CHAPTER TWO HUNDRED

WATERQUANTITY AND -QUALITY RESEARCH FOR THE RHINE MEUSE ESTUARY

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ABSTRACT
In commission of the Dutch Government (Ministry of Public Works), the Delft Hydraulics Laboratory carries out a long term research programme on the water quantity and water quality of the Rhine-Meuse estuary.
The researchprogramme has to provide the necessary hydraulic data as input for a management decision-making process. The programme is based on an "integrated approach philosophy" with respect to the various subjects to be studied and the research tools to be used (data from nature, hydraulic model, mathematical models and fundamental research).
The paper presents the essentials and backgrounds of the research programme and discusses some first results.

1. INTRODUCTION

Estuaries play an important role in life and economy. Many important cities have developed on their shores where navigation meets the inland transport systems and man has tried to interfere with estuarine systems in various ways. Hydraulically speaking estuaries are far from simple (e.g. Fischer et al, 1979). The tide penetrates, causing the water to rise and fall and to flow in and out with the regularity of its astronomical cause. Seasonal flows of fresh water from the river(s) traverse the estuaries and mix with the waters of the sea. The heavier sea water tries to intrude along the bottom, which is counteracted by internal friction and mixing with the fresh water.
Estuarine waters are far from pure. Salt penetrates from the sea, but also the "fresh" river flows carry a "natural" load of millions of tons of dissolved matter. Moreover, estuaries are often polluted by a diversity of wastes and heat from cities, industries and agriculture. Especially the suspended fine sediments absorb large quantities of chemical substances, thus contributing to the transportation and deposition of pollutants in the system.
Estuarine management tries to obtain an optimum balance between the different, often conflicting, interests. Essential for the management decision making process on estuarine system is the input of water quantity and water quality parameters, see figure 1.1. These parameters must be estimated by hydraulic research.

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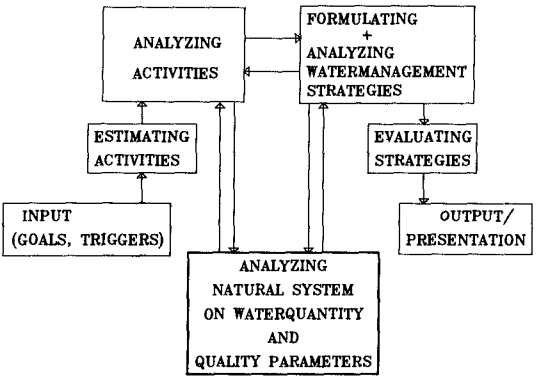


Fig. 1.1 PROCESS WATERMANAGEMENT ANALYSIS

The Rhine-Meuse estuary is situated in the south-western part of the Netherlands and covers a densely populated area. The estuary system consists of various branches, forming a network with the Rotterdam harbours in the northern part and large tidal areas in the southern part, see figure 1.2. At the upstream side the system is bounded by three fresh-water river branches, the downstream salt tidal boundary consists of a free and a regulated outflow into the North sea.
Salinity intrusion is of the partly mixed and layered type (Van der Heijden, de Jong, Kuijper, Roelfzema, 1984) and regularly reaches upstream of Rotterdam. The Rijkswaterstaat (Dutch Government, Ministry of Public Works) is responsible for the management of the Rhine Meuse estuary. The water quantity and -quality problems that play a role are safety against inundation, maintenance of infrastructural works, water supply for industrial, agriculture and public use, discharging and flushing the system and the accessibility for navigation. These management aspects show interferences and conflicting interests. The management aspects have been translated into a number of subjects on which hydraulic research is carried out. These interrelated subjects, are :

- flood and flood control
- morphological stability of the system (sedimentation and erosion)
- distribution and discharge of (fresh) water
- salinity intrusion (intake locations of fresh water)
- siltation (dredging of harbours and ecological impacts)
- dispersion of heat and waste
- discharge of ice

Guidelines for the management and therefore also for the research on these subjects are, amongst others, the economy (e.g. with respect to the dredging) and laws and legal statements with respect to the distribution of fresh water, pollution of surface water and to salinity intrusion.

