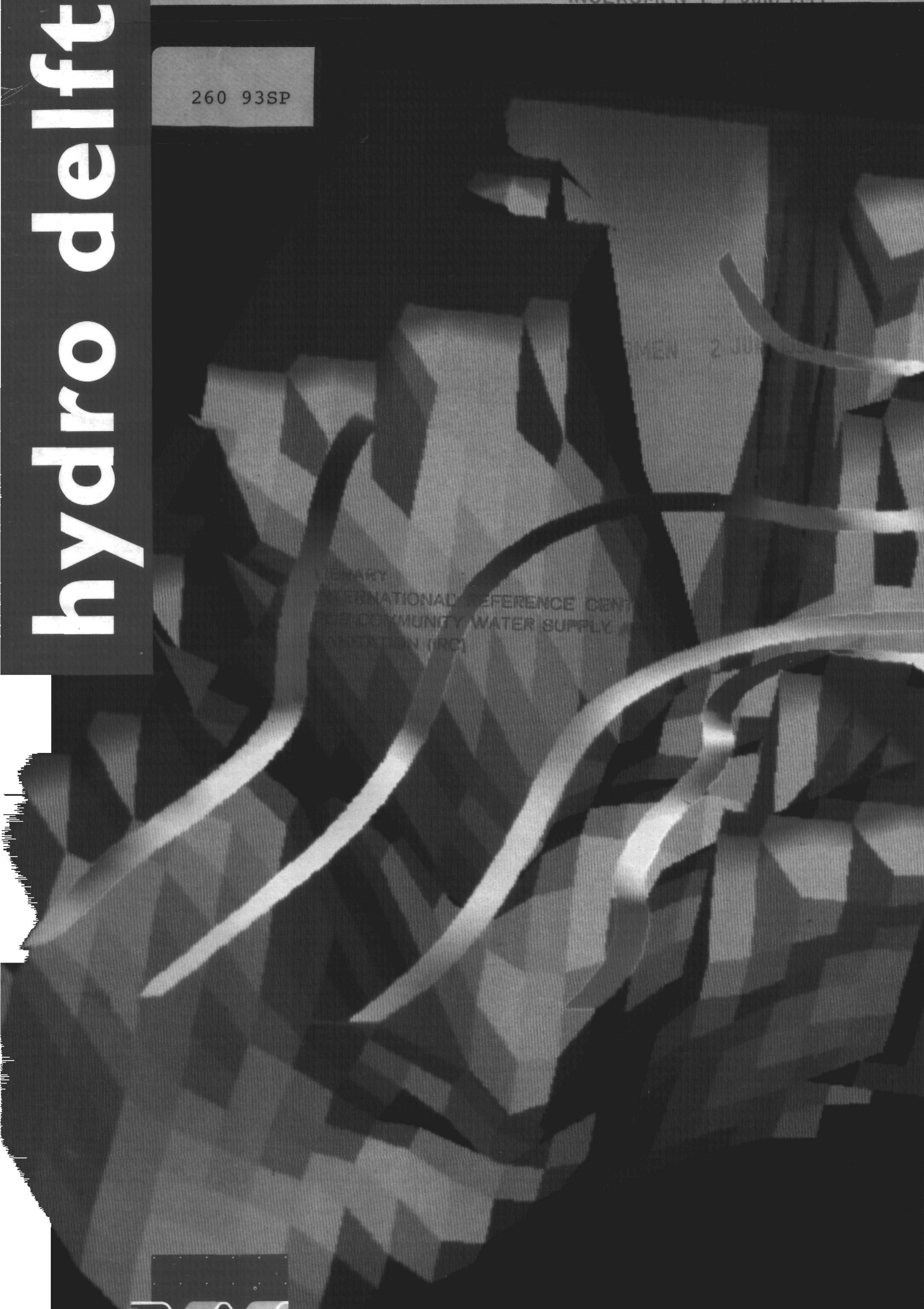
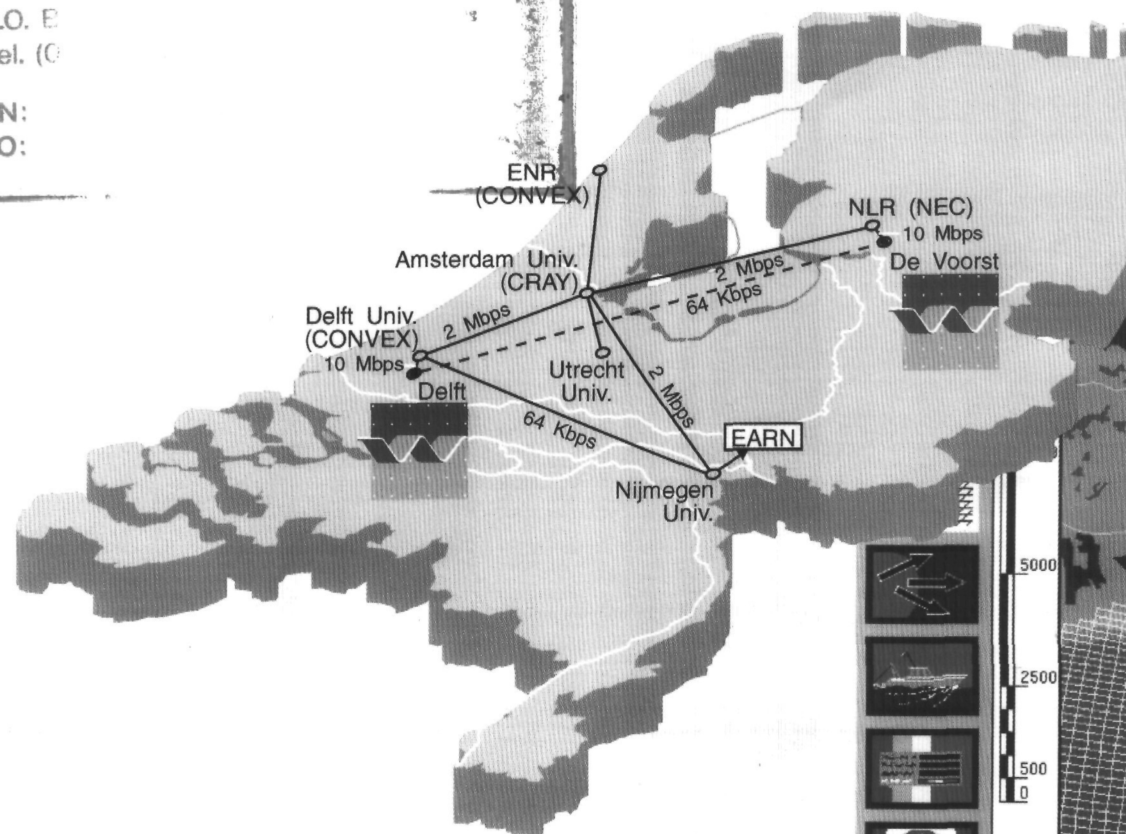
hydro delft

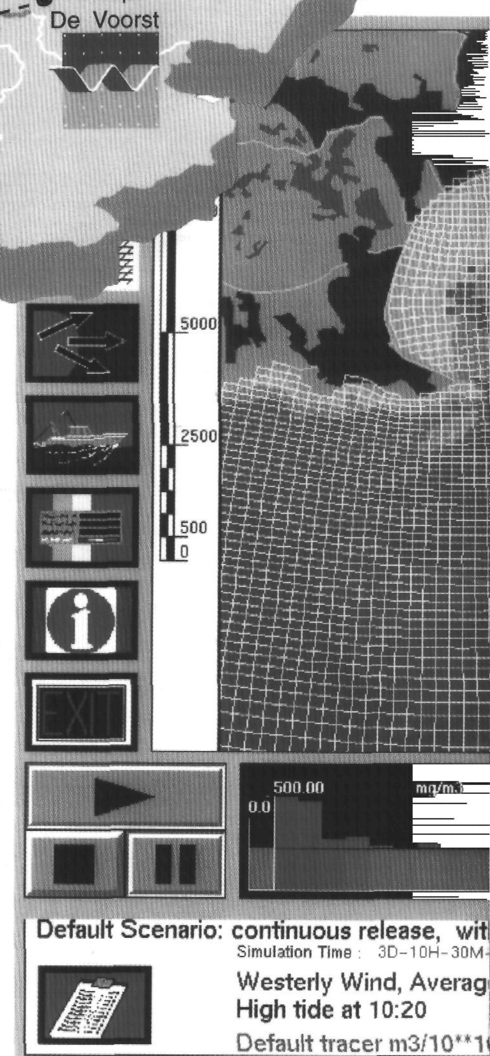
special issue on mathematical models



81

delft hydraulics

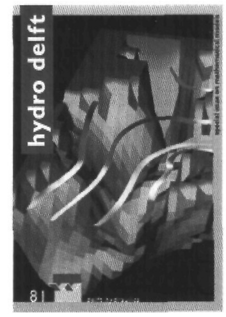




Commitment to (defacto) standards:

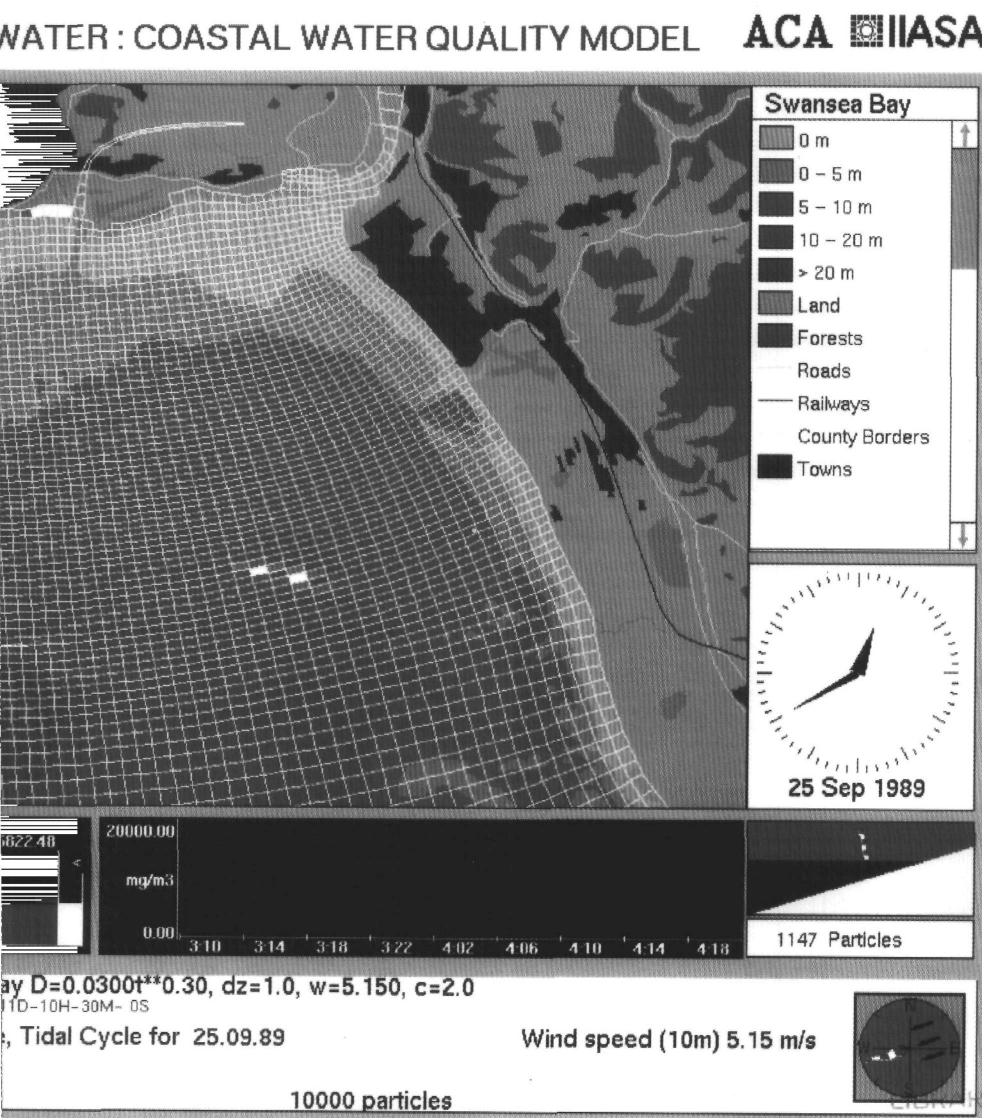
- Operating systems: UNIX, MS-DOS and OS/2
- LAN : IEEE802.2 (Ethernet)
- WAN : X-25
- Communication protocol: TCP-IP
- File transfer : NFS
- PC-network : LMX
- User interfaces: X-Windos, OSF/Motif, MS-Windows

cover



Visualization of particles trajectories as computed by the Welsh Region Model, covering a large area in the Irish Sea (see page 4).

mathematical models: development and use



Over the years numerous mathematical models have been developed to assist engineers in solving practical problems. Increasing computer power made it possible to refine the computational grid and to solve more complex problems. New developments in presentation and user interface techniques made it possible to cast mathematical models into modelling systems where the user can concentrate on the problem to be solved and need not to bother about file structures, run-administration etc. Current Information Technology makes it possible to integrate existing sub-models into complex processes, visualize input data and computed results and keep track of all aspects in an easy and self contained manner.

These kinds of model systems need to be very flexible and highly configurable to suit the needs of different kinds of users and of different scenarios of use. The expert needs to be able to control all kind of parameters and easily run through the system; an infrequent user needs context sensitive guidance through the system. So, modern modelling systems must provide facilities to adjust its functionality, its appearance and its HELP-facilities to the different types of users , user-levels and user-tasks to be executed.

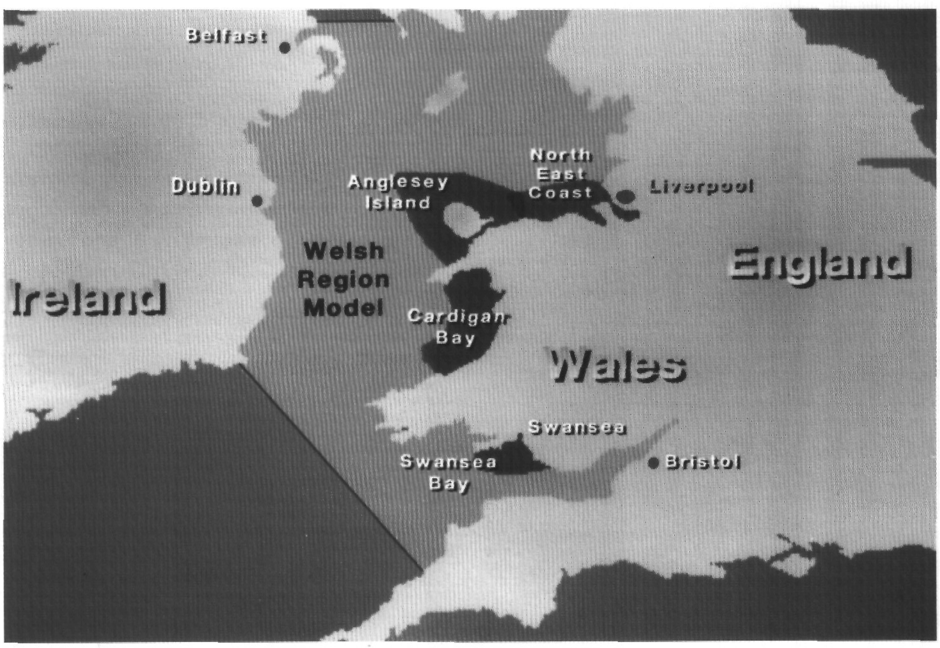
DELFT HYDRAULICS has developed several modelling systems which aim at providing these facilities. These systems are developed and used for research and consultancy projects alike.

contents of issue 81, April 1993

flow and transport

A common feature of seas, estuaries, rivers, lakes, channels and the like is a free-flowing surface. Tidal and atmospheric forcing, density differences, evaporation and condensation act on water in such a way that it is almost never calm. When water flows it transports heat, salt, silt, or chemicals, either coming from natural sources or having been dumped into the water by man through sewer systems and spills. Computer systems for the simulation of flow and transport play an important role in the analysis of modern water management policies. The delicate balance between conflicting interests such as economy and ecology requires modelling systems of ever-growing sophistication and complexity. To meet this requirement DELFT HYDRAULICS develops general as well as dedicated systems to simulate flow and transport.

Welsh Region Model and four dedicated models.

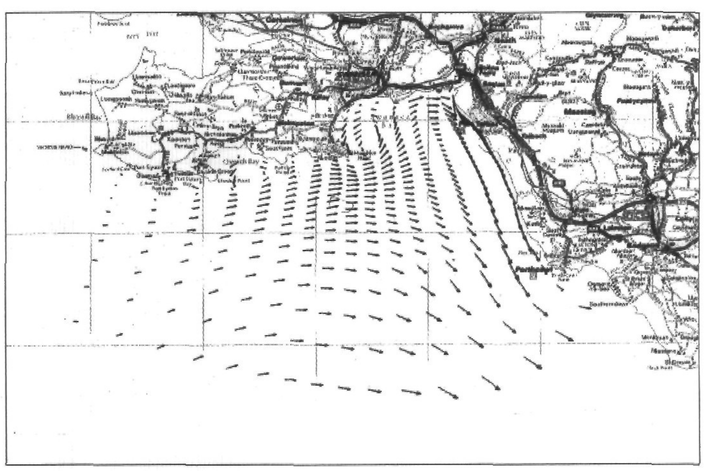


two- and three-dimensional hydrostatic flow and transport

A powerful but flexible combination is provided by the TRISULA system for two- and three-dimensional flow and online salt and temperature computations, and by DELWAQ for offline transport computations of all types of water quality parameters. In concert with Wallace Evans Ltd., UK, DELFT HYDRAULICS developed and calibrated a set of hydrodynamic and water quality models for areas such as the North East Coast of Wales, Swansea Bay, Cardigan Bay, and Anglesey. A Welsh Region Model, covering a large area in the Irish Sea, was set up to provide a common hydrodynamic basis to the four dedicated models. Currently the models are operated by Wallace Evans Ltd for design purposes and to assess outfall scenarios.

The results of three-dimensional computations depend to a large extent on how turbulent exchange processes in the vertical are simulated. Much effort is invested in developing an accurate and validated turbulence model for a broad range of prototype situations. For this, detailed experiments with refined measuring, data processing and visualisation techniques are combined with techniques of computational hydraulics.
For Rijkswaterstaat (Ministry of Transport, Public Works and Water Management) 3-D simulations of the former Keeten-Volkerak estuary were executed with a tidal range of 3.5m. In this estuary tidal flats as well as density currents were important. To study the complex flow phenomena, high performance visualization (hard- and software) tools are used, providing the investigator with the means to "move" through the area that is studied to release particles or dye and to visualize the results in arbitrary planes of projection.

