CHAPTER TWO HUNDRED THIRTEEN

CALIBRATION AND ADJUSTMENT PROCEDURES FOR THE RHINE-MEUSE ESTUARY SCALE MODEL

BY

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ABSTRACT

At the Delft Hydraulics Laboratory the hydraulic model of the Rhine-Meuse estuary has been rebuilt and extended after being destroyed by fire in 1979. The new model has been operational since the summer of 1982 for water quantity and water quality research. The present paper deals with the calibration and adjustment procedures for this hydraulic model. Successively the (physical) backgrounds for the calibrationprocess, the techniques used for provision of boundary conditions and the procedures for adjusting flows and salinity distribution are discussed. Finally, the results of calibration and verification and the experiences gained on the employed techniques will be analysed.

1. INTRODUCTION

The new hydraulic scale model is, in commission of Rijkswaterstaat (Ministry of Public Works), employed as one of the research tools in the framework of a long term research programme on water quantity- and water quality problems of the Rhine-Meuse estuary (Roelfzema, Karelse, Struijk, Adriaanse, 1984). See fig. 1.1 and 1.2. The model has, for practical reasons the same scales as those of the earlier model, i.e. the vertical scale factor is 64 and the horizontal scale factor is 640. Reviews of the earlier model are given by Van Rees, van der Kuur, Stroband (1972) and by Breusers and Van Os (1981).

Hydraulic modelling of the complicated inhomogeneous flows of the Rhine-Meuse estuary implies that the various physical mechanisms are simulated in an integrated way. A basic requirement for such a simulation is knowledge of these physical mechanisms. Based on this knowledge the appropriate scale laws and scale factors have to be estimated (or, in this case reanalysed) and the most adequate type of additional roughness - and mixing elements has to be chosen, section 2.

Section 3 and 4 deal with the time variant boundaries of the rivers and sea, section 5 describes the adjustment of the "roughness" of the river system. To adjust the flows of the complex network a procedure based on a least squares method, with a general applicability for the convergence of the calibration processes has been developed.

Adjusting the salinity distribution was achieved with more conventional methods. The actual calibration process is discussed in section 6, while in section 7 the results of calibration and verification are analysed and some concluding remarks are made.

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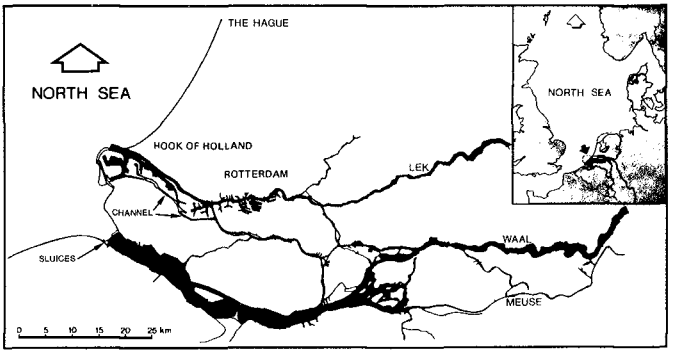


Fig. 1.1 PLAN VIEW RHINE-MEUSE ESTUARY

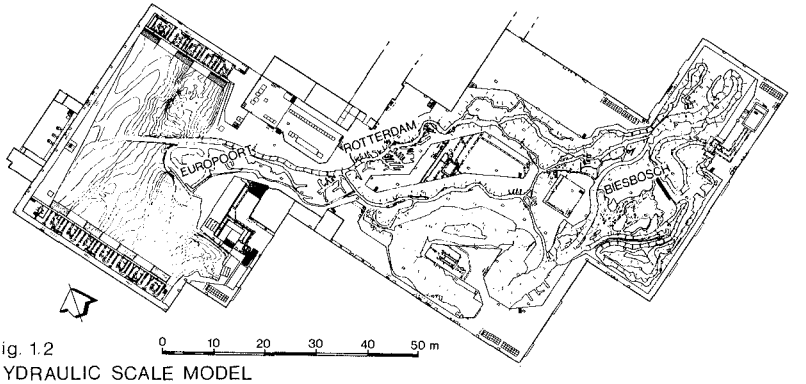


Fig. 1.2
HYDRAULIC SCALE MODEL

2. BACKGROUNDS HYDRAULIC MODELLING

Characteristic for the geometry of the Rhine-Meuse estuary is its network system, consisting of a number of rivers with almost rectangular cross-sections. Only in the upstream parts of the system there are branches with flow and storage areas. In the northern part the Rotterdam harbours are found while in the southern part large, flat storage areas are present, forming about the half of the total tidal area of the estuary system.
The system is bounded at the upstream part by three river inflows, with a total discharge ranging from about 600 m^3/s up to about 8500 m^3/s. The downstream part is bounded by a free and a regulated outflow into the North Sea. The water levels show a dominant semi-diurnal tidal variation of about 2,20 m and 1.50 m at springtide and neaptide respectively.
The density difference between the sea and the fresh river inflow is about 25 kg/m^3.

The resulting inhomogeneous tidal flows show tidal influences to more than 100 km upstream from the mouth of the Rotterdam Waterway and salinity intrusion ranging from 30 up to 50 km.
Analyses of the physics of the system has been made possible by various

measurements carried out in the last few decades. Applying the internal estuarine number E_d according to Thatcher and Harleman (1972), the estuary system appears to be a partly mixed or layered type with normal values between 2,5 and 0,5. Amongst other approaches as dimensional analyses and decomposition methods, these measurements show that the dominant mechanisms are the vertical tidal effects, including the meteorological influences on the mean sea level, the river discharges, the vertical gravitational circulations due to density differences between sea and rivers and between rivers and harbours and the vertical turbulent diffusion. Of minor importance or negligible are horizontal circulations, lateral effects, longitudinal and lateral turbulent diffusion and wind effects on mixing. Applying the Froude-law, a basic condition for the modelling of gravitational and inertial forces has been satisfied, and thus for the modelling the dominating mechanisms of tides, river discharges and gravitational circulations.