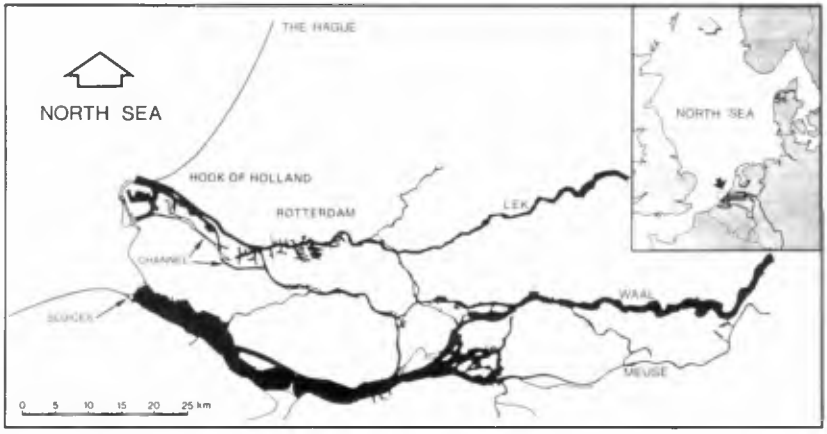


Fig. 1.2 PLAN VIEW RHINE-MEUSE ESTUARY

2. THE RESEARCH PROGRAMME

Relevant for the set up of the research programme are the complexity of the physical processes in the estuary system, the variety of water quantity an -quality problems to be studied and the required accuracies of the answers to be given. The physical processes and the variety of problems have a common basis: the inhomogeneous tidal flows in the system (= affected by the density differences between sea and rivers). These inhomogeneous tidal flows are primary determining the physics in the system.

Understanding these flow phenomena under various hydraulic and geometrical circumstances is therefore essential for analyzing and interpreting research results on the different problems, separately and with their interference, see figure 2.1. A systematic investigation on these various conditions, in this way, forms the core of the long term research programme. Within this systematic investigation the main objectives are to solve practical problems on water quantity and/or quality and to provide data based on which optimum water management strategies can be developed. Additional objectives are the development of mathematical models and the development of techniques for research and interpretation.

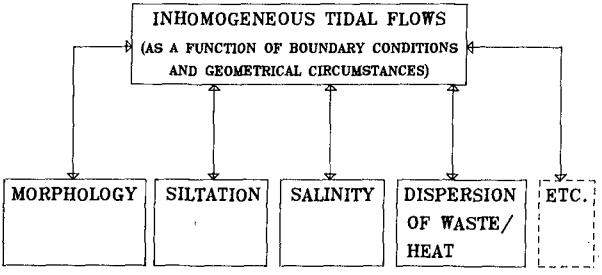


Fig. 2.1 PHYSICAL RELATIONS

The systematic investigation on various hydraulic and geometrical circumstances includes seven groups of similar subjects. The groups are a result of an analysis of the physics of nature and of the water quantity and -quality problems. The question has been to estimate the ranges of the hydraulic and geometrical conditions, regarding the present situation of the estuary system and the possible changes due to nature or due to man-made measures. The resulting groups are:

- boundary conditions (tides, including meteorological effects on mean sea levels, and riverdischarges)
- closing or opening harbours or branches
- withdrawals and changing the discharges between riverbranches
- deepening or raising bottom levels of branches
- resistance and mixing of branches
- dispersion of heat and waste, and
- small scale measures like groynes, bars (to be removed), bottomgroynes (to be build), cut-off bends, etc.

For these groups the relevant parameters have to be investigated in a systematic way for a wide, but realistic, range including the direct practical problems. Because of the necessity of an unambiguous comparison of research results the total programme is carried out under stsndardized boundary conditions. Depending on the accents to be laid, different combinations of boundary conditions, resulting from the first group, can be used (neaptide/springtide time series, change of the mean sea level due to meteorological effects and the discharge of the fresh water river inflows).

