Environmental monitoring instrumentation and data flow techniques

Environmental Monitoring Instrumentation and Data Flow Techniques
Surveillance de l'environnement et techniques de mesure des données
Umweltüberwachung und Messtechnik

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SUMMARY
This paper describes the comprehensive environmental monitoring system which is a key element in the environmental control measures associated with the construction of the tunnel and dual bridge link, connecting the Danish islands Zealand and Funen with the European Continent. Some of the novel approaches regarding instrumentation, communication, data processing and future application in general are also highlighted.

Surveillance de l'environnement et techniques de mesure des données

Résumé
L'article décrit le système global d'enregistrement de l'environnement: il s'agit d'un élément essentiel des mesures de contrôle de l'environnement associé à la construction du tunnel et des deux ponts reliant les îles danoises de Zealand et de Funen avec le continent européen. Certaines approches nouvelles relatives à l'instrumentation, à la communication, au traitement des données et à des applications futures sont décrites.

Umweltüberwachung und Messtechnik

Zusammenfassung
Dieser Artikel beschreibt das umfassende Umweltüberwachungssystem, das ein Schlüsselelement in den Umweltkontrollmassnahmen beim Bau des Tunnels und der Brücken darstellt, die die dänischen Inseln Seeland und Fünen mit dem europäischen Kontinent verbinden. Entsprechende Neuerungen betreffend Messgeräte, Datenübertragung, Datenverarbeitung und zukünftige allgemeine Anwendungen werden beleuchtet.

1. INTRODUCTION

The Great Belt monitoring system is of general technical interest, because:

- It includes a wide range of sensors - including some very advanced types - deployed over a large area.
- It makes use of a combination of data transmission methods in order to provide almost on-line access to the sensor readings.
- It provides input to - and is integrated with - numerical forecast models for currents and water levels, and with numerical model for simulation of dredging spoils.
- It includes computerized "control-room" facilities which enable the operators to maintain a very high data return and quality, and at the same time open up to a range of new applications of the data.
- It has been operating successfully since 1989 and will continue in part until the completion of the Great Belt Link Project in 1996.

These and other features of the Great Belt Monitoring System are described in detail in the following.

2. BACKGROUND - THE GREAT BELT LINK

The Great Belt is located between the brackish Baltic Sea and the saline North Sea, see Fig. 1. In terms of exchange of water between these two water bodies, the Great Belt is the main strait connecting them. The flow in the Great Belt is, accordingly, typically stratified and highly dynamical.

The Baltic Sea is an environmentally strained area and potentially very sensitive to changes in the water exchange with the North Sea. Accordingly, in 1987, when the Great Belt Link Act was passed, the Danish Parliament decided that part of the design requirements for this link should be "neutrality" in terms of the water exchange. See Møller (1989, 1991) for more details.

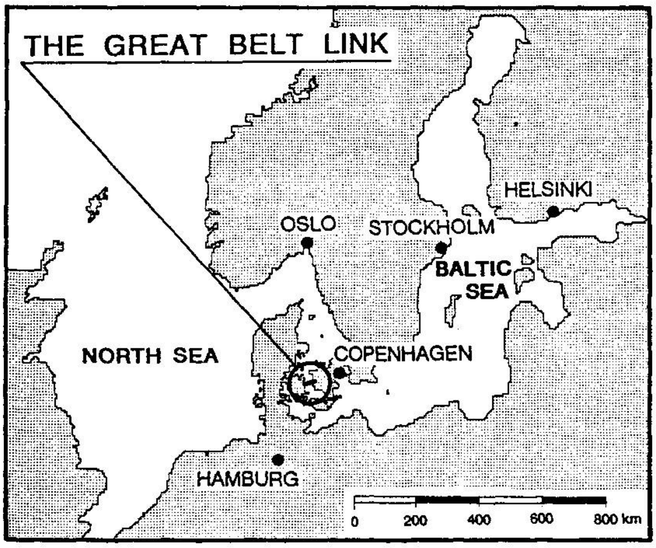


Fig. 1 Location Map.

This neutrality is ensured by compensating for certain effects - like for instance the increased resistance caused by the bridge causeways and piers - by the introduction of similar effects working in the opposite direction - for instance by compensation dredging in selected areas.

The design of these measures has to a large extent been based on the use of numerical models, primarily a model based on the SYSTEM 22, which is a generalized hydrodynamic modelling system for two-layer flow. Such a model requires a significant amount of measured data for model calibration and validation.