The vertical scale factor of 64, taken over from the former model, allows in general a sufficiently high Reynolds number to simulate the overall structure of turbulence. A resulting representive Reynolds number is of the order of 10^4. In this way the large scale turbulent eddies are reproduced correctly, satisfying a necessary modelling condition.

While the vertical scale factor had to be determined by principal considerations, the horizontal scale factor in general is determined on practical considerations of costs/economics. The horizontal scale factor of 640, also taken over form the former model, meets a reasonable optimum between the practical considerations and the experiences gained on distorted, inhomogeneous tidal models, (van Rees, et al 1972).

With these scale factors, the model (fig. 1.2) includes the research part of the estuary system along with a part of the North Sea and the fresh water rivers. These rivers have the correct scale for all hydraulic relevant parameters (length, depth, cross-sectional area etc.), but they have been bent to limit the total area of the building.

In the Rhine-Meuse estuary the bottom influence on turbulent shear stress and on mixing are strongly dominating the side wall influences. The additional bottom roughness- and mixing elements, necessary because of the distorted scales, effectuates that in the model bottom influences are also dominating. To find the most adequate type of elements, analyses and flume tests have been carried out.

Premises for these activities were that the bottom elements have to be as small as possible to minimize local disturbances. Also they have to provide the model with non-directional resistance. Furthermore the elements have to facilitate flows near the model bottom in order to allow (analyses of) sediment transport processes, they have to allow occasional cleaning of the model and they have to be removed and to be replaced easily in order to facilitate the calibration process. Several types of elements have been investigated (viz. blocks, plates, bars, etc.), finally resulting in the choice for cross-shaped elements, fixed with a short bar on the modelbottom, fig. 2.1.

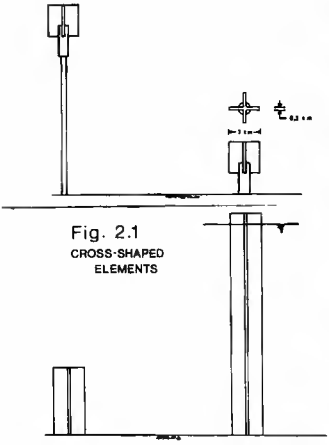


Fig. 2.1
CROSS-SHAPED ELEMENTS

With respect to the geometry to be modelled it is very hard to estimate the actual differences between a model of concrete and a prototype under water. However, experience from past models has shown that no systematic differences could be found if every possible precaution was taken to make the model as accurate as possible. The results of new economic techniques involving concrete blocks of model, cast on polystyrene moulds were carefully compared to the more labour intensive ways of manually modelling a river. Although the result does not look as natural, no systematic differences could be found.

3. THE RIVER BOUNDARIES

From a research point of view only the central part of the model is of interest. The upstream river branches and the downstream model sea serve as generators of non-reflective boundary conditions for the area of interest.

The three upstream river branches begin in the model at places where the tide is negligible or that coincide with weirs. It is necessary to prescribe discharges at the river boundaries which may vary smoothly in time. In general these discharges are derived from water levels by means of a rating curve.

Tests in mathematical models showed that accuracy of the flow control should be so good that the mean over one minute should deviate less than 0,2% of the prescribed value within the whole range from 1.8 l/s (600 m^3/s) to 26 l/s (8500 m^3/s). This could be accomplished by using a constant head water tank and a system with several flow meters and valves, that switches slowly and automatically from one valve and flowmeter to the next.

4. THE SEAWARD BOUNDARY.

The conditions in the river mouth are described by the time variant water level and by the density, which is a function of time and depth. This water level and density are not directly controlled but are generated by the real flow field in the model sea. As there is hardly any stratification in the prototype at the position of the boundaries in

the sea, these boundaries have been constructed in the model as actively mixed sections (each of four meters length) where the total flow is accurately controlled (fig. 4.1). The layout is the same as in the old model (see Van Rees et al.), but all boundaries are now flow controlled. The electronics and the real time software are comparable to that of the old model (see Adriaanse et al.), but have been updated (completely digital) and highly integrated.

The problem with the control of these boundaries is that usually when prototype measurements on the river take place, the measurements in the sea are very limited in number. The procedures described in this section make the generation of reliable boundary conditions for such periods possible by using the measurements of other periods. The time series used to control these boundaries are derived from measurements as follows:

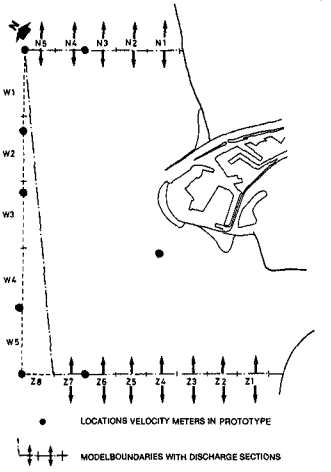
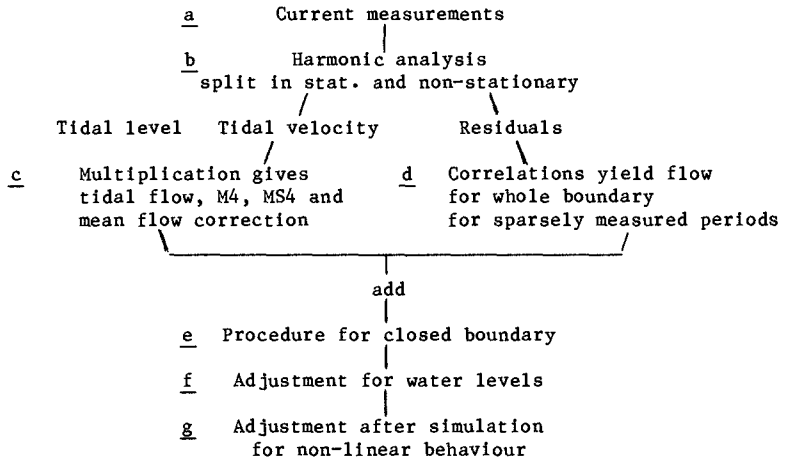