In the research programme, as described above, emphasis is laid on (the changes in) the inhomogeneous tidal flows as a common basis for analyses and interpretations. This "integrated approach philosophy" is employed also with respect to the research tools. For each specific problem an adequate set of research tools is used; the hydraulic scale model of the Rhine-Meuse estuary, various mathematical models, measurements in nature and, for general support, fundamental studies. The set-up serves two objects: the solving of the water quantity and water quality problems and the development of mathematical models, gradually making the hydraulic scale model redundant.
With respect to the solving of the practical problems, up to now the hydraulic model is the core of the programma. Field data, and mathematical models are mainly used as a guide for the measurements in the hydraulic model, by providing in a systematic way tendencies and (rough) indications. Subsequently a restricted selection of tests in the hydraulic model gives the detailed information with the required accuracies for the practical use. For example: changes in salinity distributions near intake points have to be obtained with an inaccuracy in the orde of 100 mg Cl/l. On the other hand the hydraulic model provides input for mathematical models. For example detailed measurements of the inhomogeneous tidal flows serve as input for calculations on siltation or waterquality processes, see figure 2.2.

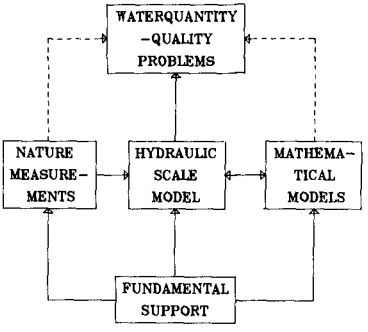


Fig. 2.2 OPERATIONAL USE RESEARCH TOOLS

With respect to the development of mathematical models one has to distinguish several phases. The actual development takes place in the fundamental framework, including estimation of numerical scheme, treatment of boundaries, research on and the description of turbulent

processes on momentum and mass etc. The hydraulic scale model is used to verify the models under systematically varied circumstances with respect to geometry and boundary conditions.
Finally a relatively restricted verification (or validation) on field data proceeds the operational use of the mathematical models. This set-up implies an interactive development process between the various research tools, see figure 2.3.

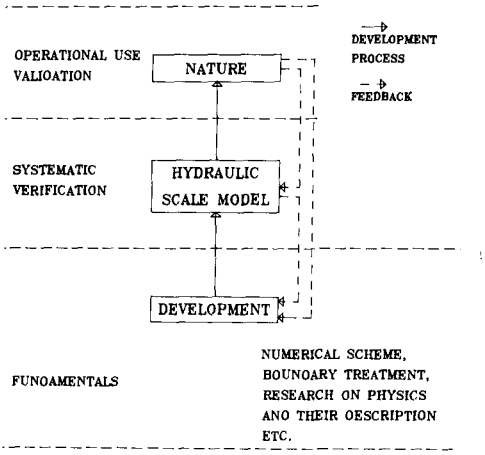


Fig. 2.3 DEVELOPMENT MATHEMATICAL MODELS

3. FACILITIES

In this chapter, a brief description will be given of the facilities "field measurements", hydraulic scale model, mathematical models and fundamental support.

3.1- Field measurements

The measurements can be divided into two types: continuous measurements of waterlevels and salinities and "special purpose" measurements. The former includes estimation on fixed locations all over the estuary system of some 40 waterlevels and of some 10 salinities. The measurements are mainly meant for long term system control.
The latter may include calibration measurements with, in addition to the permanent measurements, extensive measurements with boats of flows and salinity distributions (Van der Heijden, Kuijper, de Jong, Roelfzema, 1984), verification measurements and measurements on specific locations and on phenomena such as exchange processes between harbour and river, dispersion processes, streampattern on junctions, etc.
All the field measurements are performed by the Ministry of Public Works.

3.2- Hydraulic scale model

The hydraulic scale model of the Rhine-Meuse estuary, simulating tidal flows and salinities, is operational since summer 1982, see figure 3.1. The model covers the area of figure 1.2 and is the rebuilt and extended version of the earlier Rotterdam Waterweg hydraulic model (Van Rees, Van der Kuur, Stroband; 1972), (Breusers, Van Os; 1980). Its scale factors are therefore the same: 1 : 64 for the vertical and 1 : 640 for the horizontal scale. The model has been calibrated and verified with extensive field data showing a good simulation of the dominant physical processes, viz, tidal flows, changes of the mean sea level due to meteorological effects, river discharges, vertical gravitational circulations and vertical turbulent diffusion (Van der Heijden, Kuijper, de Jong, Roelfzema, 1984). The area where salinity intrusion occurs has been modelled, in plan view, simular to nature. The sea area and the