Computational grid and hydrodynamics of Swansea Bay.



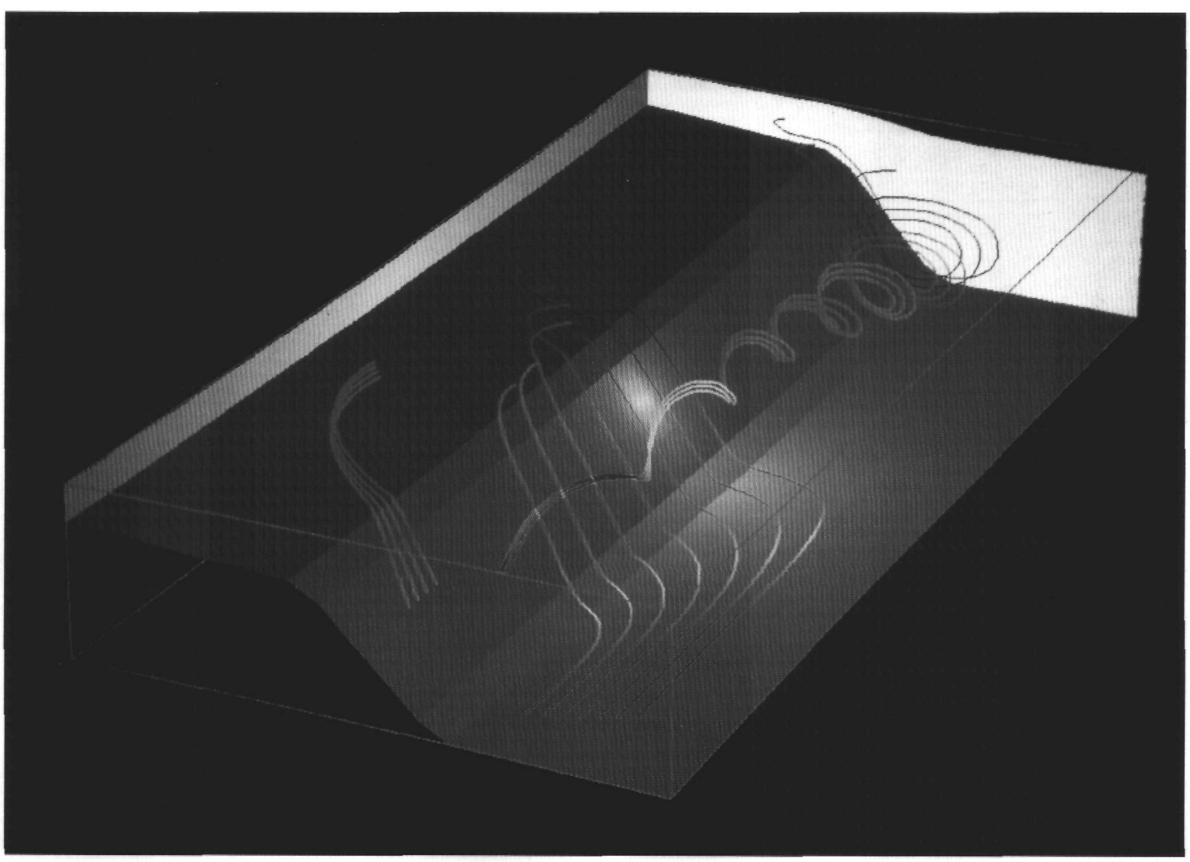
full navier-stokes simulations

Increasing computing power enables more detailed and complex flow modelling. Current high speed (super)computers are capable of handling three-dimensional viscous-flow problems including turbulence. This implies that numerical models can be used to solve practical engineering problems involving complicated geometries and realistic flow conditions. It also implies, however, that more effort is required to formulate, code, validate, operate and maintain the involved software. Hence, a multi-disciplinary approach is necessary so as to set up an advanced flow modelling system, involving mathematical physics, numerical analysis and computer science.

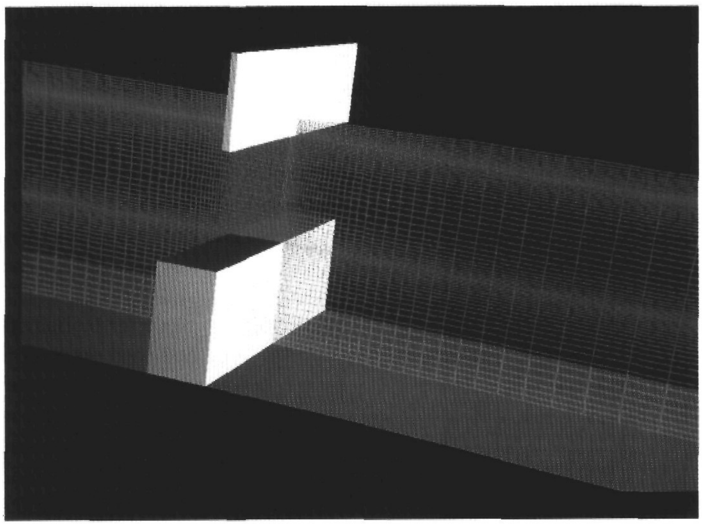
DELFT HYDRAULICS participates in the national ISNaS-project, initiated to combine efforts of technological institutes and universities in the Netherlands in numerical flow modelling for aerodynamic and hydrodynamic applications. The ISNaS-project aims at providing tools for computer-aided design and engineering by developing an information system for flow simulation based on the Navier-Stokes equations.

features of TRISULA

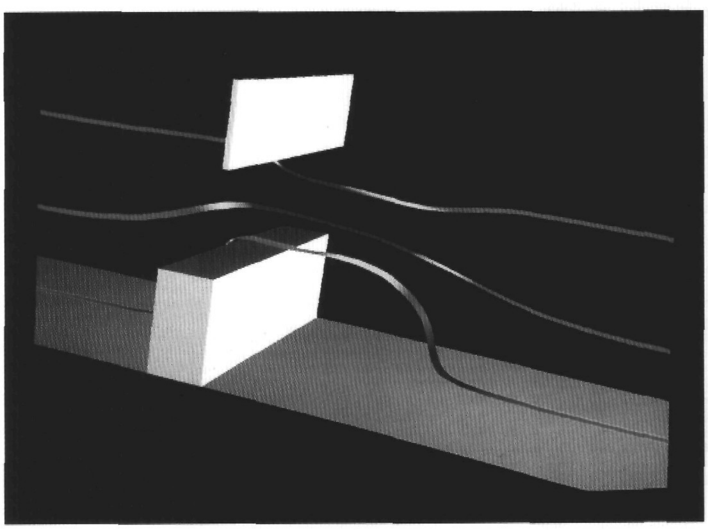
- **2-D depth-averaged and 3-D hydrostatic free-surface flows**
- **full non-linear equations, external forcings due to gravity,inventia wind, salt, temperature and waves**
- **online transport equations for salt, temperature and turbulence**
- **one- and two-equation turbulence models**
- **several types of structures**
- **finite difference, unconditionally stable, second-order scheme**
- **rectilinear and curvilinear grids**
- **advanced visualization and animation techniques**



Tidal flow with density currents and tidal flats in a 3-D computation of the former Keeten-Volkerak. Visualization of particle tracks.



Flow through a hydraulic structure.
Computational grid.



Particle trajectories.

Domain decomposition and a multi-block approach are used to model complex geometries; a structured computational grid is maintained within each block to achieve numerical accuracy. The solution strategy is based on the pressure-correction method using a conjugate gradient-type iterative procedure to solve the resulting system of equations.

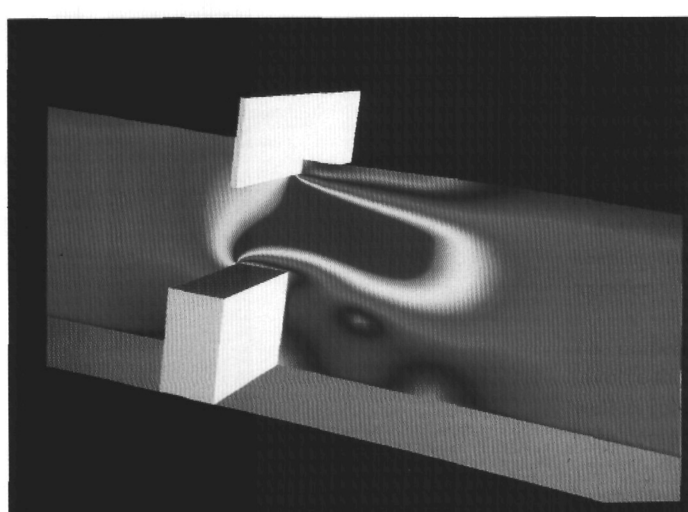
The mathematical formulations of the ISNaS-project are based on physical considerations of practical nature. Particular attention has been given to a coordinate-invariant formulation of the physical conservation laws. A range of turbulence models including k-epsilon can be incorporated into the numerical scheme.

Considerable effort has been put in numerical grid-generation and scientific flow visualization both of which are essential components in three- dimensional flow modelling.

The type of applications are illustrated by recent examples taken from hydraulic structures, sediment transport and density currents.

The computer science division of the ISNaS-project aims at the development of a Method Management System, the purpose of which is to provide tools for management and to execute applications on a distributed network of computers, keeping track of job scheduling and data transfer.

The numerical aspects of the ISNaS-project involve the development of accurate as well as robust numerical algorithms for both compressible and incompressible viscous-flow simulation. For the latter as encountered in hydrodynamic applications, the flow solver is based on a staggered finite volume discretization on a boundary-fitted computational grid.



Velocity field.

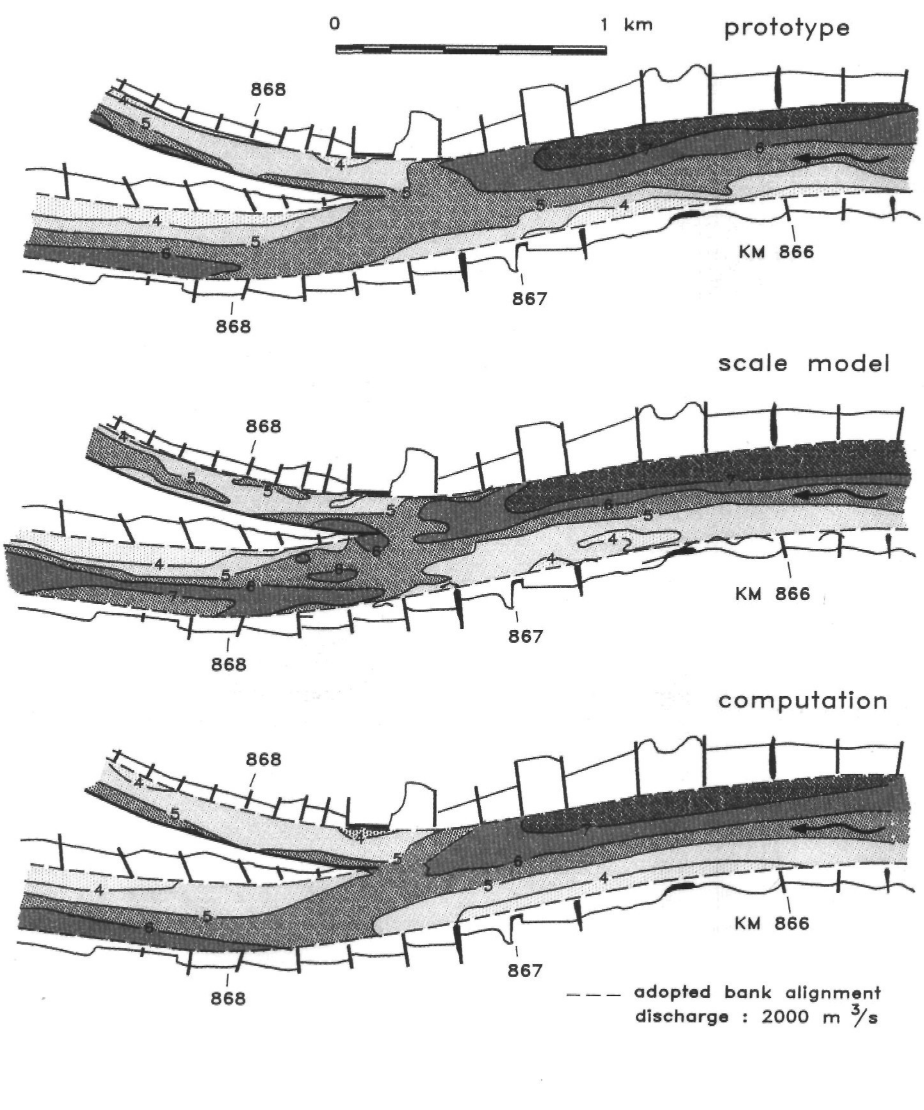
river morphology

Morphodynamic models for rivers are used to study the riverbed response to river training and other interferences. Applications include the prediction of morphological developments due to dredging and spoil dumping, width changes, riverbend cutoffs, extraction or supply of water and/or sediment, the presence of fixed layers in the bed, as well as weirs and other structures. Particularly complex situations arise when the geometry of a river contains confluences or bifurcations.

The flexible two-dimensional morpho-dynamic river model RIVCOM was developed at DELFT HYDRAULICS. It is the accumulation of more than two decades of experience and expertise (see box). This model can be considered as a substitute for river scale-models with movable bed, while adding considerably to the variety of situations that can be simulated by computer.

features of RIVCOM

- **flow field governed by 2D steady shallow-water equations, incorporating inertia, bed friction, horizontal momentum exchange and secondary (spiral) flow effects**
- **magnitude and direction of bed-shear stress depend on main flow as well as secondary flow**
- **bed level varies according to local sediment balance**
- **sediment transport and its direction depend on local bed-shear stress, bed slope and spatially varying sediment properties**
- **boundary conditions variable in time and space**
- **curvilinear spatial grid**



An example of such a situation is the bifurcation of the Rhine River in the Netherlands into the Waal River and the Pannerdens Channel, which was also the subject of a scale-model study. The computer- simulated development of the bed topography near the bifurcation point agrees quite well with field soundings and is significantly more accurate than the scale model.

Bifurcation of the Rhine River into the Waal River and the Pannerdens Channel.

coastal dynamics

Coastal dynamics deals with the analysis and prediction of coastal behaviour, encompassing coastal morphology, coastal hydrodynamics (waves, currents), and coastal sediment transport. Numerical models describing these phenomena are used as constituent modules in compound morphological models, but they also have their distinct applications.

waves in the coastal zone

Simulation of wave behaviour in the coastal zone requires computational models that are capable of predicting the generation of waves in the open sea and the propagation of these waves into the coastal zone. The wave field can be conveniently expressed as a sum of a large number of harmonic wave components, each of which posessing a unique frequency, wavelength, and direction of propagation. The evolution of the wave field can then be simulated by keeping a balance of energy of each component as it propagates across the sea surface.

Wave generation in the open sea, in deep water, is primarily determined by wave growth due to wind action, energy dissipation due to wave breaking, and non-linear interactions among wave components.

As the waves propagate towards the coastal zone other effects become important, such as wave refraction, water-level undulations due to tidal effects, energy dissipation due to bottom friction, and wave breaking due to wave steepness and depth reduction.

physical features	ENDEC	HISWA	PHIDIAS
dimensionality	1	2	2+time
wind	+	+	+
bottom dissipation	+	+	+
refraction	+	+	+
current refraction	+	+	+
directional spreading	-	+	+
wave-current interaction	-	+	+
spectral representation	Hs, Tp	parame-terized	full 2D spectrum
instationary computation	-	-	+
curvilinear grid	-	-	+
nonlinear interactions	-	-	+

Three models, going from simple to complex, used by DELFT HYDRAULICS are described below, and their main characteristics are summarized in the box.

When the bottom topography varies essentially in one direction only, the *one-dimensional model* ENDEC can be applied. This is the case, for example, in areas near a straight coast. ENDEC was designed to model the propagation of an irregular wave field under the influence of currents and wind. It is a very efficient tool for the analysis of near- shore wave propagation.

For many near-shore engineering applications the wave-and-wind conditions can be considered stationary. This is the case when the travelling time of the waves through the area of interest is less than the time scale at which significant variations of wind-and-flow fields occur. In such situations the HISWA model (HIndcasting of Shallow WAter waves) is appropriate.

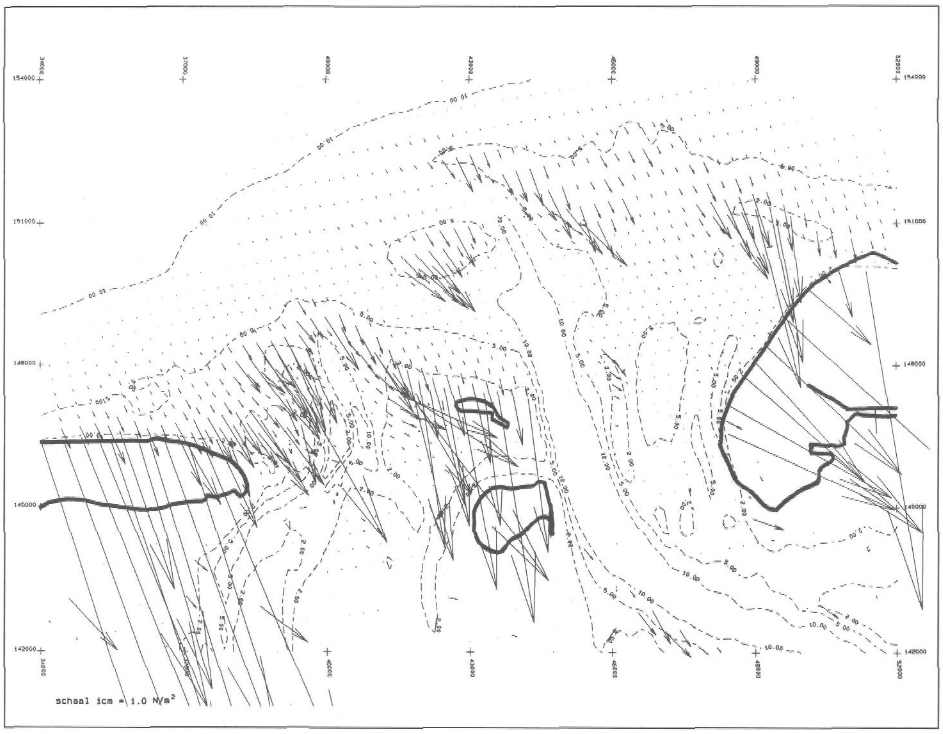
This model, originally developed at Delft University of Technology, is employed by DELFT HYDRAULICS to solve engineering problems in the coastal zone.