Fig. 4.1



a. The currents at sea were measured at about 8 points during various periods of about one month. (fig. 4.1). Several measurements were simultaneous, others were not.

b. According to good practise in time series analysis, the non-stationary part of the signal was separated from the stationary (this is the part for which the expectation does not change with

time). Harmonic analysis was used to compute the tidal part and the stationary residual was assumed to consist of meteorological effect and noise.

c. The tidal flow through each of the sections was then computed as the product of the velocity component perpendicular to the boundary and the time variant cross sectional area. This product yielded relevant higher harmonics (M4 and MS4) and gave a large correction to the mean flow. Gaps were filled in using correlations from short (13 hours) manual measurements made at many points on the boundaries.

d. For the meteo part of the flow no relevant correlations were found between the residuals of water levels and currents. Correlations between the residuals of simultaneous current meters at different positions were found to be significant for longer period variations (over 12 hours). In this way the residuals of current measurements at one position gave information about the flow through each of the model sections during the periods to be simulated.

e. As the flow pattern at sea is mainly parallel to the coast the north-western boundary of the model is a closed boundary (for economic reasons). Therefore procedures were developed in the old model to add the flow through this boundary to specific sections of the other boundaries (mainly the northern section of the north-east boundary). Afterwards these procedures were checked by studying the behaviour of the fresh water wedge in the prototype and the model sea.

f. The basic time series of the flow will not necessarily result in the correct water level in the model. Therefore cross-spectral analysis (of initial simulations) between the total volume of water in the model and the water level at the mouth of the river was used to compute a transfer function. It shows very clearly a resonance period of about 70 s. This function was measured for periods of 1125 s (= 25 hours prototype) to 56 s and extended to 28 s to give a smooth damped time representation used for convolution. Applying this function to the desired water level at the mouth of the river gives the desired total volume of water in the model. Comparing this with the basic flow of the model sections gives a correction to the flow into the model. This correction was then distributed over all model sections in proportion to their cross sectional area. The correction is small and will not affect the flow pattern in the model sea.

g. Then the period is simulated in the model. As the cross-spectral analysis uses linear relations there will be some differences between the desired and realized water levels. The same response function as used in paragraph f is then used to make another extremely small update for the flow sections to compensate for the non-linearities. A slow back-coupling from water levels to the flow sections is used to facilitate starting up and to compensate for drift in flow meters or intentional changes in river discharges.

5. ADJUSTING ROUGHNESS

The damping of the tide wave, penetrating into the system from sea is caused by loss of momentum due to turbulent momentum exchange between the flow and the geometry. Though the loss of momentum on a river is often described with a "roughness-constant" (e.g. Chezy, Manning) it is clear that the hydraulic conditions are of primary importance in determining the turbulent structure of the flow. Since, in practice, it

is not possible to measure the momentum-exchange directly in prototype or model, calibrating the flow in a distorted model implies the adjustment of the correct amount of roughness-elements in order to achieve a proper reproduction of the flow. In that case loss of momentum on a river is correctly scaled, as can be derived from the momentum equation.

Apart from the problem how to direct the adjustment of the roughness in a new and complicated model one of the first problems seems to be the enormous amount of information it generates and how to control this. Changing the roughness in one branch might cause the water to take another route and although there would certainly be a human damping factor in the procedures a tedious trial and error procedure would not be welcomed. This section describes how the dataset was reduced to give overall picture of the model as compared to the prototype. It shows how this set was then used to interactively give information about the changes in roughness to be made. For this purpose it was necessary to estimate the effect of changes in roughness from the behaviour of a mathematical model. This behaviour also gives a broad idea of the situation that will emerge after these changes have been implemented.

It was shown for a non-dendritic system (a system with islands) that the adjustment should be done on water levels and discharges simultaneously if the circumference of the islands is small with respect to the tidal wavelength. This problem was solved by using acoustic open channel flow meters at several points in the model that gave the total instantaneous flow in one reading instead of one position in a cross section (see Botma, 1978 and Roelfzema et al., 1984).

In the following sections the procedures used will be described in detail. Section 5.1 shows the principle of least squares as used for the optimisation and in section 5.2 the solution procedure is described. Section 5.3 gives an idea of how the procedures were implemented.

5.1 Least squares for optimisation

The purpose of the adjustment may be formulated as getting the best possible reproduction of the water levels and discharges in the model. "Best" was then defined to be the situation with the smallest sum F of the standard deviations of the difference between the time function f of model (m) and prototype (n for nature).

$$F = \sum_p \frac{1}{s_p^2 T} \int_T (f_n - f_m)^2 dt \qquad (1)$$

where p is the number of measured locations, T is the measured period and s_p is a weight function, that is taken to be the inaccuracy of the measurement at the point p in prototype and model combined. s_p makes F dimensionless and creates the possibility of incorporating water levels and discharges in one object function. Furthermore it was decided to compute F only for the mean and for the most relevant tidal components (M2, S2, M4, MS4, O1) or their fourier equivalents as far as they may be computed from the measured period. Each such component is called a characteristic. This leads to an enormous data reduction. Actually the calibration aimed at a correct reproduction of these characteristics, giving an overall good reproduction and discarding minor deviations.