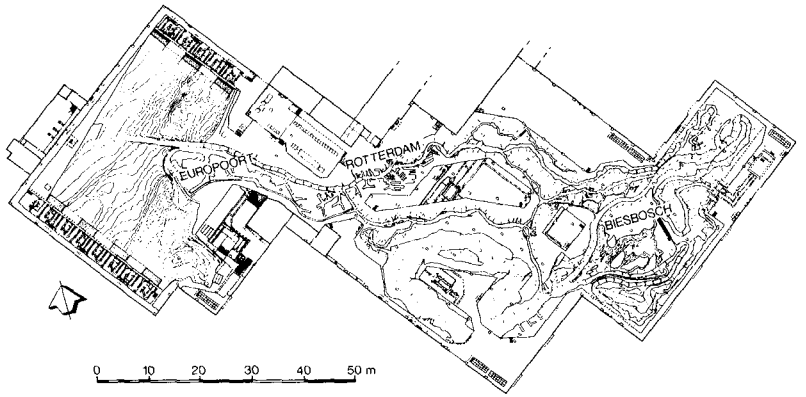
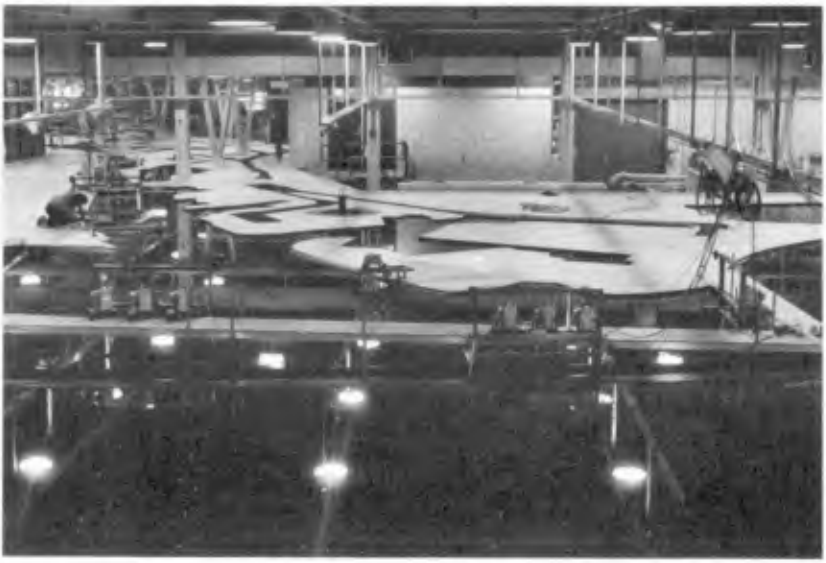


Fig. 3.1 HYDRAULIC SCALE MODEL

upstream parts of the model are mainly meant to provide the correct boundary conditions. Measurements include waterlevels, velocities, discharges and temperatures and conductives which are combined to densities. The discharges are measured on 14 locations near the junctions of branches in the network by means of acoustic instruments. Using the doppler-principle and by integrating the signals over their cross-sections, these instruments present contineously cross-sectional discharges. For the measurements of conductivities, besides of the conventional "one-point" probes, the Delft Hydraulics Laboratory developed bar-type conductivity probes. Every bar includes conductivity probes, which makes it possible to present the conductivities in 12 positions in the vertical. In the model more than 20 of these conductivity bars are operated. Combined with temperatures, these bars allow continuous measurements of the vertical salinity distribution under tidal time series.



HYDRAULIC SCALE MODEL

ACOUSTIC DISCHARGE
MEASUREMENT INSTRUMENT

CONDUCTIVITY PROBE

3.3- Mathematical models

It is the intention to replace the hydraulic model by a set of mathematical models as soon as possible. The main reasons for this are the relatively high cost of exploitation of the hydraulic model and the necessity to have facilities to study, beside the water motion and salt distribution, the transport of sediment (especially mudtransport), the transport of cooling water and the waterquality. The set of mathematical models will be a system consisting of a base model that simulates the water motion and salt distribution and several transport models coupled to the base model for the computation of sediment transport, cooling water transport or water quality.