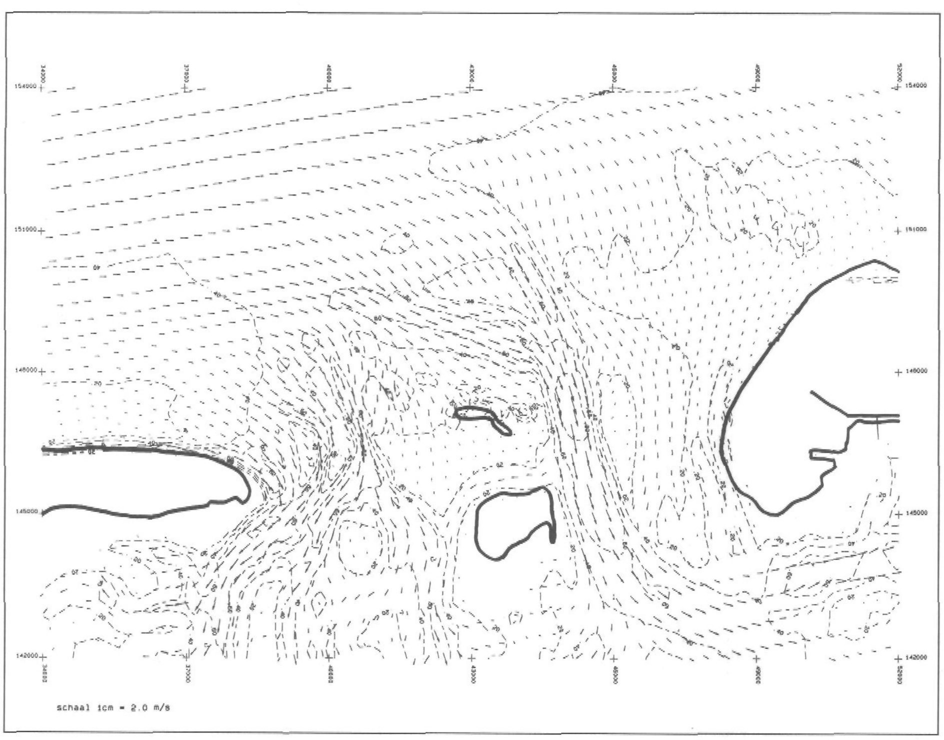
PHIDIAS (Program for HIndcasting of waves on Deep, Intermediate and Shallow water) is a state-of-the-art wave model in an advanced stage of development. It is applicable in areas with varying bottom topography, currents, and water levels and can incorporate instationary wind fields. Special care is given to the modelling of shallow-water effects, including the decay of wave energy due to depth-limited wave breaking and breaking on wave steepness. In addition, the behaviour of waves on opposing currents (including so-called wave blocking) is accounted for.

A feature of PHIDIAS, setting it apart from its predecessors, is its ability to predict the evolution of the full two-dimensional wave spectrum, without any constraints on the spectral shape. The model produces spectra that are physically realistic by incorporating all relevant physical phenomena, including non-linear interactions, thus ensuring proper modelling of swell-sea interactions. PHIDIAS uses a curvilinear spatial grid, so that it can be conveniently coupled with hydrodynamic- flow and sediment-transport models.

Friesche Zeegat tidal inlet: hydrodynamics.

A: Wave-induced current-driving forces for waves from NW
B: Maximum flood current.





coastal currents

Stand-alone applications of coastal current models deal with problems such as the design of coastal structures, water quality studies, or cooling water in- and outlets. DELFT HYDRAULICS has a range of models available to handle these problems:

- descriptions of uniform wave-driven longshore currents, commercially available on PC as part of the UNIBEST program suite;
- a cross-shore mass flux and undertow model, part of the CROSTRAN coastal profile model, also embedded in the UNIBEST PC-program suite;
- a two-dimensional depth-integrated model for shallow water flow, e.g. due to tide, wind, or breaking waves; this curvilinear finite- difference model TRISULA, described earlier in this issue, can be run in combination with several wave models, for example HISWA;
- a combination of a 1D-vertical current model, such as the mass flux and undertow model or an Ekman-layer model, and TRISULA forms the "quasi-3D" coastal-current model concept. This experimental model can provide useful descriptions of a range of 3D coastal currents;
- the three-dimensional version of TRISULA is now being extended to process wave-driven currents.

coastal sediment transport

Although mostly applied to problems related with coastal morphology, coastal sediment transport models also have their stand-alone applications, concerning for example the sediment intake of cooling water inlets, or the displacement of fine cohesive sediments including the adhering pollutants.
Here too, DELFT HYDRAULICS has a range of models available:

- transport formulae relating the transport rate of non-cohesive sediment (sand) to the local hydrodynamic and sedimentologic parameters; a number of these formulae, like the ones proposed by Bijker, Van Rijn and Bailard have been implemented in a so-called formula base (UNIBEST) and in morphological models such as COMOR;
- the PC-oriented model SUTRENCH

describing 2D-vertical suspended sand transport, bed-load transport and morphodynamics, also in environments with important effects of sea waves;
- the workstation/supercomputer-oriented "quasi-3D" model SUSTRA2DH, for suspended load sand-transport computations under the combined action of waves and currents;
- the supercomputer-oriented 3D model SUSTIM, for suspended load transport in a wave/current environment.

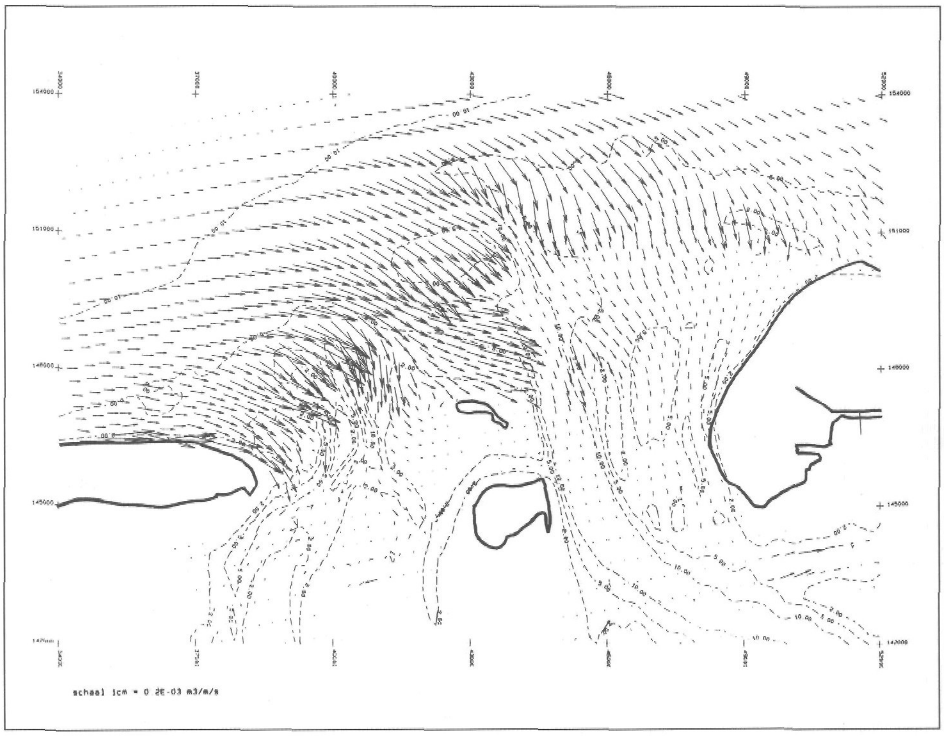
This concerns non-cohesive as well as cohesive sediments, the latter in an experimental setting based upon a still limited knowledge of the physical processes.

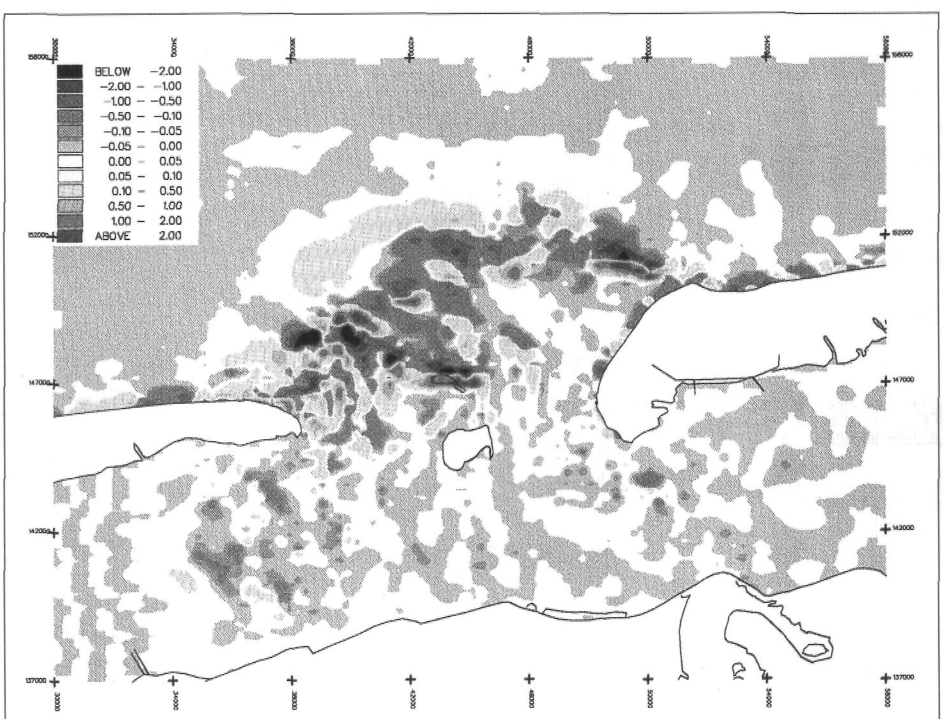
Both PC-oriented models in UNIBEST and the multidimensional models in our 2D/3D coastal program range are embedded in the same information- framework as the corresponding wave and current models. This greatly facilitates their coupling at the input/output level.

coastal morphology

One of the most important areas of application of coastal models is Coastal Morphology. The capacity to predict the behaviour of the coast, autonomous, i.e. under the influence of global climate changes, or due to human intervention is an essential element in coastal protection and coastal zone management. Forced by the geographical situation the Netherlands keep on investing substantially in this capacity. This is reflected by the range of coastal morphology models available from DELFT HYDRAULICS:

- the PC-oriented UNIBEST-suite, which includes a sophisticated coastline model and a robust cross-shore profile model;



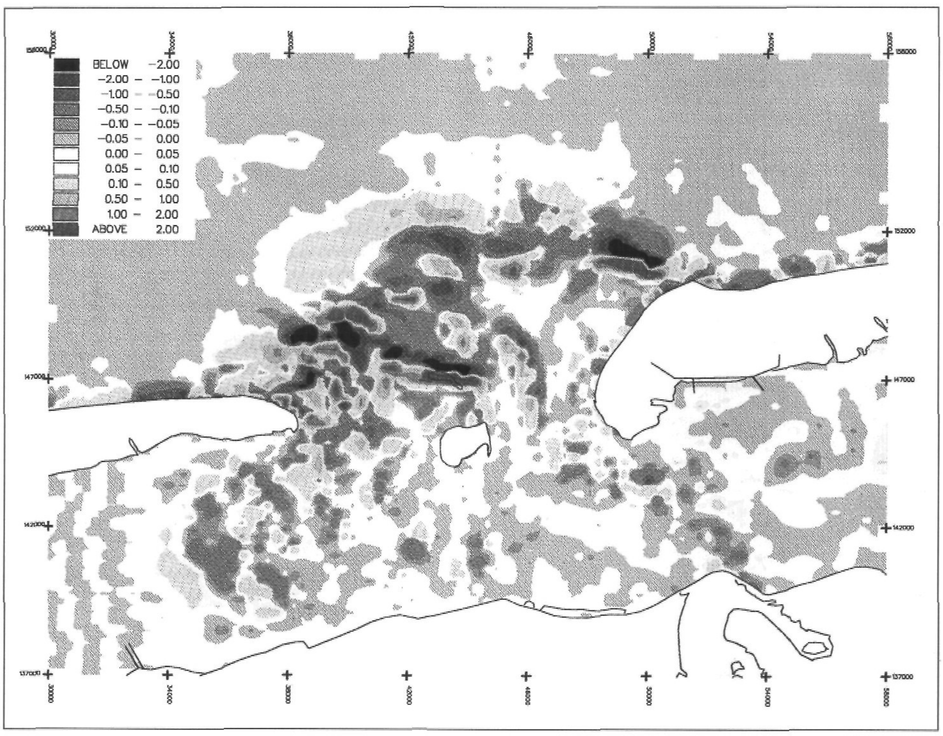


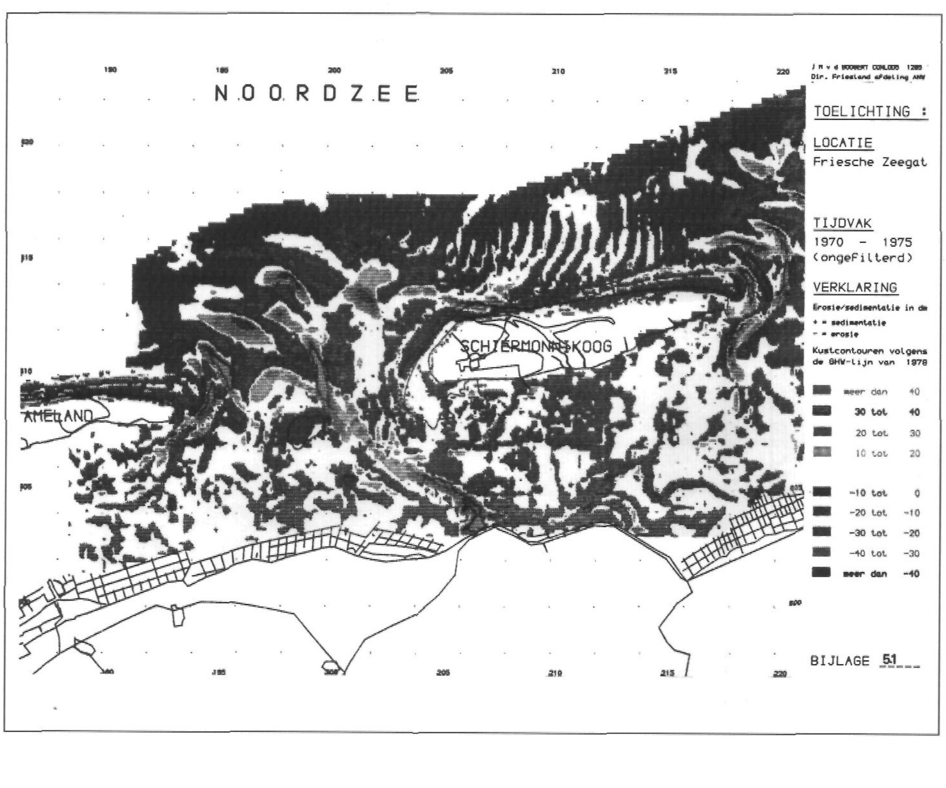
Friesche Zeegat tidal inlets:
sediment transport.

A: Transport rate according to Bijker's formula (max. flood)
B: Erosion/deposition rate (NW-winds only).

- the PC-oriented dynamic dune-erosion model DUROSTA, derived from the UNIBEST cross-shore profile model, but containing many new elements related to dune erosion;
- the workstation/supercomputer-oriented short-term morphological model system COMOR, which couples the aforementioned 2D/3D wave, current and sediment-transport models with a sediment-balance model, so helping to predict the onset of sedimentation and erosion in an area. The system provides a wide range of operational facilities to run these models for practical situations;
- an experimental workstation/supercomputer-oriented model system for coastal morphodynamic simulations in two horizontal dimensions, and at various length and time scales; this system is basically an extension of COMOR and fitting in the same 2D/3D coastal program-suite.

Much of the research underlying these models is done within the framework of extensive research programmes, such as the "Coastal Genesis" Programme, sponsored by the Netherlands Ministry of Transport, Public Works and Water Management (Rijkswaterstaat), and the "G6 Morphodynamics" project in the Marine Science and Technology (MAST) Programme of the Commission of the European Communities.





Friesche Zeegat tidal inlets: morphological changes.

A: Yearly average erosion/deposition rate (all conditions, except storms)

B: Measured erosion/deposition rates 1970-1975 [from Biegel 1991; courtesy of Rijkswaterstaat].

waves in harbours

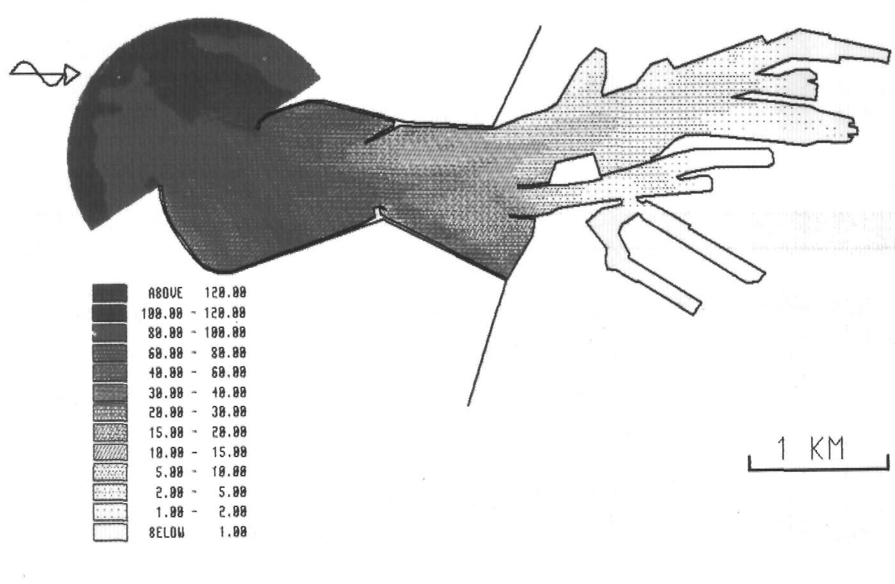
Computational models that simulate the behaviour of waves in harbours of arbitrary shape and variable depth are effective tools for harbour design applications. Wave motions may inhibit loading and unloading operations, give rise to unacceptably large forces in mooring lines, and even cause ships to be grounded. Simulation of these effects is complicated by the fact that they involve the behaviour and interaction of waves with periods that range from a few seconds to tens of minutes. The underlying physical mechanisms depend strongly on the wave period.

short-wave modelling

Wind-driven short waves (periods shorter than 30 seconds) generated on the open sea and in the coastal area can be predicted as described elsewhere in this issue. Proper numerical simulation of their behaviour once these waves penetrate into harbours requires a model accounting for the combination of several distinct phenomena. The most important of these are depth refraction, wave diffraction, and partial reflection of waves at the harbour boundaries. Other phenomena that may be of interest in special situations include wave breaking and current refraction.