Using Parceval's theorem F may now be written as

$$F = \sum_p \frac{1}{s_p^2} \left\{ (\Delta A_o)^2 + \tfrac{1}{2} \sum_j \left((\Delta a_j)^2 + (\Delta b_j)^2 \right) \right\} \qquad (2)$$

where ΔA_o is the difference in the mean value and j is the counter for the relevant fourier component, Δa_j and Δb_j are computed from the amplitude A_j and the phase ϕ_j as follows:

$$A_j \cos(\omega_j t - \phi_j) = a_j \cos \omega_j t + b_j \sin \omega_j t \tag{3}$$

$$\begin{aligned} \Delta a_j &= a_{j,n} - a_{j,m} \\ \Delta b_j &= b_{j,n} - b_{j,m} \end{aligned} \tag{4}$$

It is clear that F is a function of the roughness R_k in all the river branches k as the amplitudes $a_{j,m}$ and $b_{j,m}$ depend on R_k. F is also a function of the boundary conditions of the model; if, for example, a discharge was measured on a river branch which was different from the discharge at the boundary (both measures with the same accuracy) then one might take the discharge for the model to be somewhere in between, resulting in a lower F over the two points. By distinguishing between the boundary conditions and the measured values at the boundaries of the model one eliminates the overweight usually present there. So in the following one should not only think of roughness when R is used but also of several characteristic features of the boundary conditions that may be adjusted during the process of calibration. Six boundary conditions were used (three discharges, mean sea level and the amplitude and phase of the semidiurnal tide) and 19 sections of river branches where the roughness may be changed.

Could one be more explicit about the relation between F and R_k? In the study phase for the adjustment an analytical harmonic model was build which behaved astonishing well. From such a model (as fully described by Dronkers (1964)) the following assumptions were derived:

1. For the roughness parameter R_k the formula $R = g/C^2$ may be used where g is the acceleration of gravity and C is Chezy's C.
2. A change in R_k will give a change in the mean components A_o, proportional to the change in R_k. Actually this only applies to the tidal region but for small changes in R_k it may also be used for the upstream branches of the model where the quadratic nature of the resistance becomes significant.
3. A change in R will give a change in the amplitude A_j in proportion to the change in R and the value of A_j.
4. A change in R_k will give a change in phase that is proportional to this change.

In formula:

$$\begin{aligned} A_o^{new} &= A_o^{old} + \alpha_1 \Delta R_1 + \alpha_2 \Delta R_2 \ldots \\ \ln(A_j^{new}) &= \ln(A_j^{old}) + \Delta R_1 \ln(1+\beta_1) + \Delta R_2 \ln(1+\beta_2) \ldots \\ \phi_j^{new} &= \phi_j^{old} + \Delta R_1 \omega \gamma_2 + \Delta R_2 \omega \gamma_2 \ldots \end{aligned} \tag{5}$$

As stated the α, β and γ's are constants and valid in a very wide range of circumstances. This is a linear mathematical model of the estuary. To make F an explicit function of the change in roughness one would like to have equations in the form of

$$\begin{aligned} A_o^{new} &= A_o^{old} + \alpha_1 \Delta R_1 + \alpha_2 \Delta R_2 \ldots \\ a_j^{new} &= a_j^{old} + \delta_1 \Delta R_1 + \delta_2 \Delta R_2 \ldots \end{aligned} \tag{6}$$

$$b_j^{new} = b_j^{old} + \varepsilon_1 \Delta R_1 + \varepsilon_2 \Delta R_2 \ \ldots$$

It can be shown that

$$\delta_i \simeq a_m \beta_i - b_m \sin \omega\gamma_i \qquad (7)$$

$$\varepsilon_i \simeq b_m \beta_i + a_m \sin \omega\gamma_i$$

The substitution of the actual a_m and b_m is the reason why (6) is valid in a much smaller range of circumstances. But (6) may now be substituted into (2) making F an explicit quadratic function of all R_k. To find the minimum of F the normal least squares is followed:

$$\frac{\delta F}{\delta R_k} = 0 \text{ for each K} \qquad (8)$$

which results in (9) if we do not include the weighting factor $1/s_p$ and use the notation of the first equation of (6) uniformly for the other two equations of (6) (numbering the α 's with one more index i which runs continuously through all equations).

$$\begin{bmatrix} \sum_{i=1}^{B} \alpha_{i1}^2 & \sum_{i=1}^{B} \alpha_{i1}\alpha_{i2} & \sum_{i=1}^{B} \alpha_{i1}\alpha_{i3} \ \ldots\ & \sum_{i=1}^{B} \alpha_{i1}\alpha_{iK} \\ \sum_{i=1}^{B} \alpha_{i2}\alpha_{i1} & \sum_{i=1}^{B} \alpha_{i2}^2 & \sum_{i=1}^{B} \alpha_{i2}\alpha_{i3} \ \ldots\ & \sum_{i=1}^{B} \alpha_{i2}\alpha_{iK} \\ \ldots & \ldots & \ldots & \ldots \\ \sum_{i=1}^{B} \alpha_{iK}\alpha_{i1} & \sum_{i=1}^{B} \alpha_{iK}\alpha_{i2} & \sum_{i=1}^{B} \alpha_{iK}\alpha_{i3} \ \ldots\ & \sum_{i=1}^{B} \alpha_{iK}^2 \end{bmatrix} \begin{bmatrix} \Delta R_1 \\ \Delta R_2 \\ \ldots \\ \Delta R_K \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{B} \alpha_{i1}\Delta A_i \\ \sum_{i=1}^{B} \alpha_{i2}\Delta A_i \\ \ldots \\ \sum_{i=1}^{B} \alpha_{iK}\Delta A_i \end{bmatrix} \qquad (9)$$

where K is the total number of R_k and B is the total number of characteristics of all points.