- Choice of the base model

For the selection of the most adequate model with predictive proporties for the Rhine-Meuse estuary it is necessary to have insight into the physical mechanisms that are dominating in the problems under study. Important for the choice is the geometry of the area and the stratification of the estuary. In this respect the Rhine-Meuse estuary can be divided into 4 areas:

- the homogeneous network of tidal rivers which are relatively narrow (width/depth ratio B/H < 100). Generally a one dimensional (1D) basemodel is sufficient in this area
- the wide homogeneous southern part of the estuary. A twodimensional depth averaged (2Dh) model gives generally sufficient information
- the inhomogeneous, narrow (B/H < 100) tidal area Rotterdamse Waterweg, New- and Old Meuse in which a stratified salinity distribution is present (see figure 3.2) while gravitational circulation and exchange phenomena are important. So the phenomena in the vertical plane through the axes of the river are important and at least a twodimensionally laterally averaged (2Dv) branched model is necessary.

STRATIFICATION RWW + N.MAAS

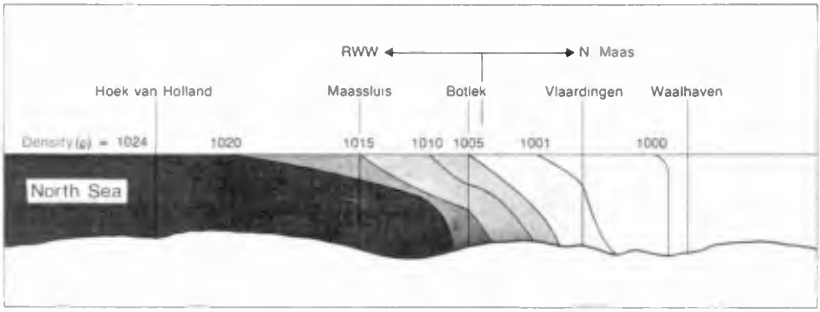
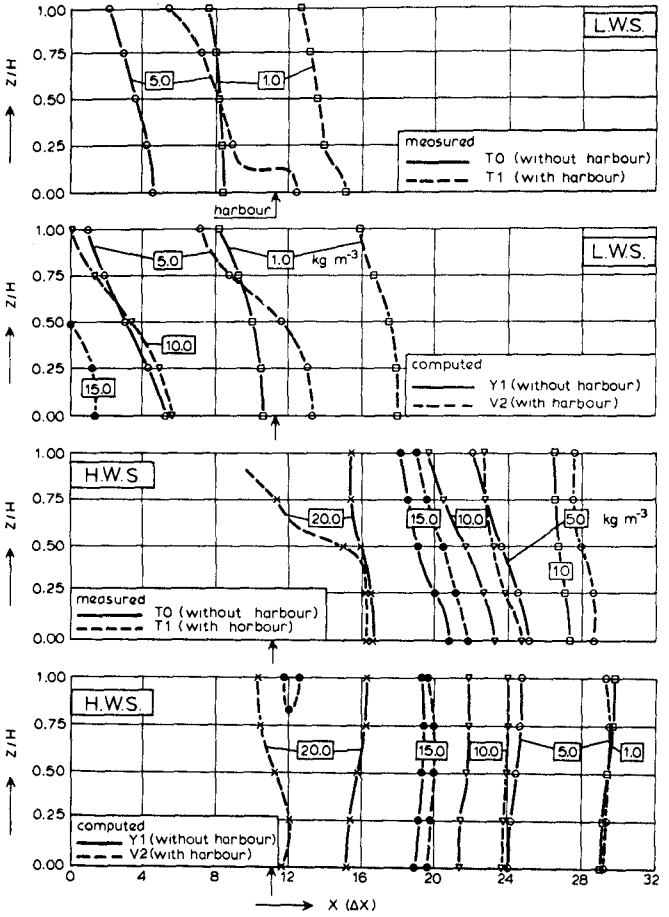


Fig. 3.2

- the stratified, wide sea-area at the mouth of the Rhine-Meuse estuary. Beside the two horizontal dimensions along the coast a stratified situation is often present because of river discharge from the estuary and so the vertical dimension is important too: a 3D model will be needed.

For the choice of the base model other important factors are the availability (now and in the future) and the cost of development and operational use. A 1D model for the whole estuary, called ZWENDL, is available, which has been calibrated for the water motion. A 2Dv model for the salt intrusion part of the estuary, called DISTRO, has been build, which was developed from a tidal flume version [Perrels and Karelse, 1981], see figure 3.3



COMPARISON OF MEASURED AND COMPUTED INFLUENCE OF THE HARBOUR ON THE LONGITUDINAL DENSITY DISTRIBUTION AT L.W.S. AND AT H.W.S.