DELFT HYDRAULICS has developed the computational model PHAROS (see box for more details) capable of representing all of the aforementioned phenomena. An example of its application to the situation at the harbour of IJmuiden on the Netherlands coast, is shown below.

Wave penetration (%) into the harbour of IJmuiden. Effects of directional spreading included. Arrow shows main wave direction.



features of PHAROS

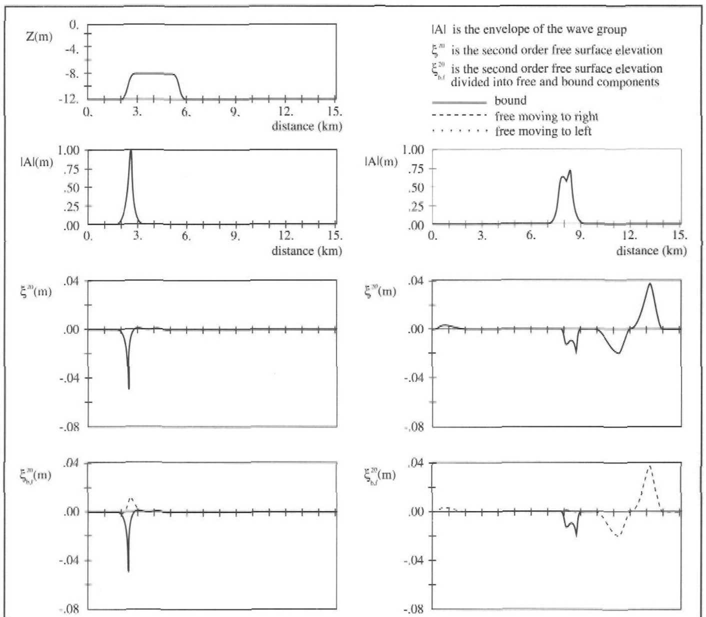
- **computation of short- and long-wave behaviour in and around coastal structures in water of variable depth in two (horizontal) dimensions takes into account:**
  - **combined refraction and diffraction,**
  - **(partial) reflection and transmission at boundaries,**
  - **dissipation by wave breaking or bottom friction (optional),**
  - **directional spreading and/or frequency spreading in the incident wave field (optional).**
- ***mathematical and numerical background:***
  - **complete mild-slope equation,**
  - **finite element method,**
  - **solution by conjugate gradients squared method,**
  - **radiation and essential boundary conditions at incident wave boundaries.**

modelling of long waves

Mechanisms for the generation of long waves (periods longer than 30 seconds) include the passage of atmospheric depressions, dissipation due to wave breaking or bottom friction, non-linear interactions between waves of different frequencies and the release of bound long waves due to processes such as refraction, shoaling and diffraction. Computational models that are capable of representing a number of these phenomena are at an advanced stage of development at DELFT HYDRAULICS, see page 13 top left.

Once such long waves enter into a harbour, they may excite the natural frequencies associated within the harbour geometry. Their behaviour is then further affected by refraction, diffraction, reflection, and dissipation by bottom friction, and can be simulated by PHAROS.

An example of a PHAROS computation of the long-wave response of the Kelantan harbour in peninsular Malaysia is shown right.

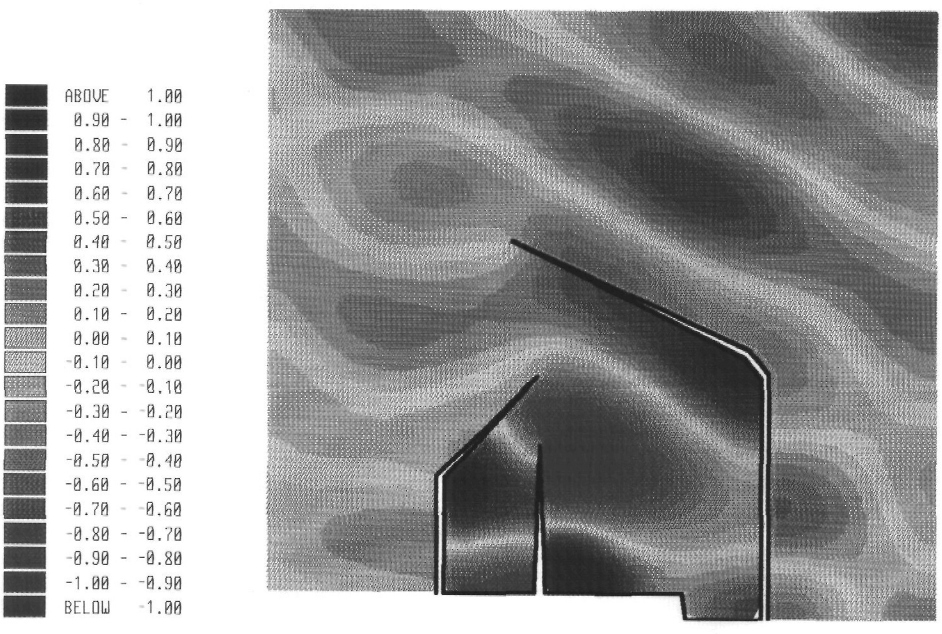


(a) situation at t=600s as wave group passes on to the disturbance in the bed

(b) situation at t=1650s after wave group has passed over the disturbance with free long waves propagating to the left and to right

The generation of free long waves due to a wave group passing over a small disturbance in the bottom topography, predicted by COLOSSYS.

Free-surface elevation computed by PHAROS for long-wave response of the harbour at Kelantan, Malaysia.

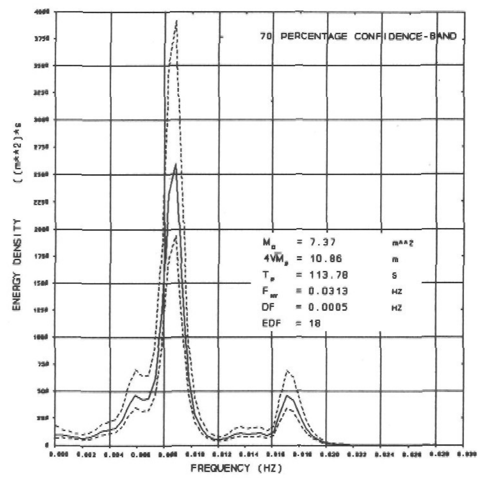


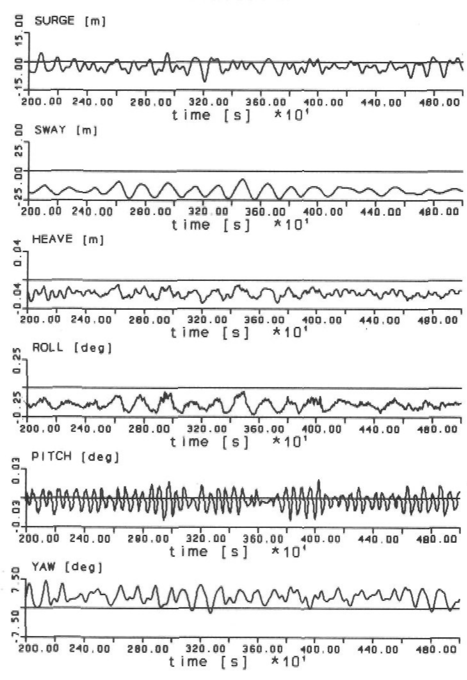
modelling of ship response

The wave motion within harbours is of interest because of its effect on ships, which may have a large heave, roll or pitch response to short waves. Large, moored ships commonly also have a resonance in surge and yaw with a period of the order of several minutes, which may be excited by forces exerted by long waves as well as by non-linear interactions between the short-wave motions and the mooring system.

The response of ships moored in a harbour can be computed using the DELFT HYDRAULICS ship-response model BAS. This model calculates the time evolution of the forces on the fenders and tension in the mooring lines according to the position of the ship, as a function of the wave motion.

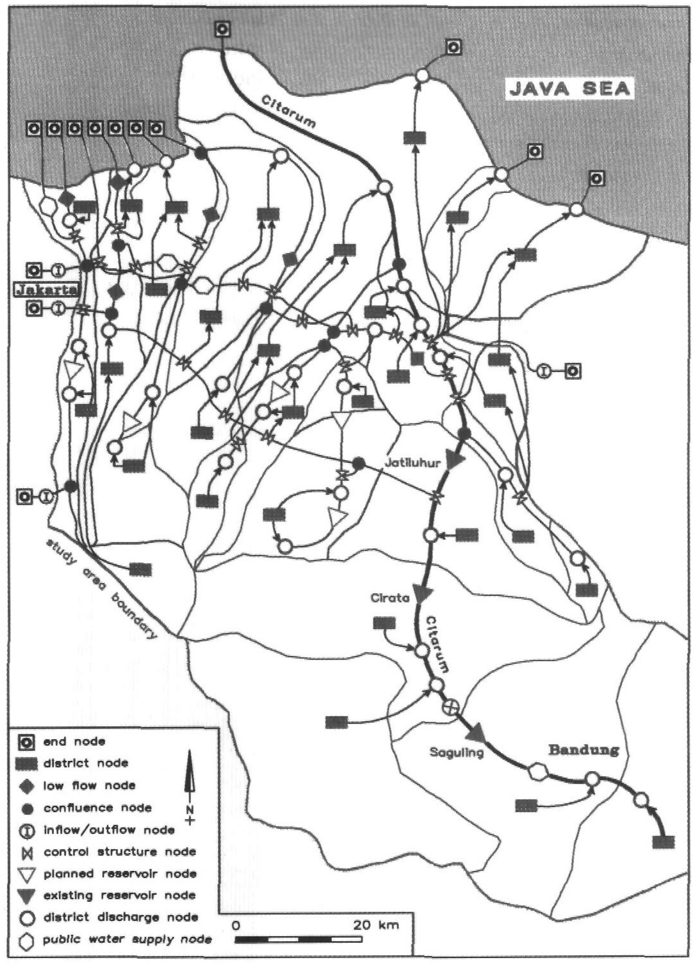
Behaviour of a moored tanker under the influence of fluctuating wind.





water resources management

Decision-makers in water resources development need information from several disciplines to make an optimal selection from alternative measures and strategies. DELFT HYDRAULICS developed a computational framework that supports the integration of results in multi- disciplinary studies.
This computational framework comprises a set of well-tuned models and databases. In many cases these models are kept simple so as to limit the computational effort when dealing with the considerable uncertainties in data, process parameters and scenario variables. However, recent developments in computer hardware enable the use of detailed simulations of real-world systems in computer models and the incorporation of these models into the computational framework. This has opened avenues in the analysis for water resources development that until recently were out of reach for the analyst.

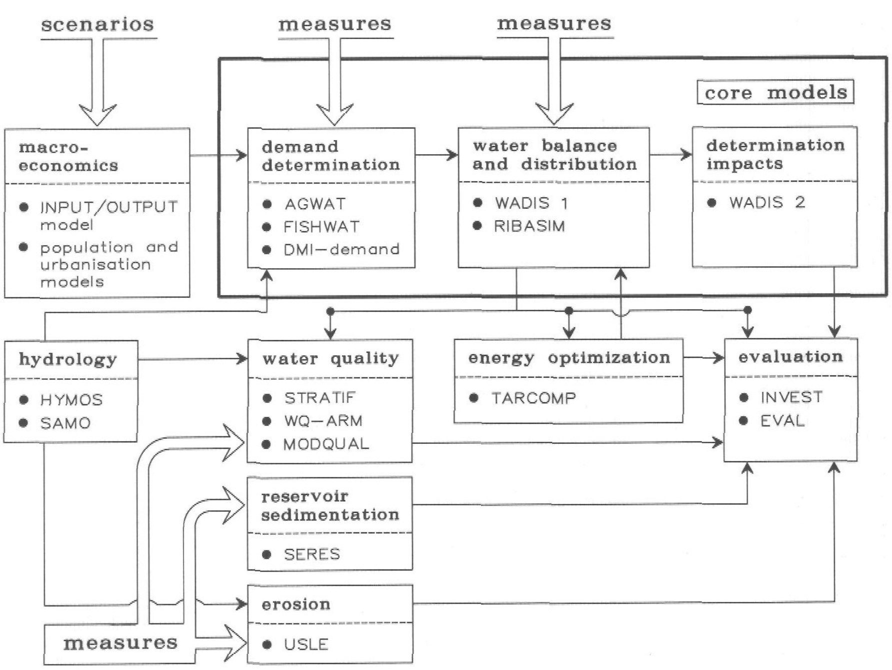


RIBASIM schematization of Citarum basin in Indonesia.

computational framework for river basin planning studies

The main components of the computational framework for river basin planning studies are shown below. Models for water demand and water supply provide inputs for water balance and distribution models to compute the allocation of water over the users and regions given a certain infrastructure and management strategy.
The results are used in several impact-assessment models.

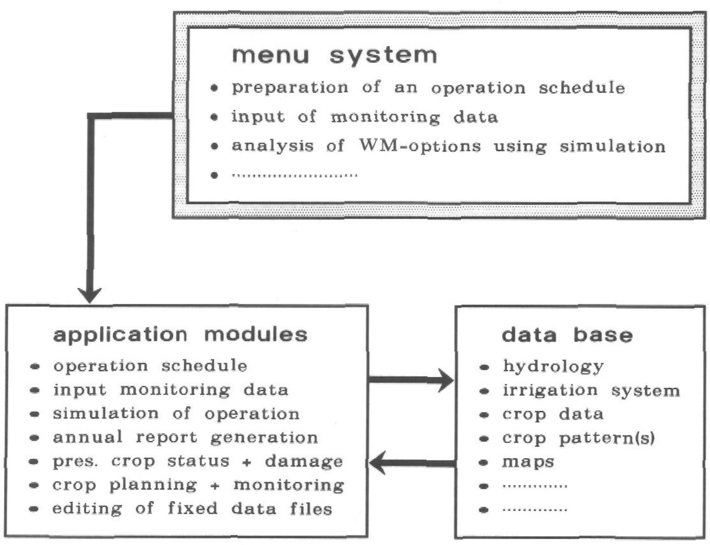
Main components of computational framework.



RIBASIM provides the backbone of the computational framework by covering the simulation of the water distribution in the network. The water supply side is simulated by HYMOS, whereas the water demands from agriculture, public water supply, and aquaculture are modelled by, respectively, AGWAT, DMI, and FISHWAT. The water distribution in the network is based on the physics of the river basin system, taking into account the operational management of reservoirs, diversion weirs and pumping stations. The effects of the water distribution is covered by a set of impact evaluation models. WADIS-2 calculates the production in agriculture and aquaculture (both expressed in quantities as well as in financial and economic terms) as a function of the allocated volumes of irrigation water. Other models deal with the generation of hydropower, the reliability of the drinking water supply, and the assessment of the resulting water quality situation.

Generally, many individual measures can be identified as potential improvements for the performance of the water resources system. Such measures include:

- physical/infrastructural measures (reservoirs, canals, pumping stations);
- operational measures (operation of weirs, reservoirs);
- incentive and institutional oriented measures.



General structure of OMIS.

The development, calibration and verification of the computational framework and the related data collection are a time-consuming activity. However, they prove to be essential in understanding the water resources system and the interactions between the various subsystems. Moreover, they are necessary for a comprehensive analysis, including many alternative strategies and scenarios. As the models are generally applicable, major parts of the computational framework can be used for similar study areas.

operational management of irrigation systems

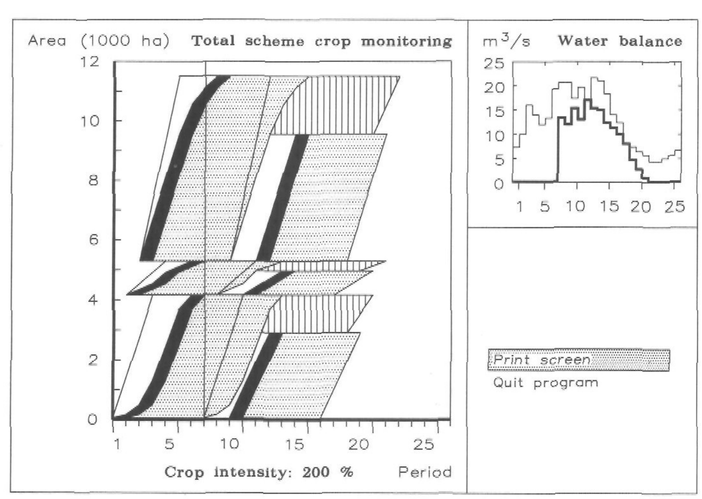
Operational management of irrigation systems requires a constant flow of dedicated information between water users, data collectors, operators, and general management. General management is interested in the status of the system (actual versus target), whereas operators require precise and timely instructions on how to operate gates. Farmers want reliable information on water availability and planned allocations so they can effectively plan investments and activities.