The linear mathematical model (the α's) is obtained from successive simulations in a mathematical model, changing one roughness parameter (g/C^2) or boundary condition at a time. As the coëfficiënts α, β, γ are valid for every period and are not very sensitive for the period used in simulation they are determined by simulating periods of 25 hours. The mathematical model does not need to be very sophisticated or to have a fine grid, small inaccuracies in the linear mathematical model (the α 's) will only result in a somewhat slower optimisation. In the study phase α 's from an analytical harmonic model were used quite successfully to adjust a finite difference model. Although differences in the roughness effects between the hydraulic model and the mathematical model may exist, obtaining the α's from the hydraulic model would be a tedious job. Solving (9) now gives a set of changes of the roughness ΔR's that will result in a lower F.

5.2 Options

It would not be very satisfactory if one were only to get a set of changes to be made to all the roughness parameters and all the boundary conditions together; one would like to see if the mean water levels and discharges relate to the same changes as the semidiurnal water levels and discharges do and so on. One might like to exclude certain R_k's; for example the boundary conditions should not yet be changed after the first simulation. One might like to get a more regional impression of the changes to be made in several branches combined, or the change to be

made in all deep and narrow branches to see whether there are systematic deviations from the expected roughness. And most of all one would like to have an impression of the accuracy and the effect of the changes to be made.

This section gives some indications how this may be accomplished within the scope of least squares procedures.

It will be clear that equation (9) may be computed for each characteristic as defined in section (5.1). The building of the matrices should then be done by summation not from 1 to B but over specified subsets. The sum may be a weigthed sum, stressing one characteristic over the others. The same applies to the function F that may be related to each of the characteristics. The equation (9) to be used then consists of the sum of several or all of the subsets. After the simulation, when all the characteristics from the model have been calculated the matrix (9) and the value of F is computed for each of the characteristics and put in a file. Thus in this way, it is possible to solve (9) once for a set that includes the mean water levels and the mean discharges and then for a set that includes the semidiurnals or both.

Before starting to solve the set of equations one might like to exclude certain R_k's by omiting the corresponding rows and columns from the matrices and lower the dimension. The solution will then never indicate a change in this R_k.

Another important operation to be done on equation (9) is the combination of several R_k's. This may be done by adding the corresponding elements of the rows and columns to one new row and column and lower the dimension accordingly. The resulting change in R_k should then be used for all the members of the combination; in this way one may get an indication of a trend, for example that the initial roughness of all the deep and narrow river branches has been overestimated.

It is outside the scope of this paper to describe how the matrix (9) may be inverted but it is good to notice the following: F is a quadratic function of all the R_k's and (9) may be written as:

$$\begin{bmatrix} \frac{\partial^2 F}{\partial^2 R_1} & \frac{\partial^2 F}{\partial R_1 \partial R_2} & \cdots & \frac{\partial^2 F}{\partial R_1 \partial R_K} \\ \vdots & \vdots & & \vdots \\ \frac{\partial^2 F}{\partial R_1 \partial R_K} & \frac{\partial^2 F}{\partial R_K \partial R_2} & \cdots & \frac{\partial^2 F}{\partial^2 R_K} \end{bmatrix} \begin{bmatrix} \Delta R_1 \\ \vdots \\ \Delta R_K \end{bmatrix} = \begin{bmatrix} \frac{\partial F}{\partial R_1} \\ \vdots \\ \frac{\partial F}{\partial R_K} \end{bmatrix} \qquad (10)$$

so with a Taylor series expansion (9) gives a complete description of F as a function of all R_k's (as far as (6) is valid). The procedures used for inverting the set of equations compute the change of F simultaneously with the step by step inversion. If it is now assumed that F has a normal distribution then one can give a simple statistical indication of the importance of a certain change in R_k, based on the decrease of F, the resulting F and the number of measured locations and R_k's involved. A good description of these statistics may be found in Himmelblau (1970). The actual inversion procedure may be found in Efroymson (1959). It does not give the solution of the whole set (9) at once, but it selects first the R_k that is most effective (that gives the greatest decrease of F). It then computes how big the change in R_k should be if this were the only change to be made; it computes the

resulting F and gives an indication of the accuracy of the change in R_k. In the next step it takes one more R_k, computes the desired change in each of them, the change in F, the accuracy of each of the individual changes and so on. The procedure may go as far as producing a completely inverted matrix (9) but obviously was stopped at the point where F does not decrease significantly any more.
Substitution of the indicated changes into the equations (5) or (6) then gives the values to be expected at the individual measured locations. Comparing these values with the values from prototype and from the previous simulation in the model gives then a very detailed view of the progress of the calibration.

5.3 Implementation

A series of programs was written for the DEC BASIC compiler. After a simulation these calculated the characteristics of the model, the matrices (9) and the F's for each of the characteristics summed over all water levels or over the discharges. Then an interactive program was run that combines a selected set of characteristics, deletes and combines R's and solves the equations step by step, printing information about the accuracies, the resulting F and so on. In each step the F that is related to each of the individual characteristics may be computed from a Taylor series using (10) giving information about the improvement of other characteristics. After this terminal session an even better idea of what may be expected may be obtained by substitution of the intended changes into (5) and plotting the expected characteristics together with the last simulation and the prototype (compare fig. 7.2-7.4). After this the change in roughness (which is still in g/C^2) is converted to a change in the number of roughness elements.