Fig. 3.3 **2-Dv MODEL**

These considerations have resulted in the choice for a base model consisting of a combination of a 3D, a 2Dv (DISTRO) and a 1D (ZWENDL) model which are coupled with each other, see figure 3.4. A two-layer model will serve as an alternative for the 2Dv model and as a special purpose model for the simulation of silt transport processes in the inhomogeneous part of the estuary.

With respect to the modelling of sediment transport, cooling water transport and water quality for each area the type of modelling still has to be chosen (the choice is limited by the choice of the base model).

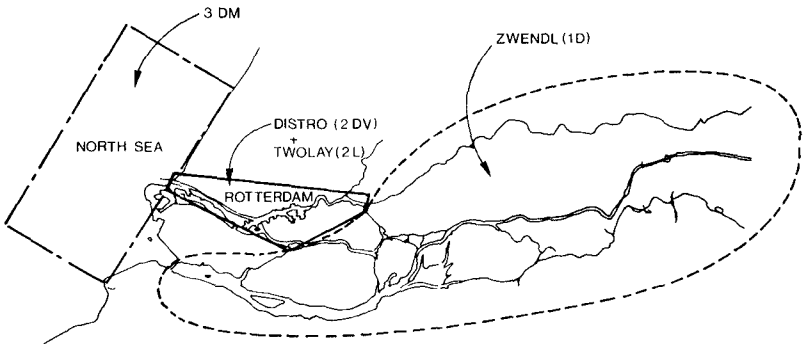


Fig. 3.4 BASE MODEL

The coupling of these models to the base model will present numerical problems. At this moment the 2Dh (preceeding the 3D development)/1D coupling is under research. Another important problem using 3 types of models and comparing computional results with each other and with measured results from prototype or hydraulic model is to get a unification of

- geometry schematization
- initial- and boundary conditions
- in- and output and the databases
- presentation of results
- way of calibration and interpretation

Activities on these aspects are carried out.

As mentioned before the 1D model ZWENDL is an operational model with respect to the water motion for the whole Rhine-Meuse estuary.

Description ZWENDL

The one-dimensional model "ZWENDL" covers the tidal part of the rivers. The sea boundary is situated near Hook of Holland. Longitudinal dispersion is modelled as a gradient type transport. At first a "Thatcher Harleman"-like approach was followed for the dispersion coefficient and the sea boundary conditions for salt.

The results of the calibration and verification of ZWENDL with this formulation for the tidal motion and salinity distribution in the Rhine-Meuse estuary were unsatisfactory. So the study is going continued to obtain best formulation for the dispersion relation as function of location, time and circumstances and the best formulation of the sea boundary for salt as function of time and conditions.
1D models for sediment transport and waterquality in estuaries are available, they have to be coupled to ZWENDL.
Description "DISTRO"
The two-dimensional vertical model DISTRO covers the salt influenced part of the rivers (see fig. 3.4).
The vertical diffusion is modelled with a mixing length approach. The reduction of vertical diffusion due to density differences is modelled as a first approach with damping functions to represent the effect of stratification. A K-ε modelling is in study. The horizontal dispersion is modelled as a gradient type transport. The sea boundary condition is similar with the one-dimensional (Thatcher-Harleman-like) approach but now for each layer in the vertical [Perrels, Karelse, 1981].

Besides DISTRO a 2 Dv cooling watermodel and water quantity model is available and a silt transport model will be developed in the near future.
The development of a 3D model for the sea part of the estuary is still in a begin stage of development

3.4- Fundamental support
A basic part of the set of research facilities is formed by the fundamental support. Also in commission of the Dutch Ministry of Public Works the Delft Hydraulics Laboratory carries out a long term research programme on inhomogeneous flows and silt transport processes. The programme includes research on turbulent mixing in stratified flows and on the transport mechanisms of silt and silt layers under inhomogeneous circumstances. Based on these studies, theoretical as well as experimental, also the mathematical models for the Rhine-Meuse estuary are developed and improved. For this fundamental research, the Delft Hydraulics Laboratory will again have the possession of a tidal silt/salinity flume (of 130 m length), to replace the flume that was destroyed by a fire in 1979.

