programme also runs every second week, but in contrast to the eelgrass programme, it runs all year round. A device called a photo-sampler is operated from the research vessel. It photographs a fixed area of the seabed and by use of image analyses the number and size of the mussels on the picture can be measured (Figure 11).

Monthly, additional samples of the mussel beds are taken by scuba divers so that the weight of the live mussels can be assessed. Once a year the distribution of mussel beds is mapped using the sound analysis software system called RoxAnn.

The stations at which sampling takes place by photo-

Figure 12. Example of model calculated sediment spreading as presented in EAGLE.



sampling or by diver are chosen on the basis of the sites for ongoing work, baseline studies of mussel bed distribution, and hindcast modelling of sedimentation.

The results of the feedback monitoring cruise are compared with the results of the baseline. If no important change is observed monitoring continues as planned. If a change occurs to the variables chosen in the mussel bed monitoring then the project manager evaluates the reasons for the change. As mentioned under the eelgrass programme, additional sampling may be necessary and also hindcast and forecast sediment modelling to assess whether the criteria will be violated. If the project management determines that the change is owing to the construction of the Øresund Link and that it will eventually result in a violation of a general environmental criterion, feedback action is taken in the same way as previously described.

Data Management

In connection with the environmental monitoring that runs during the construction of the Øresund Link Øresundskonsortiet has established an advanced environmental information system called EAGLE.
All data produced in the feedback monitoring programme are stored in a Feedback Monitoring Centre database. This database contains data collected at the monitoring surveys as well as data from the baseline studies, satellite pictures, coastal morphology photographs and other items.

Other databases in connection with the Øresund Link contain relevant data. A hydrographic database which includes immense amounts of data from the hydrographical monitoring programme is run for Øresundskonsortiet by Danish Hydraulic Institute (DHI) and Swedish Meteorological and Hydrographic Institute (SMHI). Furthermore, Øresundskonsortiet maintains a database of the earth works, position, amounts, properties and spills.

Those three data bases are linked together and supply data, which are transferred to the EAGLE database in the form of relevant information. This is, for example, maps based on a geographical information system, graphs, pictures and reports, also incident reports describing the possible conclusions and actions in connection with the feedback procedures. An example from EAGLE showing model-calculated sedimentation of spilled sediment is presented on Figure 12.
EAGLE is a highly evolved tool for decision making. Øresundskonsortiet's management has direct access to the latest environmental information through EAGLE. Furthermore, the Danish and Swedish authorities are directly connected to the EAGLE database so that their information may always be at the same level as that of Øresundskonsortiet.

Conclusions

Environmental monitoring traditionally uses methods that need a long period of observation before one can judge with statistical certainty whether a development is a lasting change or an occasionally occurring natural variation. At the construction of the Øresund Link, an environmental monitoring programme was established which allows a much quicker evaluation of impacts, in order to make adjustments in the construction activities as observed effects follow or vary from predictions. This so-called feedback monitoring includes selected variables that over short periods of time show quantifiable changes as a result of impacts from the construction work.

These variables are measured and modelled continuously or with a high intensity and constitute the main instrument for management of the construction activities. In the monitoring programme the use of computer models is integrated in the feedback system.
The models are applied in the planning of the dredging and reclamation operations. They are used to forecast the sediment dispersion and sedimentation, and the impact on water quality and the eelgrass beds. The use of the models makes it possible at an early stage to assess whether a feedback action should be taken or not, given the results of the monitoring and the future work plans.

The experience gained so far, with more than 90% of the dredging work completed, is that none of the criteria has been violated and the dredging work has been successfully carried out within the overall time and budget plans.

References

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