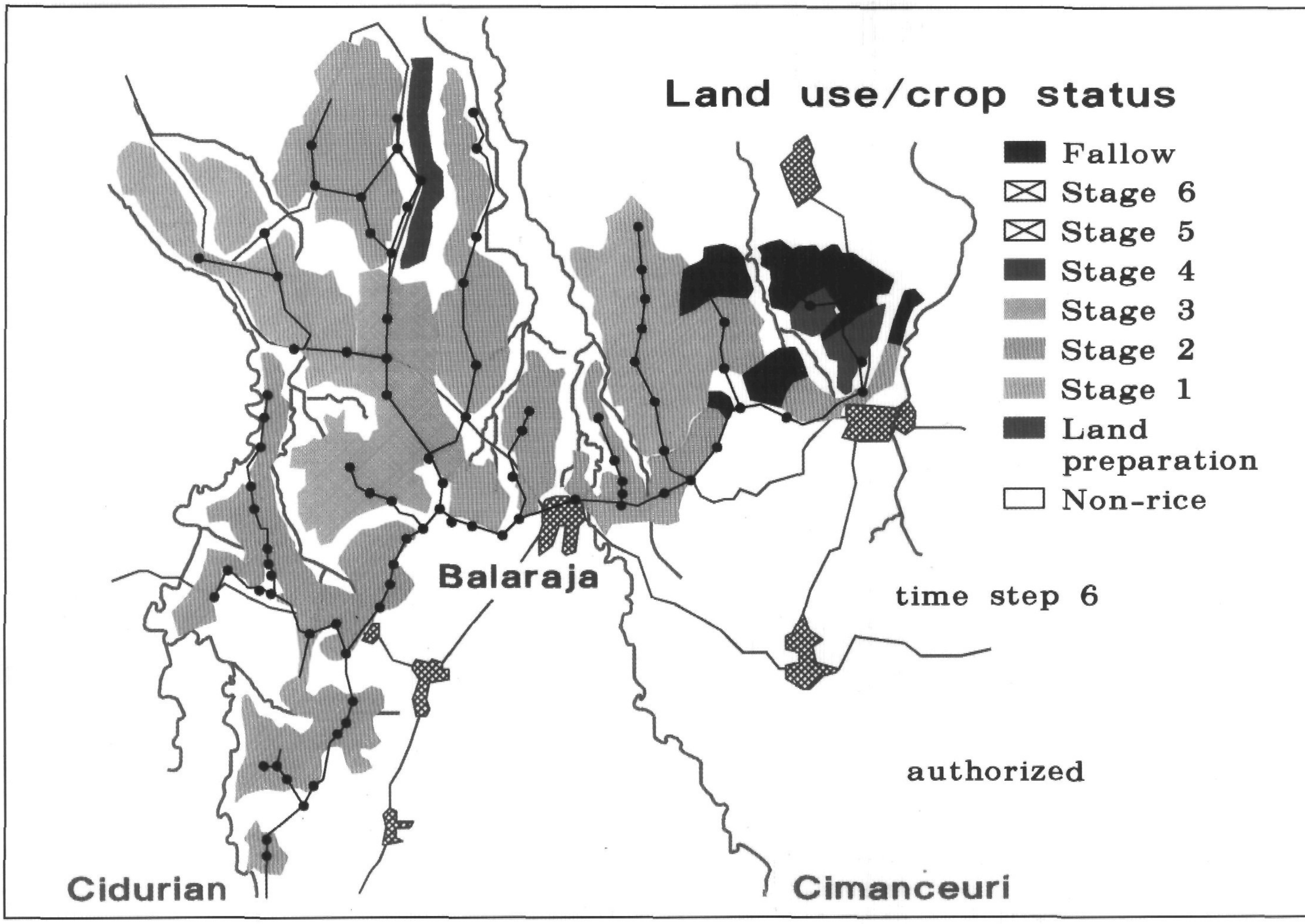
Requirements for maintaining such a flow of information are extensive in terms of computational effort, data-storage and -processing, and useful presentation of results and operation instructions.

The modelling package OMIS (Operational Management for Irrigation Systems) integrates a data base, a set of application routines, and a task-oriented graphical user interface. OMIS supports year-round activities of irrigation water management, such as:

- planning crops on a total-scheme-and-command-area level;
- comparison of alternative options of operation, using simulation;
- processing of monitoring data of rainfall, river- and canal flow, and cultivated area;
- preparing an adjusted water-allocation plan based on observed data;
- graphical presentation of the status of the irrigation system and estimated effects of water shortage; and
- performance assessment.

Crop-time diagram and associated water balance.





Presentation of the crop growing stage in a map of the Cidurian irrigation system, Indonesia.

groundwater quantity and quality

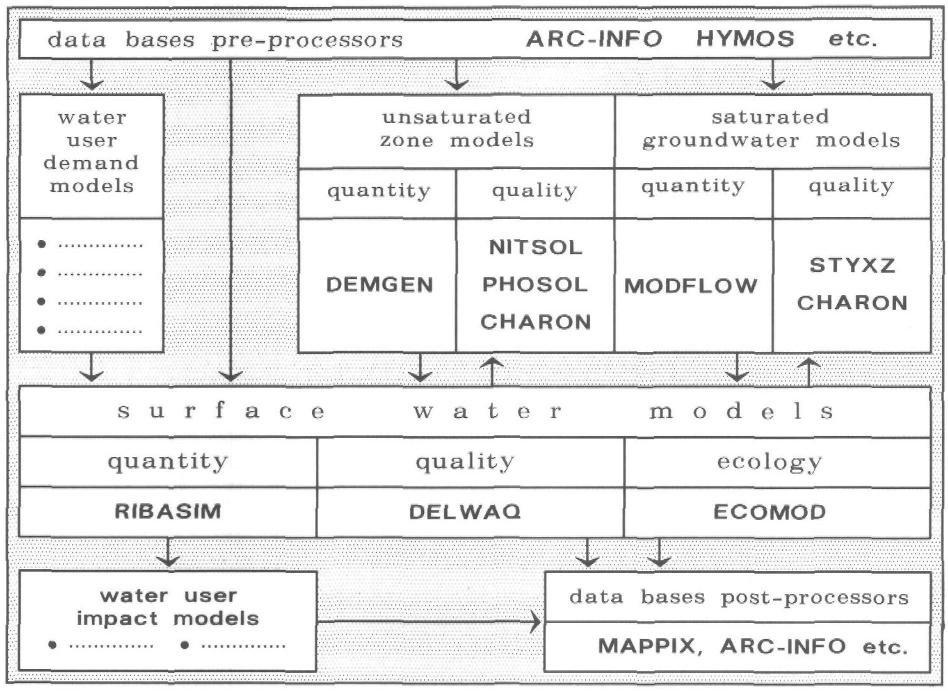
In the field of water-resources management, groundwater flow models are used to find:

- the sustained groundwater yield;
- the net recharge;
- the effect of water-management measures on the groundwater system in terms of quantity and quality;
- crop water requirements.

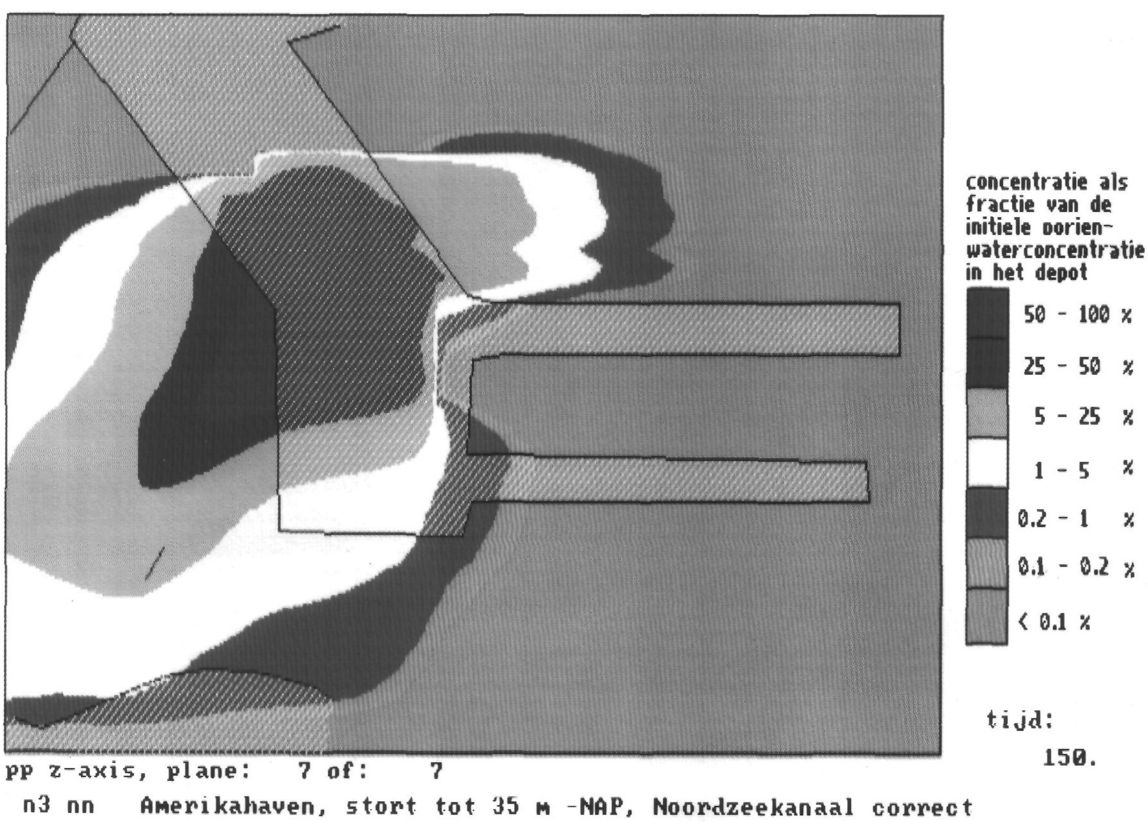
The flow in both the saturated and the unsaturated zone need to be modelled. Flow in the unsaturated zone is computed with the quasi stationary model DEMGEN. Flow in the saturated zone is computed with MODFLOW (originally developed by the USGS and adapted by DELFT HYDRAULICS). This 3-dimensional finite difference model can be coupled with DEMGEN and allows for the modelling of the interaction between groundwater and surface water. For simple flow problems one- and two-dimensional models have been developed.

Groundwater-quality computations require flow velocities, flow paths and residence time of groundwater in the problem domain. Interfaces between MODFLOW and DEMGEN provide the required information to the groundwater quality models used by DELFT HYDRAULICS. General chemical calculations in both the unsaturated and the saturated zone are performed with CHARON. The behaviour of nitrogen and phosphorus are simulated with NITSOL and PHOSOL. For problems related to sludge disposal and pollution of waterbeds STYXZ is used. STYXZ simulates the transport of linear-absorbent substances in two- and three-dimensional groundwater systems.

Computational framework of groundwater quality.



Distribution of a conservative substance after 150 years from an underwater sludge disposal site in the harbour of Amsterdam.



water quality and ecology

Water systems all over the world, be it rivers, lakes, estuaries, coastal waters or groundwater, are exposed to a seriously aggrevated supply of various substances. To assess the rate and risk of pollution, much attention is given to monitor supplies, to study transport and behaviour of pollutants, and to study their impact on the ecosystem. As such assessment depends on a complex interaction of biological, chemical and physical processes, mathematical modelling techniques are used. Analysing and predictive studies are essential in advising on an adequate strategy to maintain or improve the water quality situation.

features of DELWAQ

- **multi-dimensional solution of advection diffusion equation with user-specified reaction and process terms**
- **strictly mass conservative finite volume discretization in recti- or curvi-linear coordinates with arbitrarily shaped volumes**
- **several numerical schemes among which FCT for steep gradients**
- **steady and unsteady solution procedures**
- **special reaction modules to model temperature, sedimentation and erosion, eutrophication and toxic substances, see figure 3**
- **interfaces to all hydrodynamic models**

transport and water quality model

The core of the modelling framework for transport and water quality studies is the DELWAQ (DELft WAter Quality) program, which simulates the transport and behaviour of various pollutants and which is not limited as to the number and complexity of water quality processes. The model is capable of handling one-, two-, and three-dimensional representations either separately and/or simultaneously.

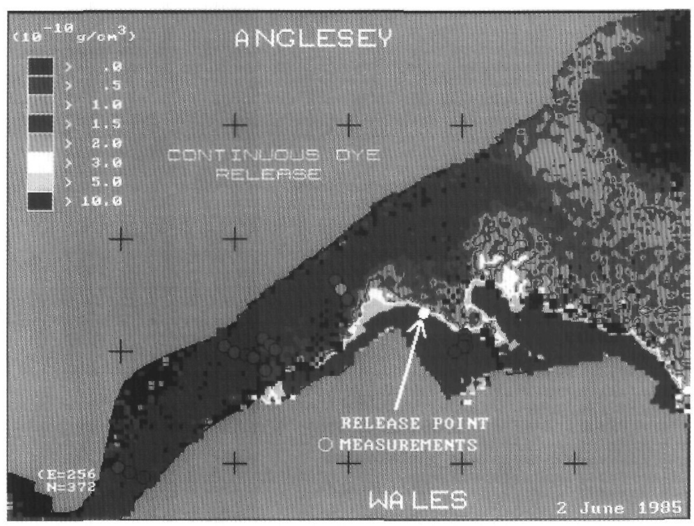


Figure 2: 2D application of DELWAQ; Continuous dye release - Wales.

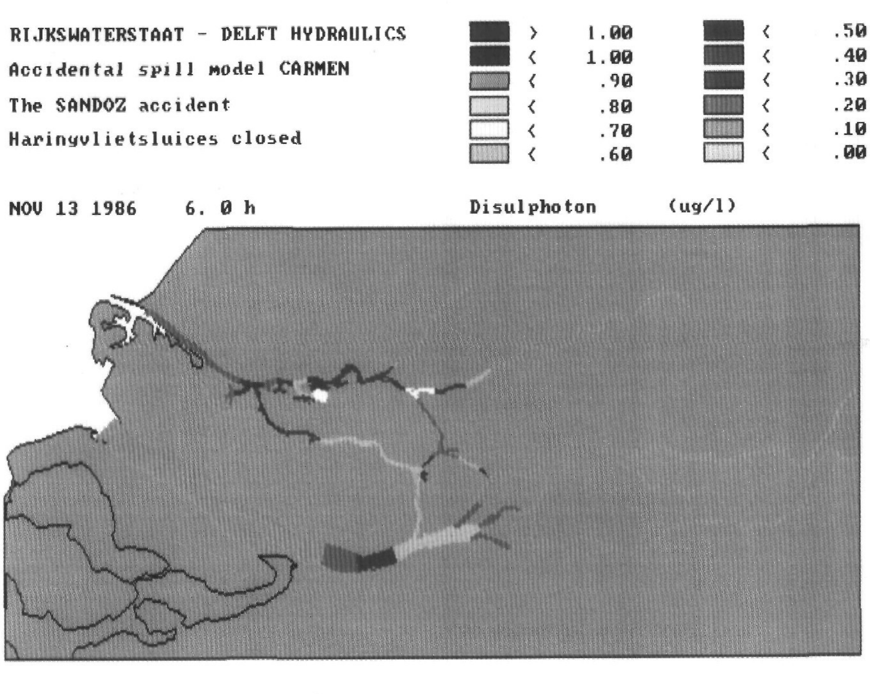


Figure 1: 1D application of DELWAQ; Sandoz accident - Switzerland.

In a one-dimensional application the transport and effects have been computed of the accidental spill at the Sandoz factory in Basel, Switzerland, see Figure 1.
For the North East Coast of Wales a two-dimensional horizontal model has been developed to study the impact of outfalls on the general water quality, see Figure 2.
To study the thermal recirculation of an incineration plant in Singapore, the transport and dispersion of discharged heat was computed with a three-dimensional model application using estimated vertical velocity distributions, see Figure 4.

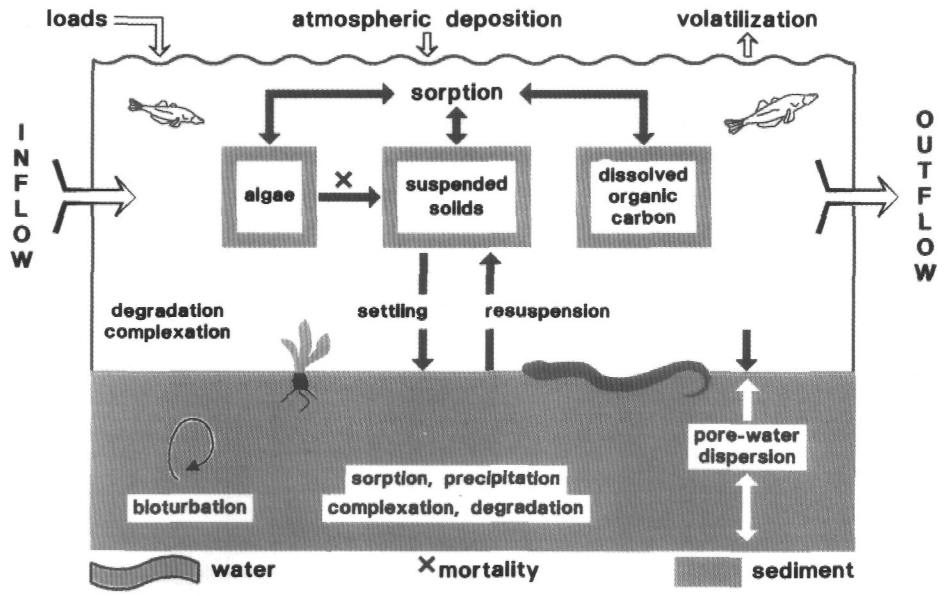


Figure 3:
Processes determining the fate of micropollutants in aquatic systems.

In Figure 5 a coarse-grid model application for the Tanshui river basin in Taiwan is shown. The objective of the study was to strengthen the clients' capability to perform quantitative analysis in support of planning for water resources management on a national and river-basin level. Part of the activities within this study dealt with the development of an integrated computational framework for water resources management. For this purpose DELWAQ was coupled to a network model, simulating the water distribution in the river system.

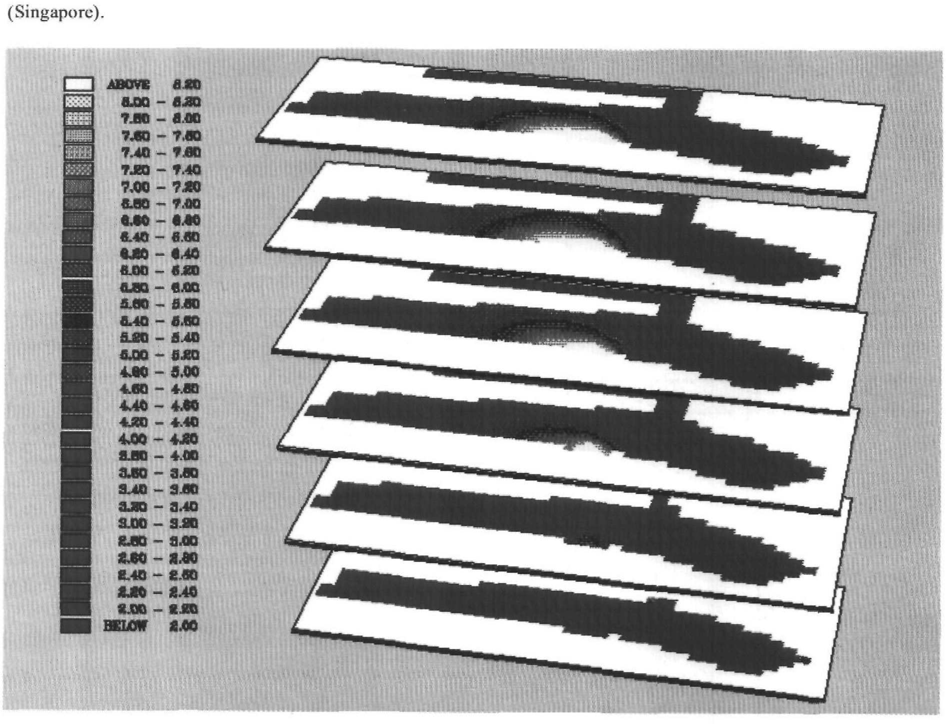


Figure 4:
3D application of DELWAQ; Cooling water dispersion Senoko (Singapore).