4. RESULTS/DISCUSSION

In the research programme, systematic studies have been carried out on the effect of boundary conditions (tides, including wind effects and river discharges) and on the effect of changes in the tidal area (building or closing harbours). Tests, carried out under cyclic and under time series conditions of several weeks show the importance of the interaction of harbours with the tidal boundary conditions. Wind effects generating elevations of the mean sea level introduce complex effects on the salinities, see figures 4.1 up to 4.2). The mixing influence of harbours on the salinity distribution appeared to be significant. Closing all the harbours, implying decreased tidal filling- and emptying

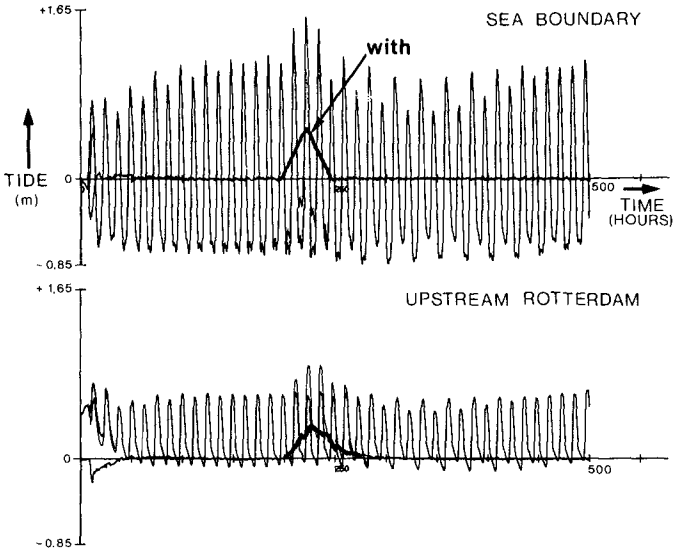


Fig. 4.1 VERTICAL TIDES AT TWO LOCATIONS, WITH- AND WITHOUT ELEVATION OF MEAN SEALEVEL

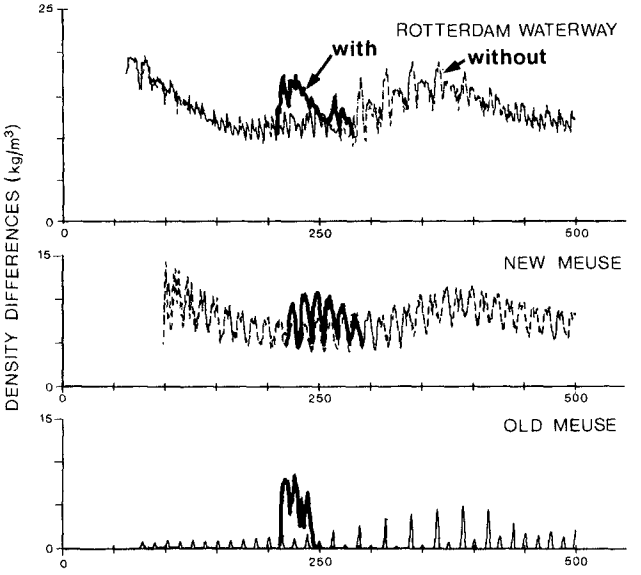


Fig. 4.2 TIME SERIES SALINITIES

volumes results in a smaller salinity intrusion on the one hand. On the other hand closing the harbours results in smaller tidal amplitudes causing less vertical mixing and therefore resulting in a larger salinity intrusion. For the Rhine-Meuse estuary, closing all the harbours results in an increase of vertical stratification and thereby an increase of salinity intrusion, figure 4.3). The same tendencies result from closing single harbours on the Nieuwe Maas, (see also: Abraham, De Jong, Van Kruiningen, 1984).