6. CALIBRATION AND VERIFICATION

For the calibration and verification of the model an extensive measurement campaign has been carried out by Rijkswaterstaat (Ministry of Public Works) in 1979. Four periods of three days in May and September were used for the measurement of flows and salinity distribution, with 35 boats simultaneously. These periods included the weekends when nautical activities on the river are less. In this way detailed information about the vertical velocity- and salinity profiles was obtained. From the velocity profiles discharges were derived in the main branches of the estuary. During the whole period of May and September 1979 waterlevels all over the system and salinities at some locations were measured continuously, thereby providing data about springtide-neaptide-springtide time series. Finally some automatically monitoring instruments were used for measurements at sea. Considerations with respect to salinity intrusion, meteorological influences (wind), possible withdrawals and the integral quality of the measurements resulted in the choice of September for calibration of the model (relatively low riverdischarges) and of May for the verification. Within September the first period of three days with the 13 hours discharge- and salinity vertical measurements was selected for the adjustment process (wind influences being almost negligible in this period).
In order to verify the model on hydraulic conditions with extreme low river discharges, which are especially of interest from a research point of view, use was made of available prototype data of August 1976.
For that period only time series of waterlevels and a restricted number of salinity recordings are available. Essential for the above described

prototype data is the possibility to adjust the model on large scale phenomena under time series conditions, thereby allowing an assessment of the time-fluctuating dominant phenomena of the tide, mean sea level, river discharge and gravitational circulation. Within these time series the consistency of the detailed reproduction of the vertical velocity and salinity profiles can be considered, giving also insight into the simulation of the vertical turbulent diffusion process.
The actual calibration and verification was then carried out as follows. Based on experiences with one-dimensional models and on a reanalyses of the characteristics of the network system, the hydraulic model was provided with an initial amount of additional roughness.
Subsequently the flows of the September time series were adjusted in a first approximation by means of the procedures as described in chapter 5. By doing so, also the density distribution will be simulated in a global sense as it is primary determined by the advective transportprocesses. Then the next phase is the final adjustment by optimizing in an alternating way flows (of the September timeseries) and density distribution, based on the first period with detailed information about the vertical salinity profiles. This optimisation completes the calibration resulting in a mix of various additional roughness- and mixing elements. Based on this model lay-out the verification was performed on the timeseries and vertical salinityprofiles of May 1979 and on the timeseries of August 1976.

7. RESULTS/DISCUSSION

The provision of boundary conditions was straight forward. Updates could easily and quickly be made. The water levels in the mouth of the river are accurately reproduced from prototype data (see fig. 7.1).

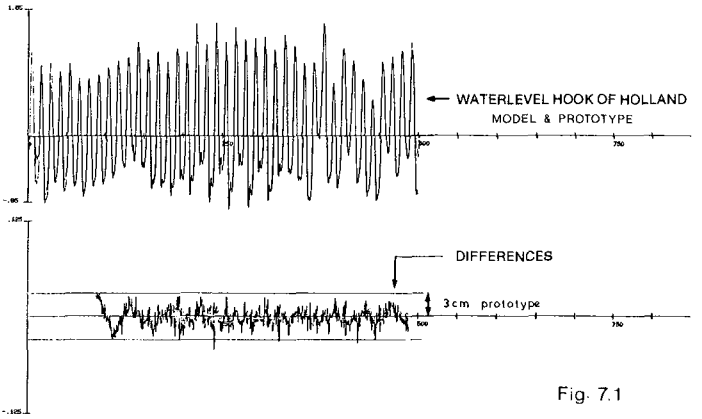


Fig. 7.1

The flow field at sea in front of the river mouth is rather satisfactory, according to comparisons of floats from model and prototype and according to the behaviour of the fresh water wedge at sea.
For optimisation of the salt boundary conditions at the mouth of the Rotterdam Waterway a calibration on tidal flows and on salinity distribution (thin fresh layer due to the riveroutflow) appeared to be necessary. For this reason additional field measurements in the sea near

the mouth of the Rotterdam Waterway have been carried out in order to verify the model on these data, which may lead to a combined (flows and salinities) improvement of the downstream boundary provision. In this respect it is relevant that the accuracy of the prediction of tidal currents may be considerable less than the accurary of the prediction of water levels (Godin, 1983).

The adjustment procedures for the waterflows gave very good results. For the complicated network system the final accuracy of the reproduction of the vertical and horizontal tides was met in a few steps. It is very well possible to adjust the roughness in several branches at a time without loosing control. The linear mathematical model may be derived from a simpler model than the model that has to be adjusted. The procedures aided in stopping the process of calibration at the point when the result of going on would have been negligible. In this way, this part of the calibration process was accelerated manifold with respect to conventional methods. Based on these experiences, the principles of this optimisation technique will be used also for the development (calibration/optimisation) of mathematical models for the Rhine-Meuse estuary network system (Roelfzema, et al., 1984).

The final result of the calibration and verification shows a fairly good agreement with the prototypedata. Flow characteristics of the vertical tides generally are reproduced within inaccuracies of about 1%, horizontal tides within about 5 to 10%. With this respect figures 7.2 up to 7.4 show some illustrations of the reproduction quality of the mean waterlevels, the semidiurnal amplitude of the vertical tide and its phase as mean values over a neaptide/springtide/neaptide time series, while figures 7.5 and 7.6 show the reproduction of waterlevels and discharges as functions of time.