Another example of a coarse-grid application is shown in Figure 6. The lagoon of Venice is facing considerable ecological problems, demonstrated by extensive seaweed blooms (Ulva). Within this study a computational framework was used to describe and quantify the cause-effect relations about the excessive Ulva production. In this study DELWAQ was coupled to a finite element hydrodynamic model and to an ecological model for shallow eutrophic marine water systems. The calculated carbon, nutrient and oxygen balances facilitated the evaluation and prediction of eutrophication phenomena in the lagoon.

The North Sea is very important to its surrounding countries for fishery, transport, nature conservation, energy resources and recreation. To properly manage such a system one has to combat and prevent the negative impacts of the aforementioned interests, aiming at restoring and perfecting the desired uses. The pressure on the natural marine environment, however, has increased due to numerous activities at sea and the dumping of waste through rivers, outfalls and the atmosphere. Throughout the years public opinion and political awareness in the Netherlands have resulted in the development and application of a set of tools to support and evaluate managerial decisions.

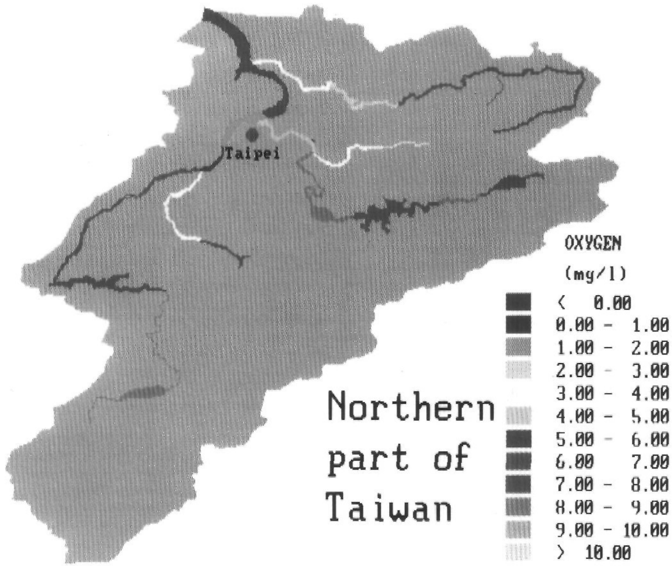
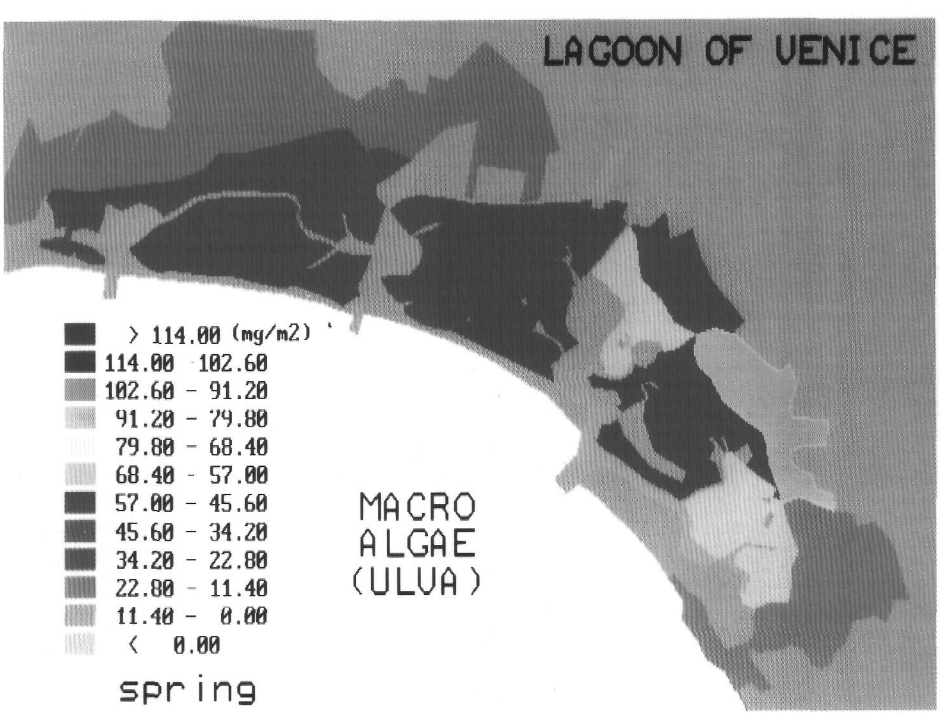


Figure 5:
Simulation of biological oxygen demand in the Tanshui river basin, Taiwan.

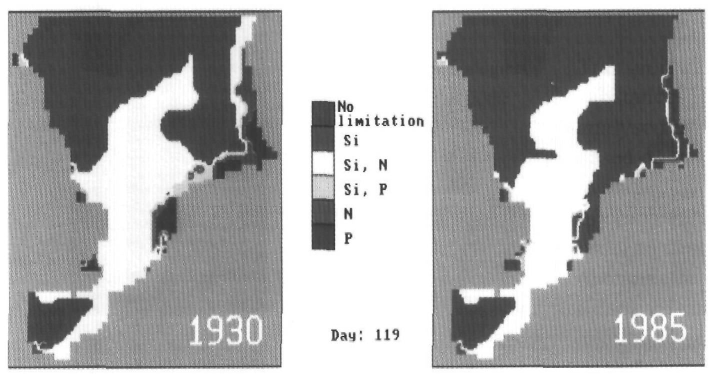
Transport and behaviour of various substances in the North Sea have been analysed using DELWAQ applications based on two-dimensional vertically averaged hydrodynamic models. Thousands of computational elements were used in order to describe properly the transport phenomena. The residence times of dissolved substances in the North Sea is about one year. Therefore, interest has been focused on the long-term distribution patterns.

Figure 6:
Simulation of Ulva biomass in the lagoon of Venice - Italy.



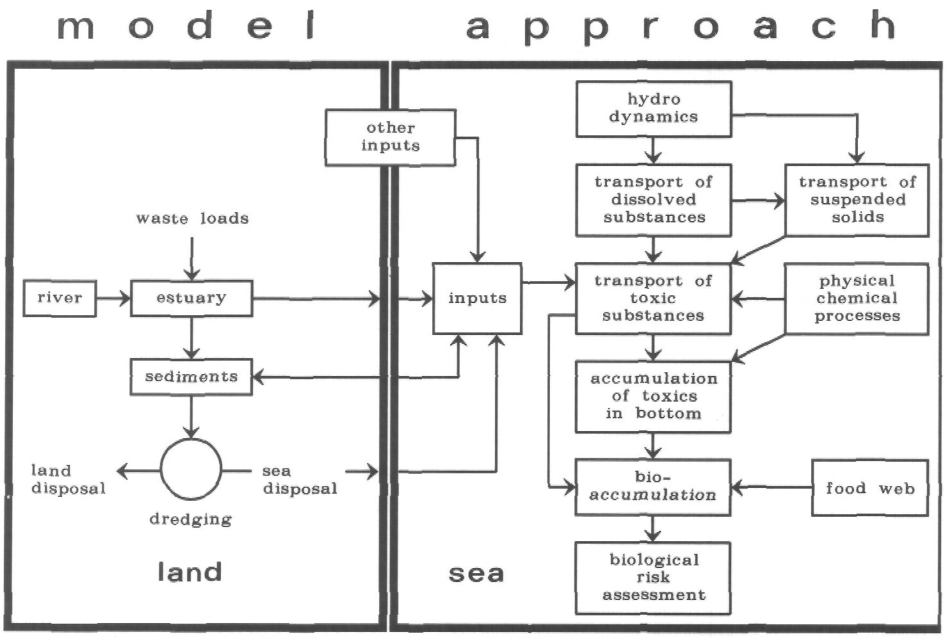
With a biological module coupled to DELWAQ, time-and-space dependent distribution of the major nutrient pools in the water phase and the sediment can be simulated. Figure 7 shows a comparison of the state of potential nutrient limitation for phytoplankton between 1985 and the hypothetical conditions for 1930 (the reference situation). Only tide and wind induced residual flows were used in this study.
The impact of anthropogenic micropollutant supplies on the quality of water, sediments and biota has been quantified in recent studies. The model approach is schematically shown in Figure 8.

Figure 7:
Simulated potential nutrient limitation for phytoplankton in the North Sea in 1930 and 1985.



The transport of pollutants through the North Sea was simulated, taking into account all relevant processes. Based on the settling of both organic and inorganic particles the accumulation in the sediment was quantified. A steady state bioaccumulation model was used for the estimation of accumulated concentrations of micropollutants in some specific functional groups, as part of a characteristic North Sea food web. The physiological description and the feeding behaviour of the modelled functional groups were derived from a (foodweb) carbon fluxes optimization model.

In Figure 9 the approach using available data interlinked with mathematical modelling techniques is illustrated for PCB153. This approach enables a spatial evaluation of the present status of North Sea pollution with micropollutants. Although the risk of all pollutants is not yet fully understood, there are strong indications of toxicological effects on marine ecology. In this respect, the negative impact of PCB pollution on the seal population in the Wadden Sea is an alarming example.



As the transport of pollutants and their impact on the ecosystem depend on a complex interaction of various processes, mathematical modelling techniques were used in the above studies. With the aid of models it is possible to reproduce the distribution of the various pollutants that affect the water quality. The models described may be employed for all types of water systems to analyse past data and to assess current conditions, scenarios and to project future needs.

Figure 8:
Integrated modelling approach for micropollutants.

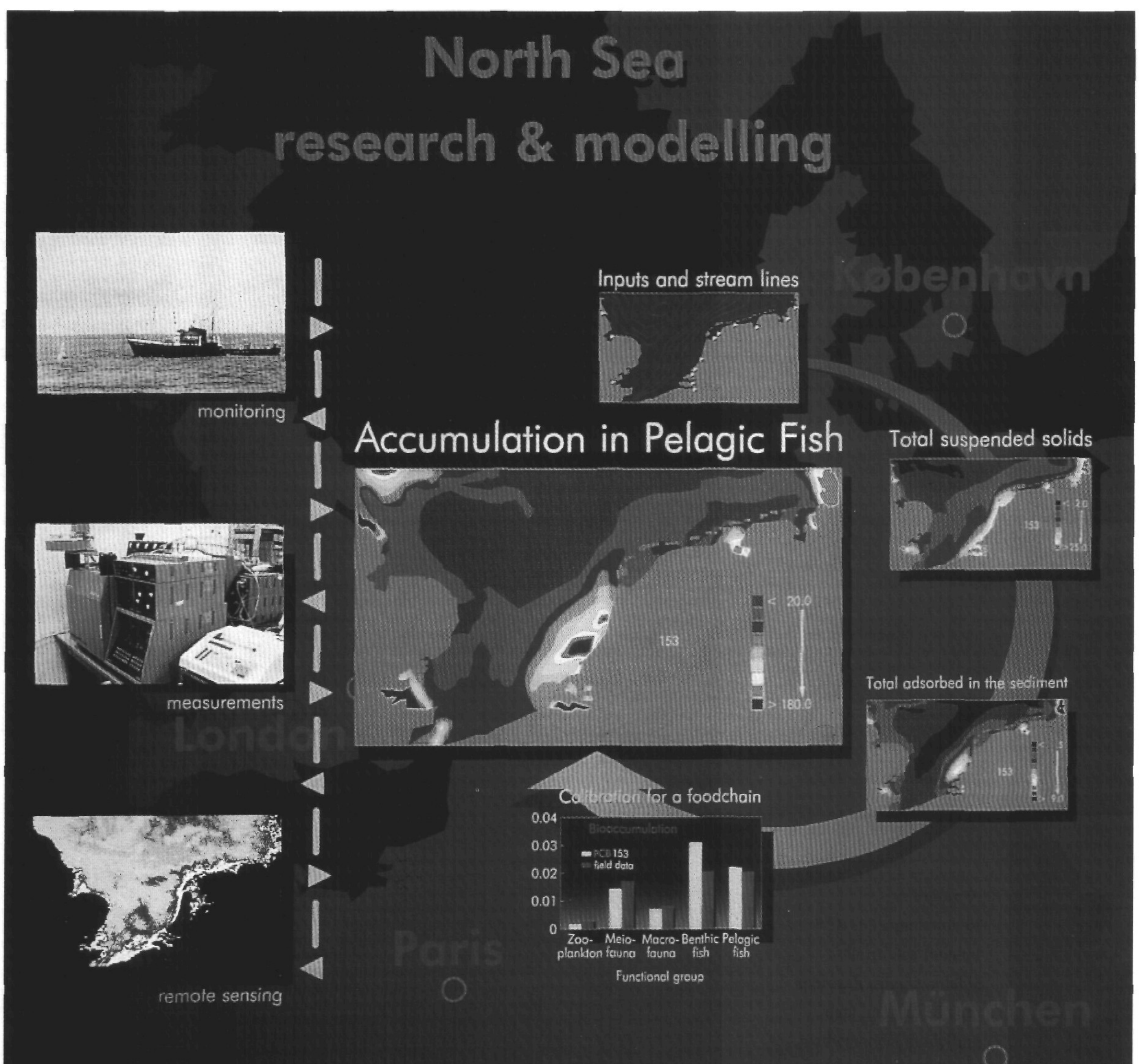


Figure 9:
PCB153 simulation of North Sea Integral approach using available data interlinked with mathematical modelling techniques.

operational management systems

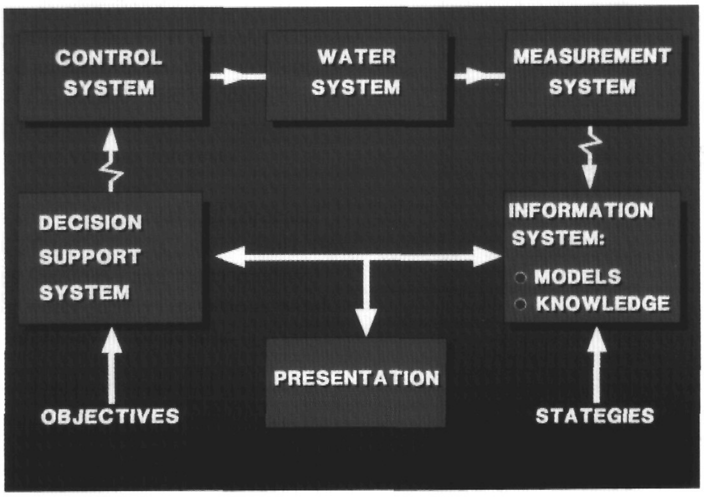
Operational management of infrastructure deals with the daily operation of existing infrastructure with well-defined functions. Examples are lock and sluice operation, vessel traffic services and river flow forecasting.

structure

The data flow in an operational management system is shown in Figure 1. The real-world water system is monitored with a measurement system. Data are transferred to a central site, where information processing takes place using mathematical models and site-specific knowledge. Results are displayed to the manager in an easily interpretable format. These results include an overview of the actual situation, and short- term forecasts. The manager can interactively simulate operation of the structure, compare results of alternatives, and decide on the best course-of-action. Wherever the number or complexity of the alternatives is impeding the decision-making process, support can be given by a dedicated decision-support system. The actual decision is transmitted to the field and implemented. Effects of control actions are registered by the monitoring system at the next time interval. This closed-loop approach is used in a real-time system for flow forecasting and flood control.

In river flow forecasting three components of the hydrological cycle are of particular interest: quantitative precipitation, runoff from subbasins, and flow propagation through the open channel network. In a real-time setting, forecasts are confronted with actual measurements at a regular time interval. Data-assimilation techniques are used to combine these two sources of information, taking into account their respective accuracy, and resulting in an estimate of the actual state, Figure 2. This estimate of state is presented to the manager in an easily interpretable manner and used as the initial condition in model computations for the next time interval.

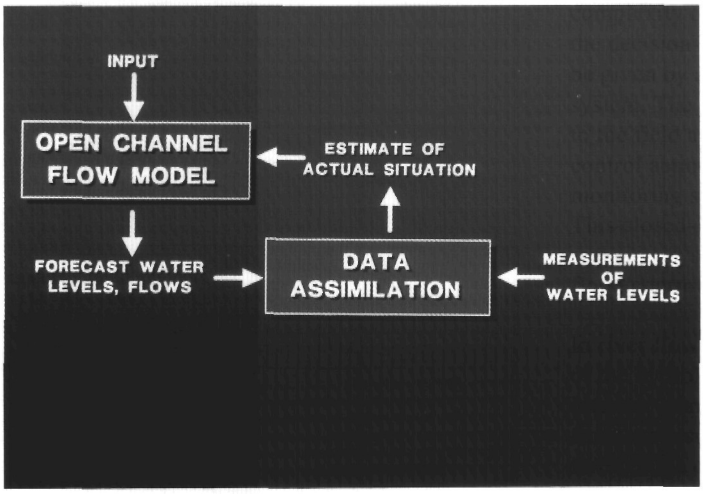
Figure 1
An operational management system.



integral water management

Today the multi-functional use of rivers makes decision-making often a difficult process, as so many interests are involved. The operation of the weirs of the Meuse river, for instance, will affect navigation, ecology, water quality, industry, hydro-power, irrigation, drinking water supply, nature conservation, recreation, and fishery. Operational costs should also be accounted for.

Figure 2
Data assimilation in mathematical models.



In order to visualize the effects of proposed weir operations, DELFT HYDRAULICS has developed an operational management system of the Meuse. The window-based user interface enables simultaneous assessment of various interests.

Figure 3 shows the actual and forecast situation of water levels (navigation), flow velocities (ecology) and water quality (drinking water supply) in various windows with different levels of details.