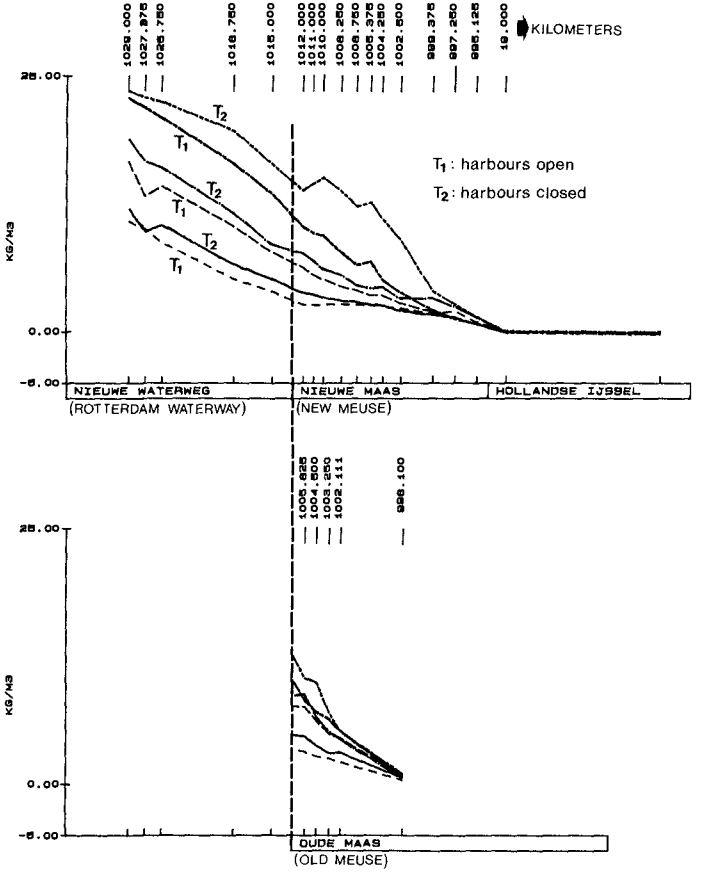


Fig. 4.3 ISOHALINES AT HWS

These experiences are relevant for the mathematical modelling, especially with respect to the length of the time series to be simulated and the density of data to be aquired. On the short run the experiences are used for the improvement of the inhomogeneous 1-D dispersion description and for the further verification of the 2-Dv model. Tests in the hydraulic scale model provide velocity- and salinity distributions on the base of which, in an inverse way, one-dimensional dispersion coefficients are estimated. Analyses of these coefficients may lead to an improved dispersion formulation.
A first test of the 2-Dv model with damping functions to represent the effect of stratification, resulted in a systematic difference between the model and nature; the model generates too much mixing. Besides of the implementation of the more sophisticated K-ε modelling, the schematization has to be refined resulting in the lay-out of fig. 4.4. Subsequently a systematic research on the sensitivity for numerical, geometrical and hydraulical parameters has to be carried out (gridsize, boundaries, harbours, junctions, roughness, longitudinal viscosity and dispersion and stratification).

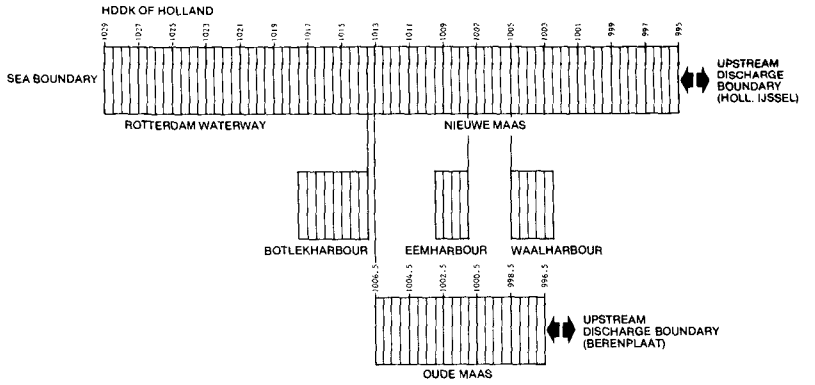


Fig. 4.4 SCHEMATIZATION OF SALT INTRUSION PART OF RHINE MEUSE ESTUARY IN DISTRO MODELLING ΔX = 500 m

In this integrated approach as described above, the results of the research programme provide information for the practical management of the estuary system. For example on the effect on the inhomogeneous tidal flows due to the eventual closing of smaller Rotterdam harbours, or on the impact of exchange phenomena between harbours and rivers on local siltation processes.

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