3. A MULTI-PURPOSE MONITORING SYSTEM

Apart from providing the necessary data for the modelling tasks in the design phases, the environmental monitoring system also serves the following purposes:

- To assist in the daily supervision of the environmental impact of the operations in the Great Belt area.
- To serve as part of an on-line forecast system for use by the contractors during weather sensitive operations.
- To demonstrate - through long term measurements - that the "neutrality" requirement has actually been met.

4. SYSTEM OVERVIEW

The environmental monitoring system is an important element in the complete hydrographic information system, which has been established for the Great Belt. Fig. 2 gives an overview of the complete hydrographic information system.

Apart from the measuring stations which are distributed over a wide area, also the other parts of the information system are distributed:

> The forecast services based on numerical models for prediction of the weather conditions and the hydrographic parameters - are operated by the Danish Meteorological Institute (DMI) at their main computer facilities in Copenhagen.

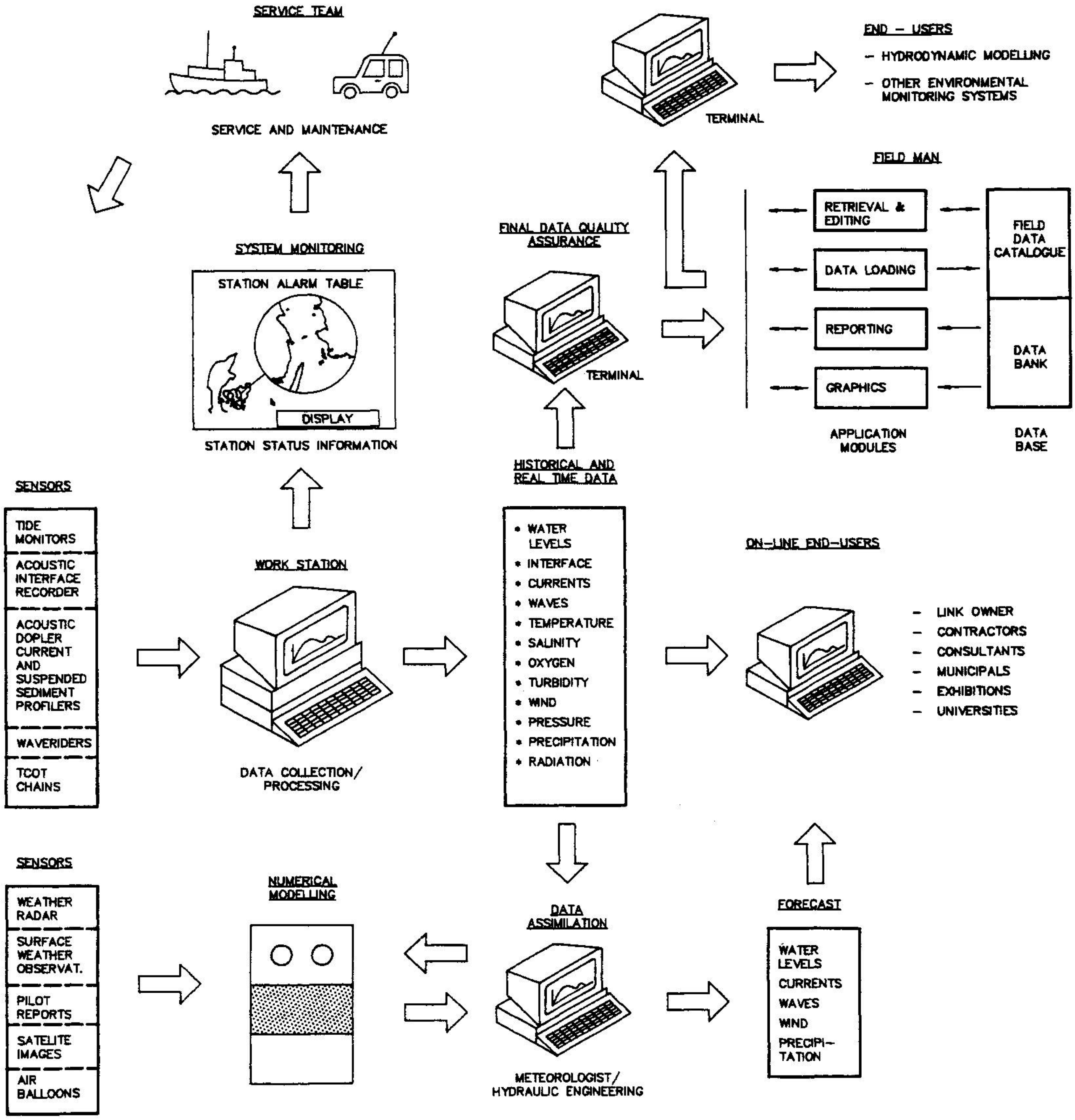


Fig. 2 Hydrographic Information System Setup.