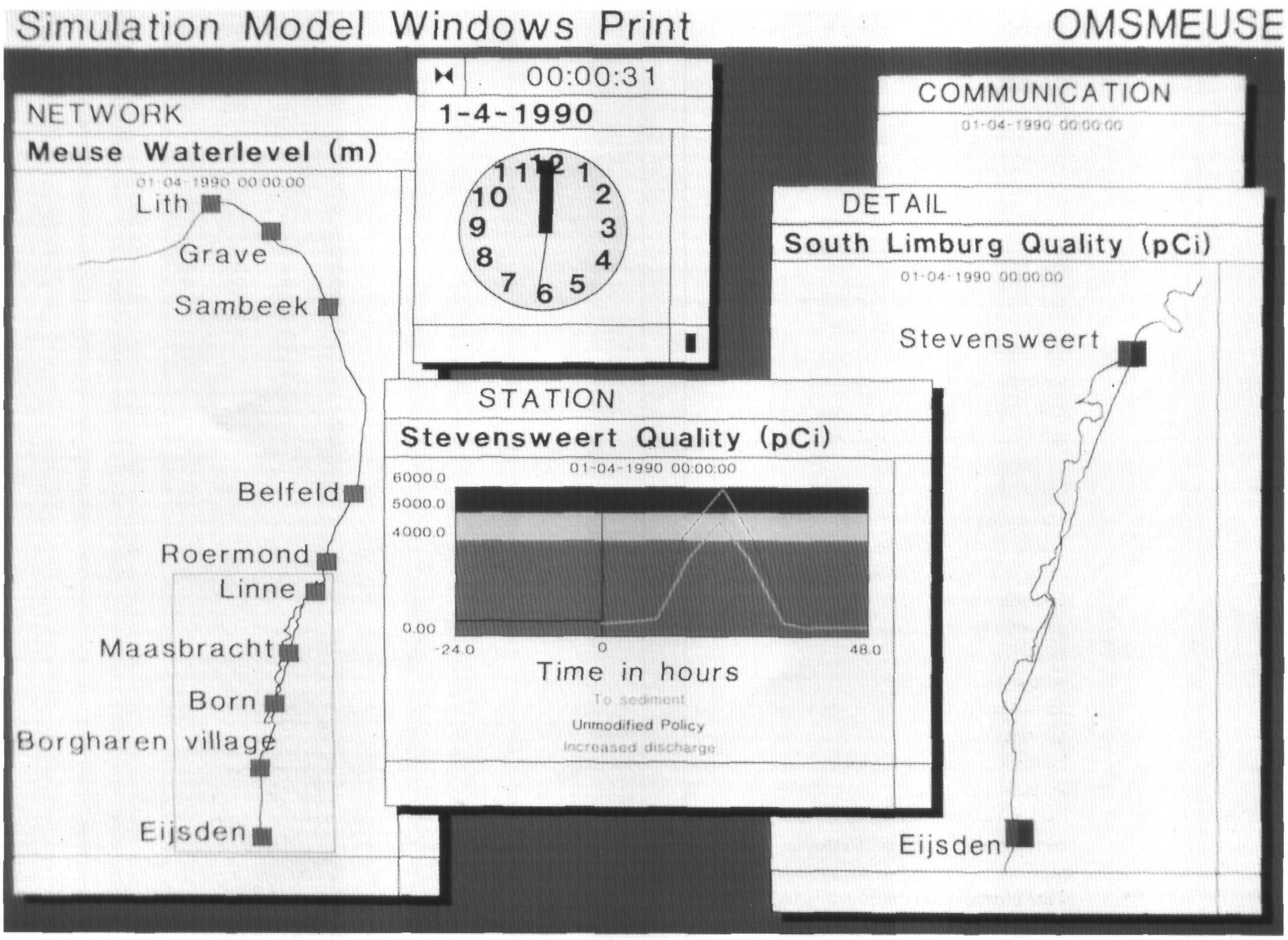
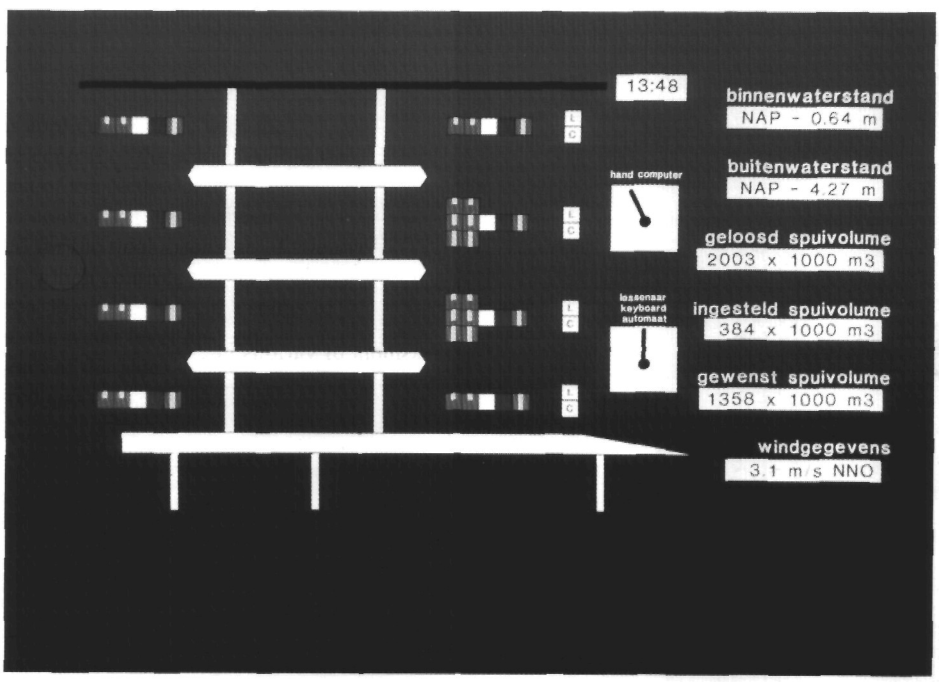


Figure 3
Screen picture of the Meuse-model.



A similar application deals with the automatic control of the water level in the North-East of the Netherlands. An automatic control system has been developed for the tidal discharge of Nieuwe Statenzijl, which controls the water levels in this area. Figure 4 shows the status of the gates, the water level up- and downstream of the gates and information on required and realized discharge.

Figure 4
Screen layout of Nieuwe Statenzijl control system

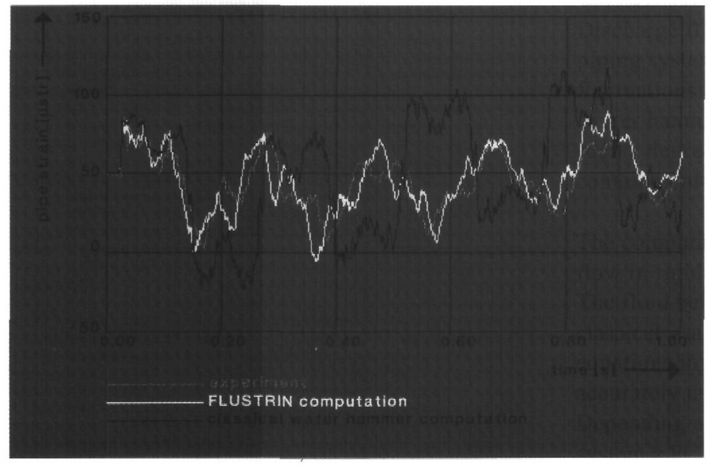
pressure transients in pipeline systems

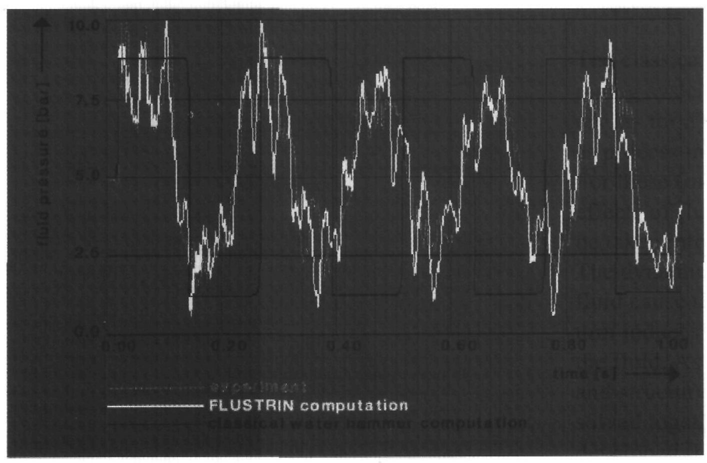
Discharge fluctuations in pipeline and piping systems may cause severe pressure fluctuations. This phenomenon, known as 'water hammer', may impair the system to such a degree that loss of integrity and containment will occur.

The computational modelling of transient flow in rigid pipelines has become of age. The fluid behaviour is described by classical water-hammer theory and the equations involved can be solved accurately using numerical methods. Depending on the complexity of the piping system a PC (WTSL+) or a mainframe program (WILMA) is used.

The classical approach of a fully rigid piping system does not yield reliable results for a number of piping systems such as process installations and loading lines. For these (often) high risk systems the effects of fluid structure interactions must be taken into account.
The dynamic loads of pressure waves in the fluid cause the structure to move and this in turn induces additional pressure waves in the fluid. As a result the motions of fluid and structure are coupled and must be solved together. DELFT HYDRAULICS developed the FLUSTRIN-program (FLuid STRucture INteraction); the pipe motion is described by equations for axial, lateral, and rotational displacements. The results of an extensive validation program underscored the importance of fluid structure interaction on extreme pressures and stresses. Classically calculated extremes can be exceeded by as much as 100% or more.

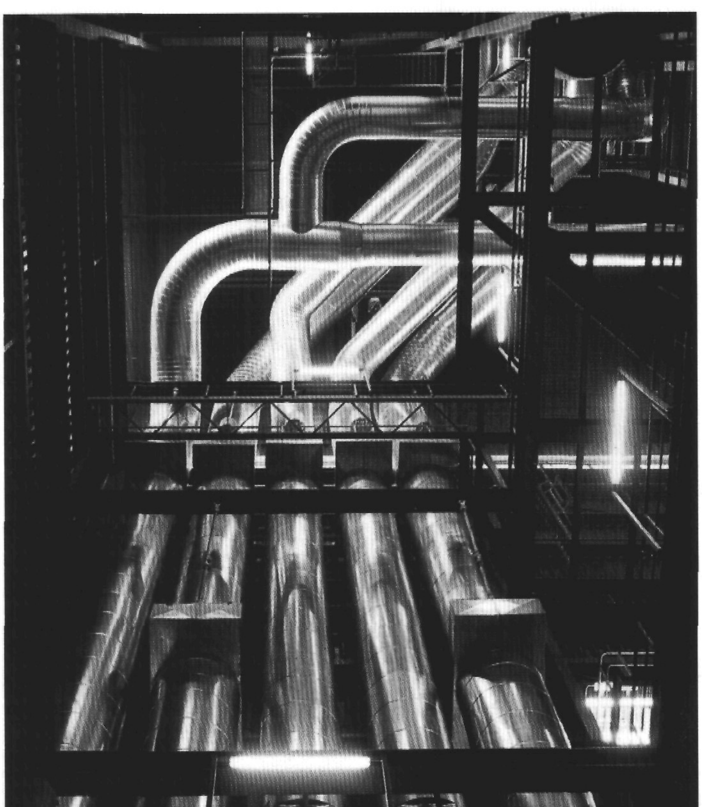
FLUSTRIN was partly developed within the framework of the FLUSTRIN-EUREKA project. This project is supported by 12 national and international companies working in the fields of mining, oil business, power generation and chemical industries. Now FLUSTRIN is extended to handle large and complex networks, including a cavitation model. The computational methodology is being included in the new Dutch steel pipeline design standard NEN 3650, which will also form the basis for the new European standard.





Results of FLUSTRIN (coupled computation) vs. tradional waterhammer simulations (uncoupled computations).

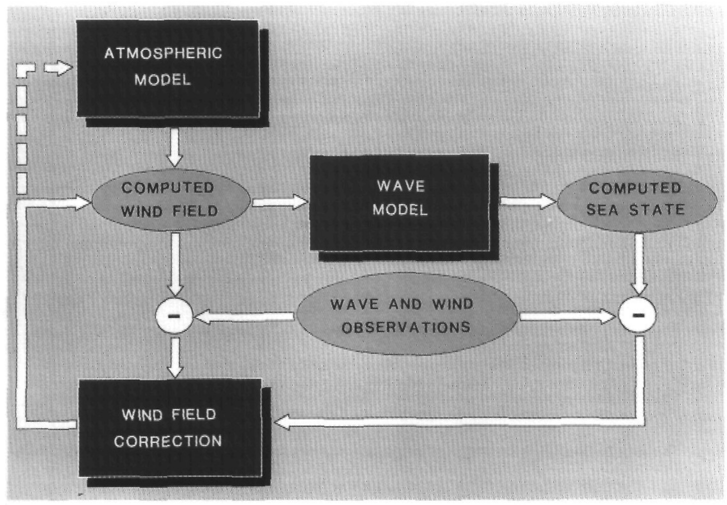
Piping network.



inverse modelling

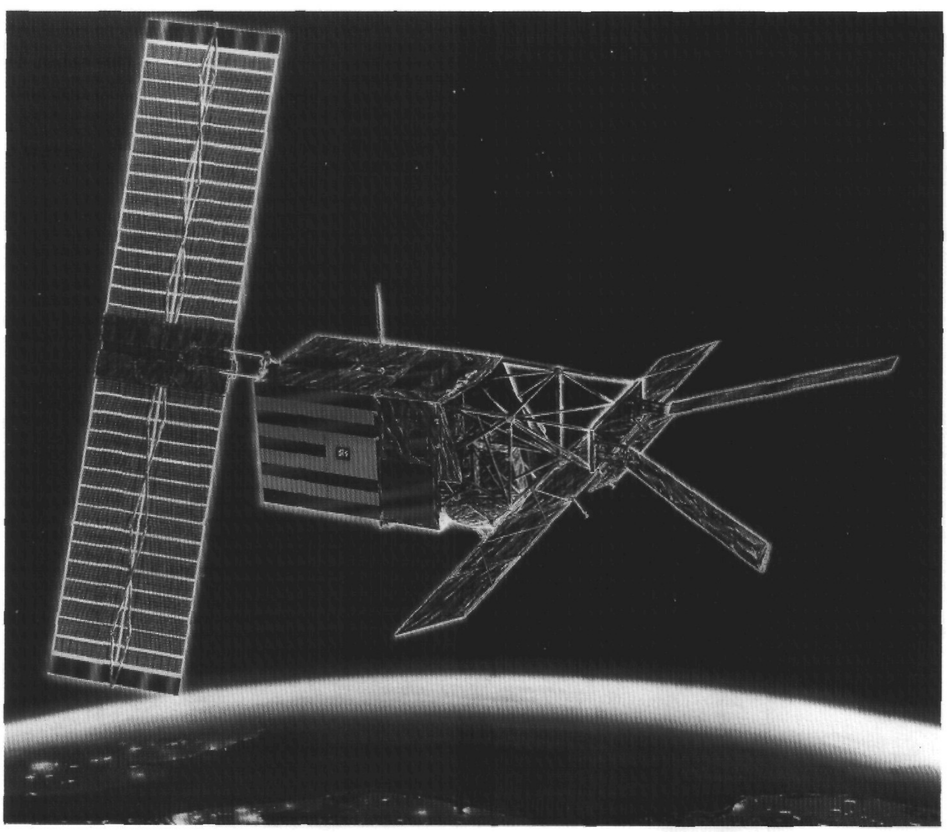
Numerical model predictions are prone to errors caused by uncertainties in model input data (initial or boundary conditions, or external forcing parameters) and simplifications made during the formulation and implementation of the model. Measured data yield, at best, only limited information about the modelled process, and they usually pertain to model output rather than input. In INVERSE MODELLING it is attempted to reconstruct unknown model input data from the available observations or model output.

Currently, development of inverse modelling techniques is of growing interest in the many fields where computational models are employed. DELFT HYDRAULICS is working at the front line in this area, applying ideas from optimal control theory and statistics in order to reconstruct state descriptions and input parameters of computational models. The objective is to correct the main sources of error in a given model simulation in such a way, that the resulting computation is consistent with the model dynamics and matches the available measurements as closely as possible. In certain cases, the accuracy of the reconstruction can be estimated as well.



Examples of actual applications are:

- estimation of a spatially variable dispersion coefficient in a 1D salt transport model
- calibration of a 2D model of hydrodynamic flow and heat transport in a river on the basis of thermal infrared imagery
- reconstruction of temperature distribution as a function of depth in the North Sea from thermal infrared
- online estimation of the water levels in a channel network, in the context of a decision support system
- reconstruction of current-velocity profiles from HF radar surface current-data
- reconstruction of the state of a model employed for the prediction of sea surface waves.



validation and software quality assurance

Providing quality in all its services has been a prime objective of DELFT HYDRAULICS ever since its foundation. But, implementing quality control and quality assurance procedures is more than only describing them in manuals. It requires a constant awareness that quality should be demonstrable and verified on accepted criteria and standards. Quality of a computer model depends on an appropriate and accurate model formulation, as well as the correct and meaningful behaviour of the software, both receiving a great deal of attention at DELFT HYDRAULICS.

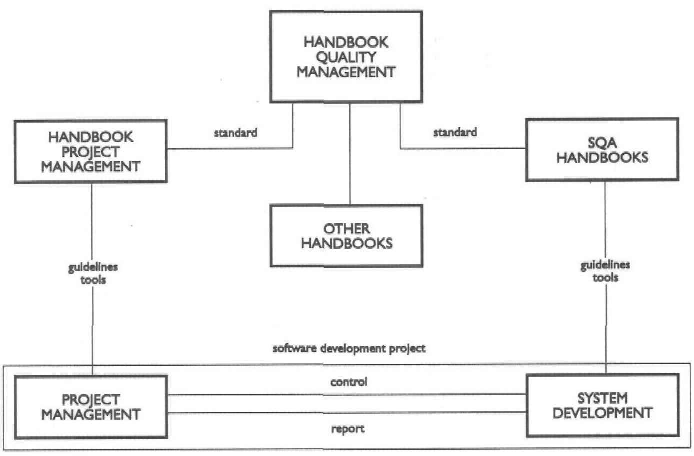
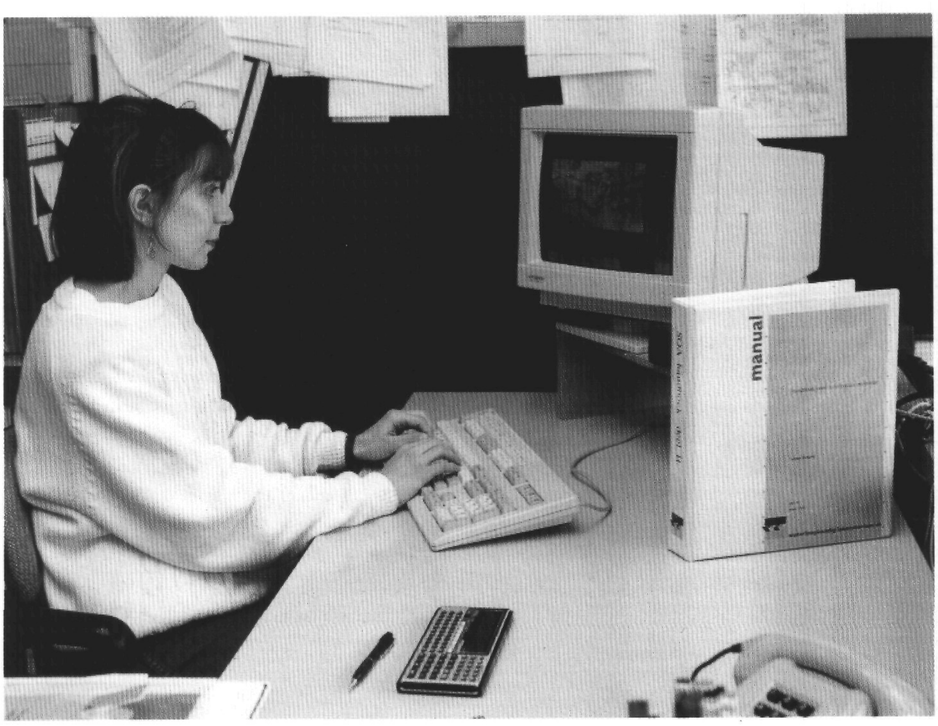


Figure 1: DELFT HYDRAULICS quality system.

model validation

The tendency to create increasingly powerful modelling tools — based on complex physics, advanced numerical techniques, and sophisticated software systems — has been accompanied by a growing awareness of the need for model validation. Users require explicit information about the reliability and accuracy of the computational results, as well as useful guidelines about the applicability and sensible use of these tools. Recognizing this need, DELFT HYDRAULICS has invested a substantial research effort aimed at the development and implementation of a methodology of model validation.