Instantaneous inaccuracies of the densities generally vary between 1 to 10%. Tidal mean values show considerable lower inaccuracies. It is important to remark that, in spite of instantaneous differences between model and prototype, the long term tendencies, in general are reproduced fairly, thereby showing the capability of the model to reproduce the overall, dominant characteristics of nature, see figures 7.7 and 7.8.

A remark has to be made with respect to the verification quality of the second period in September 1979. In this period with a combination of neaptide and strong gradients in the meanwaterlevels the model probably generates insufficient turbulent diffusion, resulting in larger differences between the vertical salinity distribution of model and prototype, see figure 7.9. For smooth parts of some riverbranches an opposite effect appeared in the contribution of the additional roughness- an mixing elements in their contribution to the resistance on the one hand and to the mixing on the other. These parts required less resistance and more mixing so an optimum had to be found.

This evidence and the result according to figure 7.9 emphasize the importance of studies on the quantative knowledge about the vertical diffusion process and requires fundamental research work in a tidal salinity flume on the turbulent exchange processes on mass and momentum and their modelling (physical and mathematical).

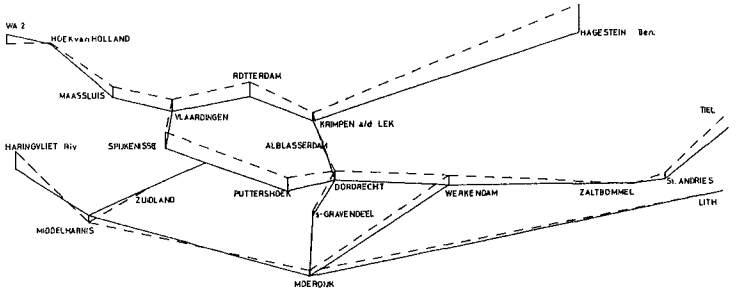


Fig. 7.2
DIFFERENCES
MEANWATERLEVEL: (model − proto)
3 SEPT. 1979 — 17 SEPT. 1979