- The supervision of the monitoring system, central storage of data, data quality control, etc. takes place at DHI in Hørsholm (125 km from the project site and 20 km from DMI).

The users of the system can get access to information from the system in one of the following ways:

- They can log in directly on the Great Belt computer "Hub", which is hooked on to the ETHERNET network at DHI. This requires a network connection to DHI and proper authorization. Normally, only DHI engineers are allowed to use this method.
- They can get access to (i.e. browse and copy for later local processing) selected data through a PC with modem. This is of course also subject to proper authorization.
- Finally they can subscribe to reports sent by telefax with only limited forecast information.

5. MONITORING SYSTEM

5.1 Design Aspects

The first step of the development of the Great Belt monitoring system began in connection with a Field Measurement Programme in 1987. New measuring techniques were introduced, eg. the acoustic doppler current profiler, and measuring schemes for the hydrographic parameters relevant for the verification and calibration of the numerical models were defined. Furthermore, the survey vessel instrumentation setup and tactical survey plans required to obtain the geographical distribution and variation of current and stratification conditions were established. However, the challenge involved with design, installation and operation of the present monitoring system were still many after 1987:

- To find the correct mix of physical monitoring instrumentation tailored to meet the specifications set forth by the modelling people but with an eye towards compatibility and application flexibility.
- To monitor the aquatic environment data accuracy is of primary importance and, as the system interrogates many remote measuring stations, it should therefore be capable to efficiently manage the complex tasks of data collection, processing, analysis, control, report and display the information.
- A monitoring system involving real-time acquisition and remote control application software requires a robust design of the data communication link as well as of the autonomous operated field measurement platforms.

Below a very brief description of the setup is given followed by a few selected examples of novel approaches within the field of environmental monitoring.

5.2 System setup

At the peak in 1990 the monitoring system comprised 18 stationary measuring stations and one vessel based station based on the survey vessel M/S PIP, see Fig. 3.

The full monitoring setup involves more than hundred sensors which, on an almost real time basis, provide data on **stratification** by measuring temperature, salinity, oxygen and turbidity along vertical strings supported by acoustic interface recordings measured with an instrument developed by DHI for this project - **current** conditions by measuring velocity profiles with Acoustic Doppler Current Profilers - **wave** conditions obtained by wave rider buoys and **water levels** measured with acoustic tide monitors.

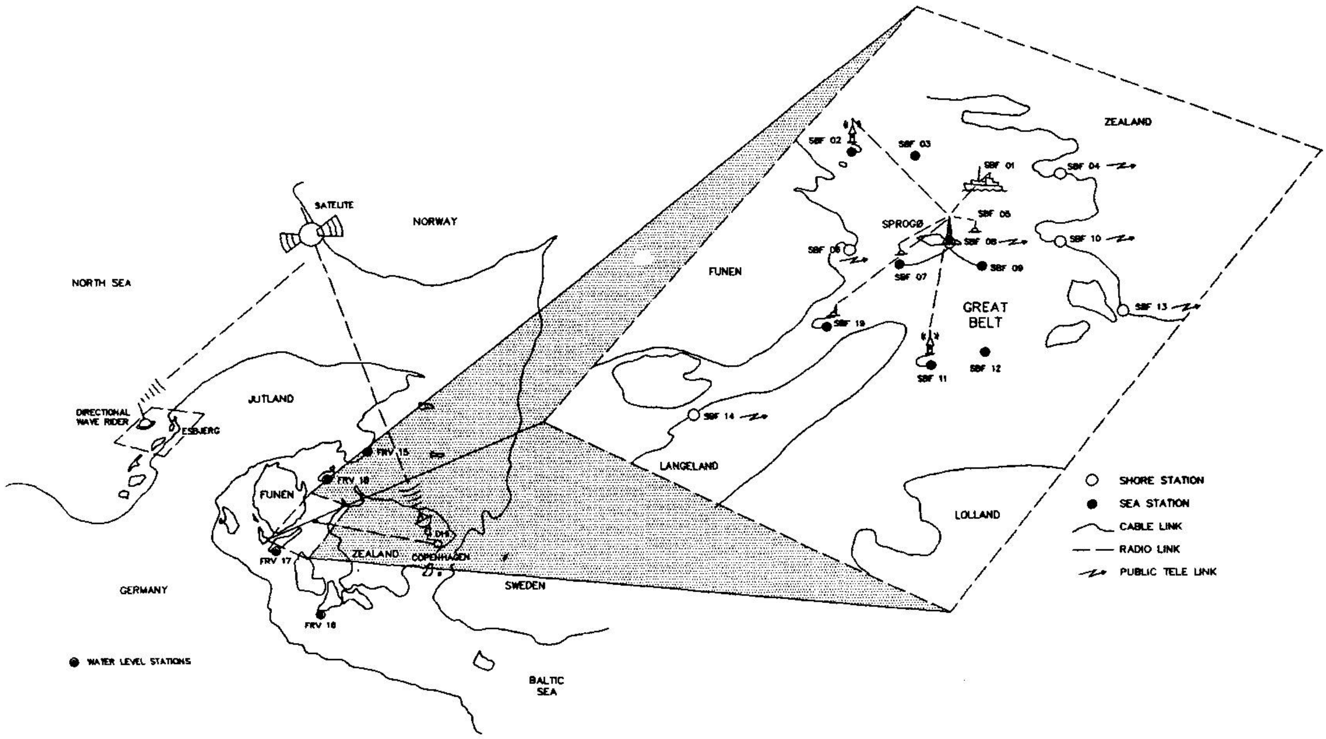
Meteorological parameters - wind speed and direction, temperature, pressure, precipitation and radiation - are measured on Sprogø and are also transmitted to the data central at DHI.