In close co-operation with other leading hydraulic institutes, DELFT HYDRAULICS is formulating standards about validation documentation, which will become an integral part of our modelling software and serve to show the technical and professional expertise that has been incorporated in our modelling tools. It aims at (1) providing a critical and comprehensive description of all aspects of the model formulation and implementation of that factor into the quality of the computational results, and (2) reporting on the results of validation studies in a recognisable format.



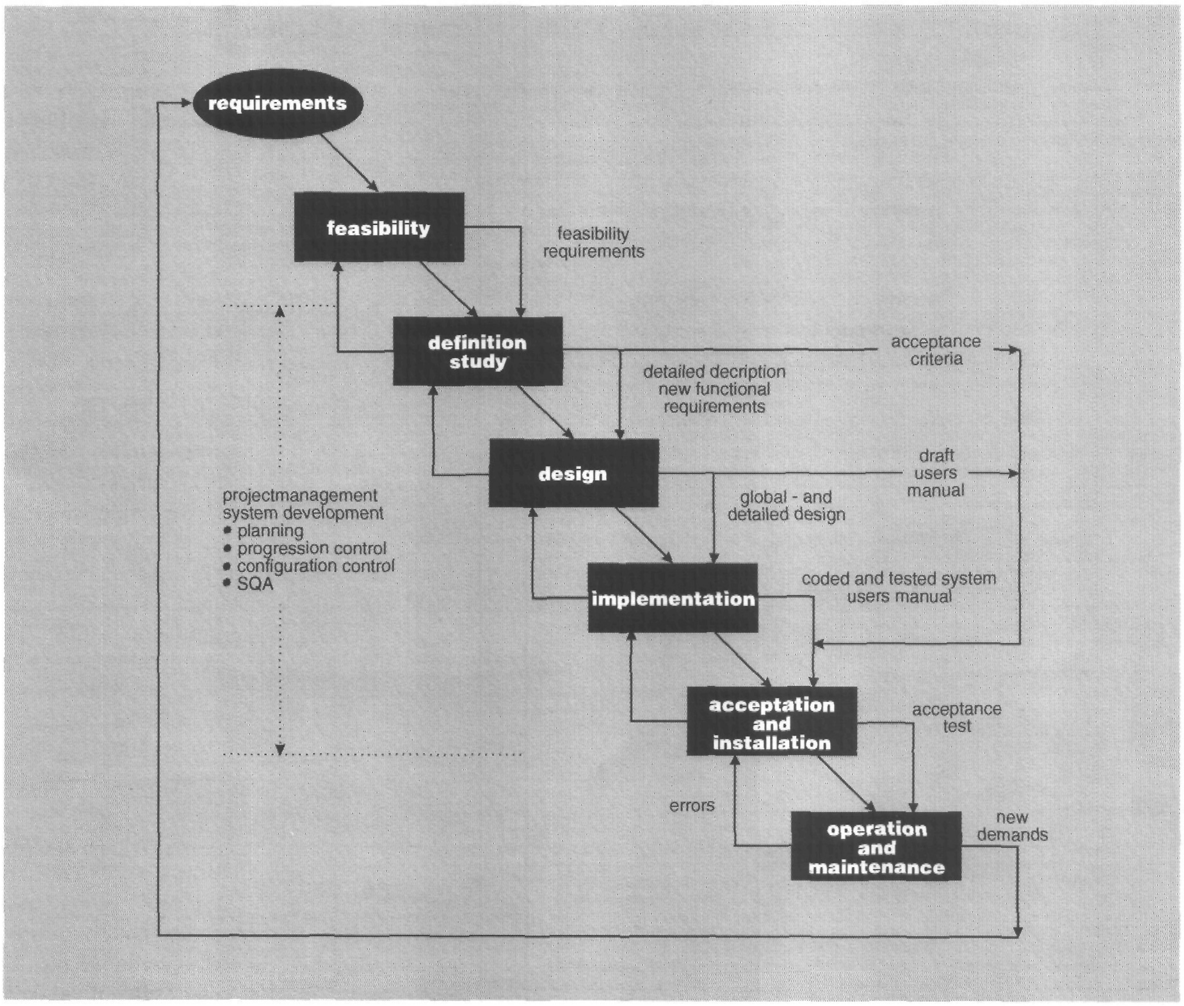


Figure 2: Software development life cycle.

software quality assurance

In order to control software development projects and work out the quality objectives, DELFT HYDRAULICS has defined a Software Quality Assurance (SQA-) methodology. The SQA-methodology as documented in the SQA-Manuals, comprises a framework of procedures and applied standards for software development and maintenance. These SQA-Manuals are part in the general quality system that is in progress of development, Figure 1.

As for software development a so-called software development life cycle model has been adopted, Figure 2, comprising a framework of methods, techniques, tools, and procedures to be applied to new software developments. Though depicted as a linear model this life-cycle model should be interpreted as just one 'twist' in an evolutionary (spiral-like) development cycle. In addition to the documented SQA-methodology a Software Quality Assurance Plan is to be prepared for every software development project, reflecting the project-specific procedures, standards, and requirements. All products, software and documentation, are reviewed to check whether they adhere to the quality standards.

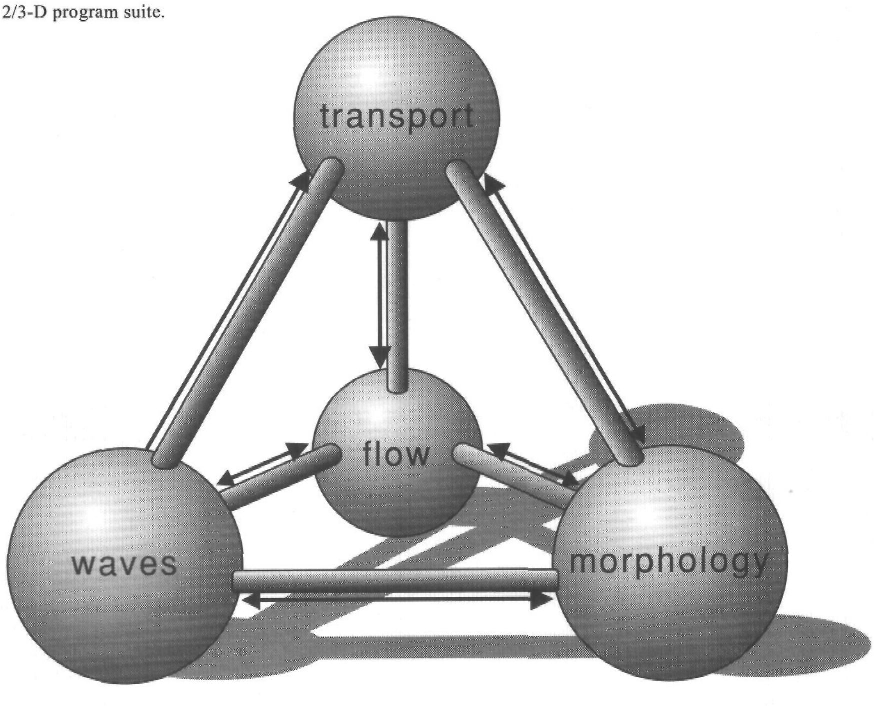
The SQA-procedures apply to new software developments. For existing software checklists were defined reflecting the objectives of the SQA- procedures, and all software and documentation is being reviewed in the light of these checklists. Recommendations for improvements are scheduled in maintenance or redesign plans. Reviewed software and documentation is put under strict Software Configuration Management (SCM) so as to ensure that no undocumented changes can be made.

towards open systems

Throughout this issue of Hydro Delft, the reader will have noticed the tendency towards larger models. Larger in the sense of more detailed and complex representation of separate processes, but also more complex because of the greater number of processes in one application. The need of more complex program systems and information exchange between distinct programs has stimulated the development of an Architecture for Integrated Modelling (AIM) and a NEutral FIle System (NEFIS).

AIM comprises a set of guide-lines on how to structure complex software in such a way that even these complex systems remain flexible and extendible. This is obtained by specifying the required model formulations and program functions into generic formulations and functions and maintaining this high level of modularity in the software. Libraries of generic functions and generic compound functions are developed and made available to software engineers. In this way AIM stimulates the re-use of generic software.

System definition of 2/3-D program suite.



To structure the exchange of (large volumes) of data between applications, where the applications may run on various computers in a network environment, NEFIS has been developed. As no industrial standard exists, DELFT HYDRAULICS decided to develop its own standard. NEFIS is made up of a library of functions to store and retrieve compound sets and subsets of multidimensional data as used in engineering computations. Much attention was paid to efficiency and performance both in storing and retrieve operations. Tools are being developed to work on these files. NEFIS is being implemented in all operational software and on all relevant hardware platforms.

development of program suites

To facilitate an optimal environment for complex applications so-called program suites are developed. A program suite is characterised by a set of possibly interacting programs with standardised program interfaces, structured in line with AIM, file structures according to NEFIS, and a uniform userinterface and visualization of results.

Two new program suites are being developed for, respectively, one-, two- and three-dimensional problems. Both program suites comprise flow, transport, waves, water quality and morphodynamic computations. After a detailed system definition of required processes and functions, existing computer programs were mapped onto these requirements. As a result the number of programs will be reduced and the remaining programs will be modified and, if necessary, restructured or redesigned so as to fulfil the design criteria of the program suites. To the end-user these program suites will provide a computational environment in which processes can be added or deleted in a flexible way without having to worry about data transfer or file structures. For the developer they provide a testing environment for new modules that can replace existing ones and take advantage of all standardised pre-processing and visualization facilities. Running the program suites in a network environment is a design criterion.

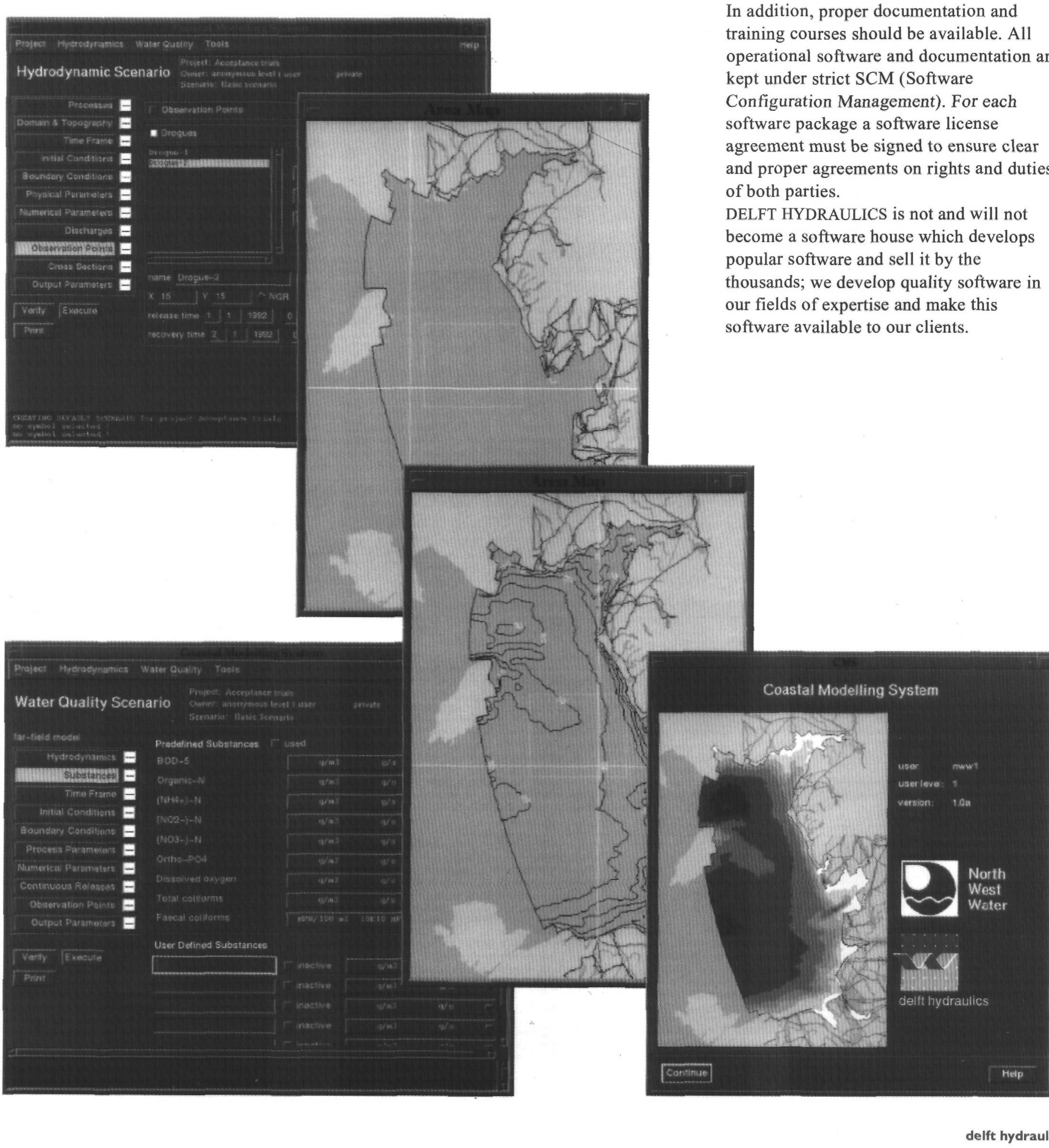
software sales policy

Over the years DELFT HYDRAULICS has developed a broad range of computer programs applied in consultancy and basic research projects. There is an increasing demand from customers to acquire or use these programs in their own projects; either as a dedicated version, or as a general consultancy or development tool.

Recognizing that it takes more than only a PC or even a supercomputer and a couple of equations from literature to build reliable software packages, DELFT HYDRAULICS decided to make all its operational software available for third parties.

Operational software meets the criteria explained in the section on Quality Assurance. These concern both software quality and application validation criteria. In addition, proper documentation and training courses should be available. All operational software and documentation are kept under strict SCM (Software Configuration Management). For each software package a software license agreement must be signed to ensure clear and proper agreements on rights and duties of both parties.

DELFT HYDRAULICS is not and will not become a software house which develops popular software and sell it by the thousands; we develop quality software in our fields of expertise and make this software available to our clients.



Coastal ModellingSystem: a program suite for coastal water quality studies. Collage of user interface windows.

selection of recently developed computer programs

AAD Simulation of water and salt flows in free flow and controlled network systems. Prediction of regional water and salt flows and resulting agricultural crop damage.
AUKE Time series processing; data acquisition and analysis.
BEACH 2DV non-linear wave deformations on beach slopes.
BREAKWAT Designs of armour layers of statically stable breakwaters and revetments.
BLOOM II Algal bloom in lakes or shallow reservoirs.
CLODES Design of closure works.
CMS Program suite for coastal water quality studies.
COMOR Coastal morphology package including approximately 60 programs.
DBS Integrated eutrophication model system.
DELMOR Program based on TRISULA to simulate the 2DH transport of sediments (i.e. cohesive, non-cohesive, bed load, suspended load) in estuaries and seas. The morphological model accounts for the effect of change in bottom topography due to erosion and sedimentation on the water movement.
DELPAR Midfield dispersion model.
DELWAQ Multi-dimensional water quality model (can use output of TRISULA).
DIFFRAC 2DH wave diffraction in simple harbour configuration.
DIPRO Dimensioning of protections in inland navigation fairways.
DUROSTA 2DV time dependent dune erosion model due to storm surges.
ENDEC Wave energy decay along a wave ray path incorporating non-linear dissipative processes due to breaking and bottom friction.
FLOWSIM Dynamic flow of water channel networks with CAI-Shell.
GETIJSYS A program package for the processing of tidal records and tidal prediction.
GRID2D Grid generator for curvi-linear flow and transport.
HYMOS Storage and processing of hydrological data for water management systems.
MIANDRAS Meandering rivers (2 dimensional simulation).
NITSOL Nitrogan transport through the unsaturated part of the soil
ORPHEUS Screening model for sludge disposal in sandwin pits.
PHAROS 2DH wave oscillations in harbours of variable depth, based on mild slope equation.
PHIDIAS Prediction of wind wave energy of random surface gravity waves in deep, intermediate and shallow water using a spectral description of the ocean surface.
PHOSOL Phosphorus transport through the unsaturated part of the soil.
QRIUS Package for managing chemico physical and ecotoxicological data.
RFWAVE Local wave surface elevations and kinematics according to a stream function method.
RIVCOM 2-dimensional bed level changes.
RIVMOR Bed load transport and bed configuration in river systems (1-dim).
SAMFIL Real time rainfall-runoff model.
SCATTER Analysis of wave data to give joint occurrence tables for classes of wave height, period and direction. Translation of data to nearshore location.
SEDIM Sediment extraction in irrigation systems.
SERES Sedimentation in reservoirs.
SKYLLA 2D Navier-Stokes model for simulation of waves on a slope and flows through poreus structures.
SOMOW Real-time multi-tasking system for decision system in flood management.
STYXZ 3D simulation of transport pollutants in groundwater systems.
SUSTRA 3D Morphological changes as a result of sediment transport.
SUTRENCH 2DV version of SUSTRA-3D.
TRISULA A program for the computation of non-steady flow and transport phenomena on orthogonal curvilinear grids in 2 or 3 dimensions.
UNIBEST-CL Coastline development from an extended one-line approach.
UNIBEST-LT Longshore flow and sediment transport on an arbitrary beach profile due to random waves and a tide.
UNIBEST-TC Prediction of profile development due to sediment transport.
WAM Research wind-wave hindcast "third generation" model deep and shallow water with special emphasis on non-linear wave-wave interaction.
WAROS Ship and water motion during the passage of locks.
WENDY Integrated package for dynamic flow of water in channel networks including density effects, suspended sediment transport and morphology.

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