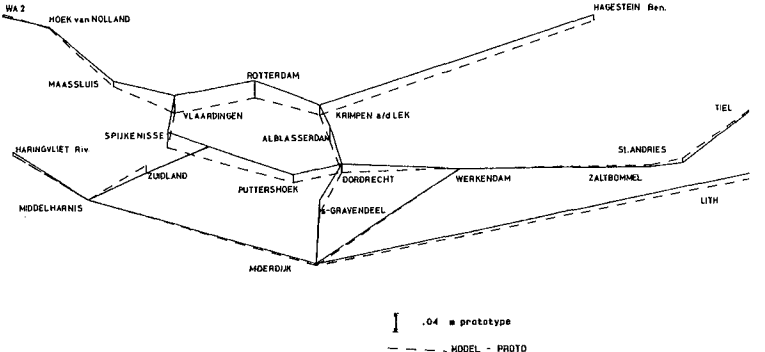


Fig. 7.3
DIFFERENCE M2-AMPLITUDE (model − proto)
3 SEPT. 1979 — 17 SEPT. 1979

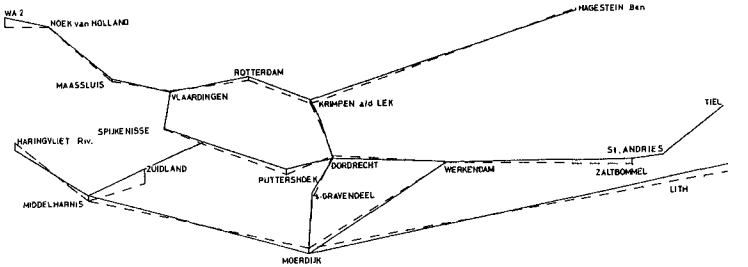


Fig. 7.4
DIFFERENCE M2-PHASE (model − proto)
3 SEPT. 1979 — 17 SEPT. 1979

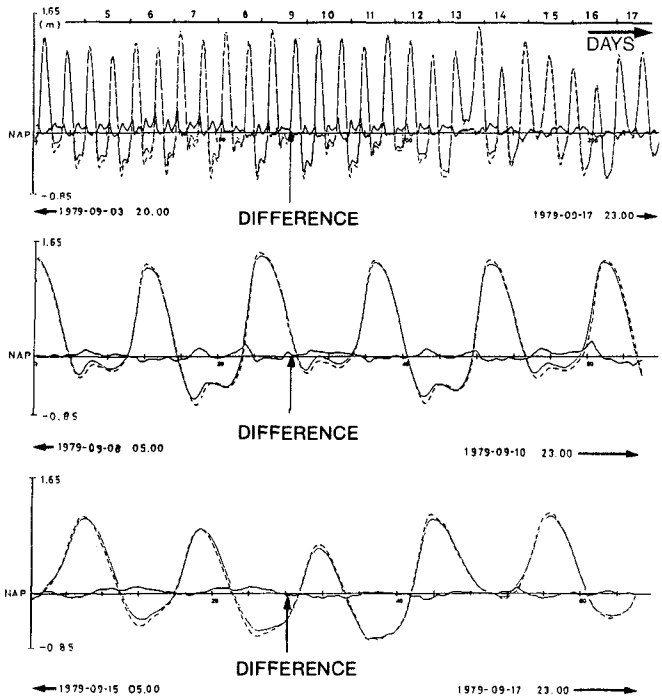


Fig. 7.5 WATERLEVELS ROTTERDAM ----PROTOTYPE ——MODEL

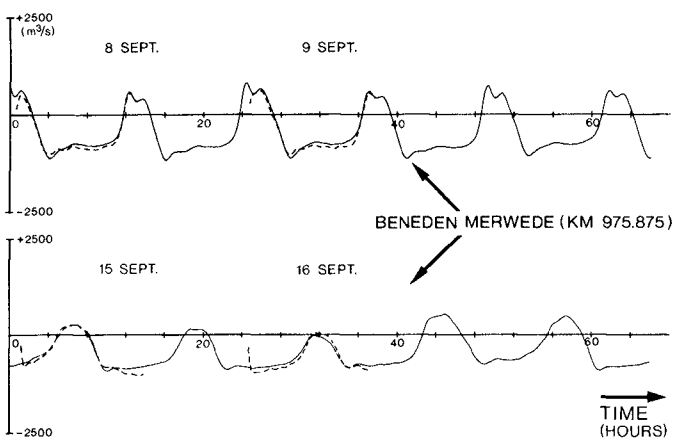


Fig. 7.6 DISCHARGES

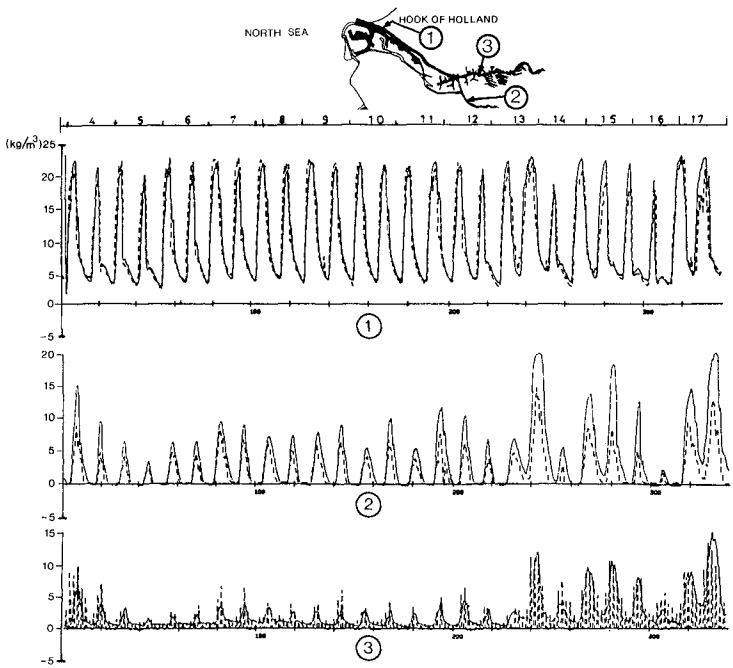


Fig 7.7 DENSITY AS FUNCTION OF TIME (CALIBRATION) – – – – PROTO ——— MODEL

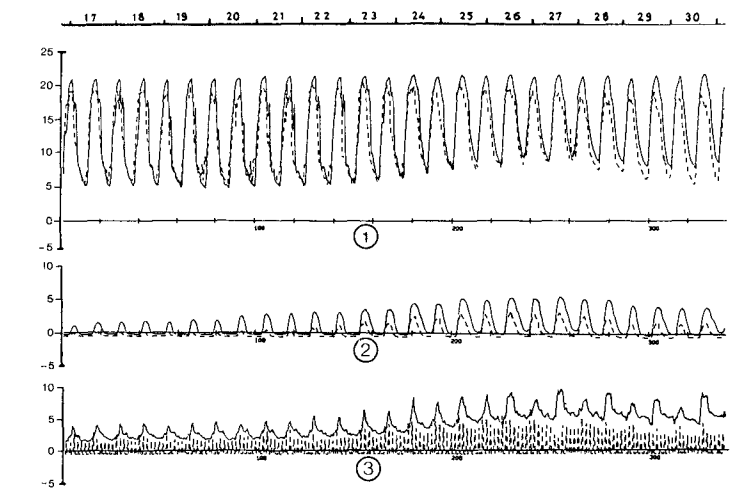


Fig. 7.8 DENSITY AS FUNCTION OF TIME (VERIFICATION) – – – – PROTO ——— MODEL

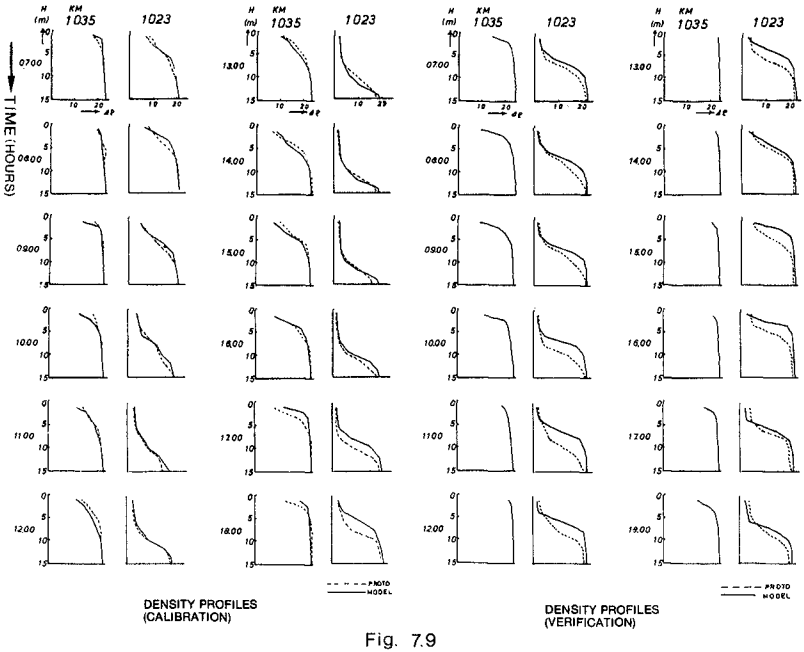


Fig. 7.9

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