The ship based station is used for service and maintenance of the fixed sea stations, temporary replacement of malfunctioning sea stations, intensive hydraulic surveys for establishment of the horizontal distribution of hydrographic parameters and tracing of sediment plume during dredging operations.

For these tasks it is equipped with a variety of profiling instruments and a radio- and data communication link to the data central and directly to the sea stations.

The on-line communication takes place directly through the public tele net work for the Shore Stations (water levels) and for the sea stations via the Data Link Centre on Sprogø. The Data Link Centre communicates with the sea stations by either cable or radio link, see Figure 3.

On the figure is also shown a satellite communication link to a directional waverider located offshore the West coast of Jutland. This arrangement is part of an environmental monitoring programme carried out by DHI for the Port Authorities in Esbjerg. Six monitoring stations are included in this programme. The satellite passes the area approximately eight times a day and wave spectra are transmitted directly to DHI from the Danish Meteorological radar station in Rude Skov 3 km from DHI.



STATION	NAME	INSTRUMENTATION	ABBREVIATIONS	
SBF01	SURVEY VESSEL	AIR, ADCP, ASP, CTD, EMCP ES, POS, VAR, WS, VC	WLR	WATER LEVEL RECORDER
SBF02	ROMSØ TUE	WLR, AIR, TCOT	AIR	ACOUSTIC INTERFACE RECORDER
SBF03	ELEFANT GRUNDEN	AIR	ADCP	ACOUSTIC DOPPLER CURRENT PROFILER
SBF04	REERSØ	WLR	ASP	ACOUSTIC SUSPENDED SEDIMENT PROFILER
SBF05	SPROGØ NE	WR	WR	WAVERIDER
SBF06	SLIPSHAVN	WLR	TCOT	TEMPERATURE/CONDUCTIVITY/OXYGEN/TURBIDITY CHAIN
SBF07	VESTERRENDEN	AIR, ADCP, WR, TCOT	EMCP	ELECTROMAGNECTIC CURRENT PROFILER
SBF08	SPROGØ	MET, DATA LINK CENTER	VAR	VARIOSENS
SBF09	ØSTERRENDEN	AIR, ADCP, TCOT	WS	WATER SAMPLER
SBF10	KORSØR	WLR	MET	WEATHER STATION
SBF11	LANGELANDSBÆLT	WLR, AIR, TCOT	POS	POSITIONING SYSTEM
SBF12	OMØ WSW	AIR	ES	ECHO SOUNDERS
SBF13	STIGSNÆS	WLR, AIR	CTD	WATER COLOUMN PROFILER
SBF14	RUDKØBING	WLR	VC	VIDEO CAMERA
FRV15	GRENÅ	WLR		
FRV16	HESNÆS	WLR		
FRV17	BALLEN	WLR		
FRV18	SPODSBJERG	WLR		
SBF19	LANGELANDSSUND	AIR, TCO		

Fig. 3 The Great Belt Monitoring System - Station and Instrumentation Plan.

6. NOVEL APPROACHES

6.1 Instrumentation

Two measuring principles and instruments, which are new, or at least not that widely used yet, and employed by the monitoring programme, are the Acoustic Interface Recorder (AIR) and the Acoustic Suspended sediment Profiler (ASP).

AIR:
In order to obtain data for numerical model verification and on-line environmental data display, and to reduce survey vessel operation time for CTD profiles, the AIR system was designed both as sea bed and vessel mounted versions and as self recording and for on-line transmission and display (see Meister, 1990).

The main purposes of the Acoustic Interface Recorder are:

- to detect the acoustic reflection from the micro organisms settling in the area where temperature and salinity changes rapidly - the stratification layer.
- to digitize all the received signals with stamped signal strength and depth marks.
- to process the data and determined the position of the acoustic interface reflections.

The AIR system consists of four sybsystems: the acoustic, the processing and the data handling subsystem and finally the power supply shown in the simplified block diagram below.

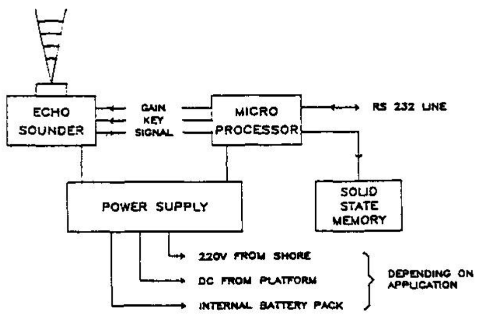


Fig. 4 Simplified block diagram.

In this instrumentation setup the Acoustic Interface Recorder is incorporated in seven deployed sea bed stations and one on the survey vessel.

Today the AIR systems have been in operation for 24 months and the average data coverage has been as good as 90% with no electronic break downs or any major fouling problems on the transducer surface.

Based on the data analysis and the unexplored options in the AIR system, further development will be obviously particularly in three quite different areas:

1. Tracing a sediment cloud in the water column from a survey vessel giving a relative picture of the sediment concentration.
2. Tracing the mixing of atmospheric air bubbles in the upper wave column from sea bed deployed stations.
3. Wave and tide recorder from a sea bed deployed station in shallow waters.

One could even consider that some of the above mentioned parameters could be gathered together with the 'normal' AIR data either as an on-line instrument or a self recording unit.

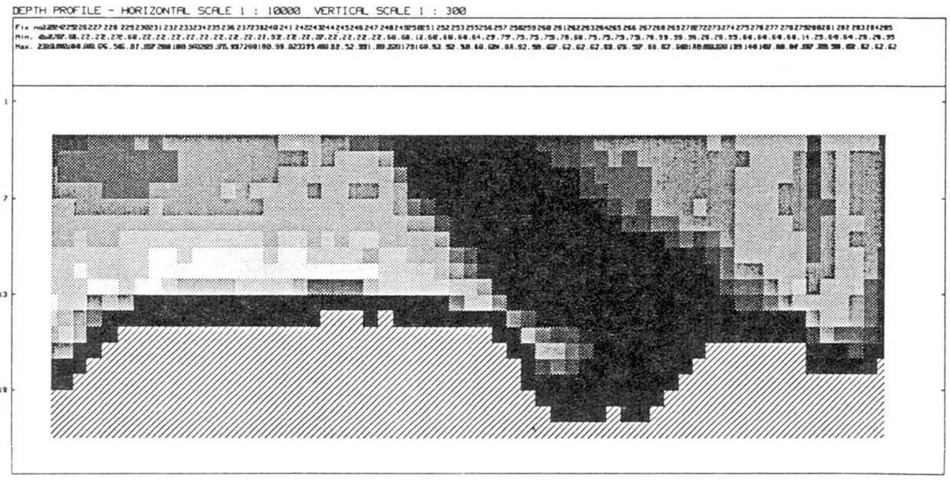
Not to forget the yet undiscovered possibilities which may be in the basic AIR system design.

ASP:
The Acoustic Suspended Sediment Profiler is a kind of bi-product or result of using the Acoustic Doppler Current Profiler, ADCP, (RD Instruments - San Diego, USA). The idea of using an ADCP for measurements of suspended sediments originated from the experience people had with echo sounders. Eg. on 20 kHz echo sounders, the internal waves propagating on the interface when sewage material is dropped into the ocean, can be seen. On 200 kHz echo sounders one can also see the cloud of material in the upper layer after dredge material is dropped from a barge. However, as more detailed information about the plume is required, ordinary displays used with echo sounders were found to be quite inadequate because the sediment plume normally appears as a big black cloud on the paper read out. To be able to display the enormous dynamic

range present in the back scattered signal, the data from the echo sounder have to be digitized an recorded for later processing.

Compared to a echo sounder, the ADCP has much poorer vertical resolution. However, since the data are digitized, the large dynamic range - given the right software - can be displayed and in contrast to the echo sounder the variation in the back-scattering coefficient can also be displayed as a function of space instead of time.

The vessel mounted ADCP system is provided with a software package which enables real time display (colour contour plots) of the intensity of the reflected signal corrected for geometrical spreading and absorption and combined with the current profilings the sediment flux as well as the direction of the plume can be obtained in the surveyed lines - transects. This saves a lot of time "looking" for the sediment plume and makes the ASP unique under operational conditions.



During Plume tracings a number of water samples are gathered for suspended sediment analysis over a wide dB range in order to establish a calibration curve between the back-scattered signals strength and concentration

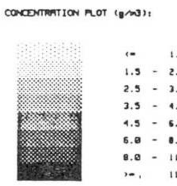


Fig. 5. Contour Plot of Suspended Sediment Concentration .

6.2 Communication

One of the challenges in the design of the monitoirng system was to ensure the ability to receive and analyse the data in real time and at the same time to be able to control and monitor the function of the measuring stations. These facilities would allow the data integrity to be under close scrutiny. For this purpose a special interface, SI, were developed based on the Dallas 5000 microprocessor, to support the operation of the remote sea-stations communicating via radio link. Among other facilities the SI involves two options for communication modes to the deployed instruments. Automatic data collection under the command of SI following a preset sampling scheme or a transparent mode of SI which allows a direct contact between the data control and each Sensor. (See Mogensen et al. 1991).

The SI is installed in the sea stations which use the light houses as platform (SBF02 and SBF11) and in the data gathering buoy launched between Langeland and Funen (SBF19).

6.3 Data Collection Control, Processing and Display System

Data collection and transmission from the various on-line sensors to the Data Centre at DHI is managed and controlled by a central computer - UNIX work station.

The central computer performs under unattended operation a number of background tasks. Eg. built-in diagnostics, generation of alarms and error and information logs.

In the central computer is installed a generalized data display and management package developed for use on engineering work-stations - the X-Windows Display System (X-DISP). The package is based on common industry standards for Graphical User Interfaces, and enables the user to build a customized, interactive graphical user interface for use as front-end to an on-line monitoring system or similar systems (see Vested et al. 1991).

7. COUPLING WITH NUMERICAL MODELS

On-line data collection offers a wide range of possibilities for using computers as assistance to the management of human intervention in the aquatic environment.

Two numerical modelling systems are integrated with the Great Belt monitoring system. The hydrodynamic model SYSTEM 21 is used in combination with meteorological models to provide forecast of water level and current velocity in the upper layer of the Belt for a five day period. The wind and air pressure over the North Sea and the Baltic are together with the tidal motions governing the hydrographic conditions in the Great Belt; but also the density difference between the brackish Baltic Sea and the southern Northsea Water contributes. By use of coupled meteorological and hydrodynamic models, and extensive use of the monitoring system, it is possible to predict the water levels and currents for these complex hydrographic conditions.

The DHI software system PARTICLE is installed on a PC on board the survey vessel to provide information on the spreading of dredging spoils.

A first step in the environmental impact assessment of dredging spoils is to predict how much of the material is brought into suspension, how much will be confined to the dredging/disposal site and the amount which will be carried away by the current and for how long it will remain in suspension.

It is in this context that numerical models are important and powerful tools when provided with sufficient information.

The concept used in PARTICLE is that the dredging spoil (or pollutants) is considered as particles being advected with the surrounding water body and dispersed as a result of random processes. Sedimentation of suspended sediments is accounted for via specified particle settling velocities. The light dampening caused by sediments in suspension is calculated on the sea bottom based on the background dampening for clear water, particle size and spacial distribution and water depth (see Petersen et al., 1990).

Particle assumes that current velocities and water levels can be prescribed in time and space in a computational grid covering the model area. This information can be provided e.g. by means of a proceeding (or parallel) hydrodynamic model simulation.

As the PARTICLE model installed on the survey vessel is used as an operational tool for optimization of the ship-based control measurements it can be run in either a 'Now-Cast' or Forecast mode.

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