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R&D 2004
Annual Report

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1 Introduction

WL | Delft Hydraulics is an independent research and specialist consultancy institute based in the Netherlands. For over 75 years, we have been providing clients with expert advice and technical assistance on water-related issues. WL | Delft Hydraulics is internationally renowned for its expertise in fields such as hydrodynamics, morphology, surface water hydrology, aquatic ecology and water quality. About 340 qualified and committed professionals combine an in-depth knowledge of these areas with a comprehensive overview of water systems.

Through cutting-edge research and a thorough understanding of water management and related infrastructure, WL | Delft Hydraulics provides its clients with practical and cost-efficient solutions for a wide range of water systems. These systems may be designed to be open or closed, salt- or freshwater, natural or man-made.

Because water management is an ever-changing and complex issue, we are constantly expanding and improving our innovative research and technological expertise to meet these changing needs. Today there is a growing need for integrated solutions based on the latest technologies. As a result we are not only integrating various knowledge disciplines, but also intensifying partnerships with businesses and consultants in the private sector, along with technical institutes and universities.
Our activities range from short- and long-term projects to targeted research as well as multidisciplinary policy and management studies. All of these are carried out under a quality system in accordance with the ISO 9001 international standard. WL | Delft Hydraulics is also well-known for its unique experimental facilities as well as its powerful software, most of which has been developed and validated in-house.

This Annual Report

The corporate policy objective at WL | Delft Hydraulics is to increase the accessibility of R&D results by using the Internet for communication and the dissemination of reports, publications and software systems. The layout of the Annual Report corresponds to the style of WL | Delft Hydraulics’ website, which is naturally updated regularly and contains additional information, such as dynamic animation imagery of R&D results.

A PDF-version of this annual report R&D 2004 is available via the website of WL | Delft Hydraulics at www.wldelft.nl

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2 R&D policy & issues

WL | Delft Hydraulics’ objectives were to obtain a coherent research and development programme, to participate in several joint research programmes (usually requiring matching funds and controlled by external programming bodies) as well as to initiate specific internal projects in order to strengthen its core activities.

WL | Delft Hydraulics’ strategy aims to achieve an optimal balance between research and development and specialised consultancy work. In this way, all of the aspects related to the full knowledge cycle may be covered: from innovative research to practical applications to the formulation of research requirements, and so on.

Although government-funded R&D constitutes an important component of all research and development activities at WL | Delft Hydraulics - and is in fact the main topic of the present annual report - additional R&D projects are acquired and conducted as well.

On a national level, a number of research and development projects involve joint development (the role of “advisor to the advisors”) activities in which specialised institutes such as the Ministry of Transport, Public Works and Water Management (notably DWW, RIKZ, RIZA) are involved. In addition, R&D projects are carried out directly for industry. In 2004 participation was continued in several national joint-research programmes (notably Delft Cluster, Netherlands Centre for Coastal Research, Netherlands Centre for River Studies).

Internationally, WL | Delft Hydraulics has been successful in acquiring European research projects, with each project lasting a couple of years. Participation in joint (inter)national research programmes invariably requires matching funds from each participant. Hence these projects often form an integral part of the annual R&D programme, while at the same time creating a multiplier effect to achieve the strategic goal of WL | Delft Hydraulics: devoting 50% of its time and effort to research and development. In 2004, a level of 39% was achieved.

Research and development at WL | Delft Hydraulics is related to marine systems, inland water systems or industrial systems and involves the use of experimental facilities as well as software systems. Hence, R&D projects have been grouped accordingly in this Annual Report.

The R&D programme was based on external as well as internal considerations. Market developments were monitored and demands for new research or products were identified. Representatives from the Rijkswaterstaat (Dutch Ministry of Transport, Public Works and Water Management), local and regional authorities, policy makers and consulting engineers participated in special workshops held in March 2003 and June 2004 to discuss the task-oriented research segment of the financial contributions from governmental departments. Scientific developments were identified through contacts with universities and technological institutes. Implications for the Annual Research Programme were discussed with the Scientific Advisory Board, which is composed of members from universities, industry and government.

Positioned to act as the bridge between fundamental research and practise, WL | Delft Hydraulics converts new knowledge and model concepts which have been developed at universities into applications, and thus cooperates with both sides: universities and other knowledge organisations as well as engineering firms.

Part of this cooperation is institutionalised in the Netherlands Centres for Coastal Research and River Studies (NCK, NCR) and Delft Cluster. Various joint research projects conducted with the specialised institutes of Rijkswaterstaat, Delft Cluster projects and projects acquired within the EU Framework Programmes continued and some new projects were started. Preparations were made for the next series of projects within the R&D programmes at Delft Cluster (2nd phase, financed by Dutch government ‘Bsik’ programme), “Leven met Water (Living with water, another Bsik financed project),” and the EU (6th EU Framework Programme).

WL | Delft Hydraulics wants to boost innovation in water management and water engineering. Listening to signals from society or those from our clients on the one hand and examining our possibilities on the other, we are always in search of opportunities to supplying new products and services which really make a difference for governmental bodies and or private companies in these fields. At the end of this chapter, we provide eleven examples of instances in which we have received recognition for innovative products.

For further information on specific aspects related to R&D policy and programming please contact Huib.deVriend@wldelft.nl or Rob.deJong@wldelft.nl

Scientific Advisory Board
The annual R&D programme is reviewed by the Scientific Advisory Board at WL | Delft Hydraulics. This board plays an important role in achieving a balance between the various subjects for both short- and long-term developments. It is composed of external members from academic institutes, engineering consulting firms, industrial organisations and government agencies. Meetings are held regularly throughout the year for the purpose of monitoring the ongoing programme as well as to prepare the upcoming programme. Thanks to the background of its members, the Board is able to provide valuable input related to external developments which may be relevant for WL | Delft Hydraulics. During the year 2004, the Board met twice and discussed the progress of the R&D projects from 2004 as well as the Annual R&D Programme 2005. In 2004, the Scientific Advisory Board was composed of the following members:

Prof. Dr J.A. Battjes Professor of Fluid Mechanics Delft University of Technology
J.W.C. Remmerswaal Directorate Science and Technology Ministry of Education, Culture and Science
A. van der Horst, M Sc Director Delta Marine Consultants
J.M.J. Leenen, M Sc Director STOWA Foundation for Applied Research on Water Management
Prof. H. Ligtering, M Sc Professor Ports & Waterways Delft University of Technology Member of Board of Directors of Royal Haskoning Member of ONRI
G.J. Schiereck, M Sc Head Staff Bureau Strategy Rijkswaterstaat (Ministry of Transport, Public Works and Water Management)
Innovative products

WL | Delft Hydraulics develops knowledge and tools to deal with present day questions of marine, coastal zone, river, regional and urban water managers and designers of hydraulic structures. To assure an effective R&D output, cooperation is sought with these problem owners, universities and other research organizations. Many intermediate products developed in R&D-projects are further developed in interaction with clients, which is a prerequisite for genuine innovation. This has led to a number of innovative products and services, of which some examples are given below.

Planning Kit - Room for the Rhine Branches
Information system for water managers aimed to provide rapid insight in the effect of flood management measures to lower flood water levels in rivers. The user-friendly system is applied to the River Rhine branches and resulted in enthusiastic interest from stakeholders and other actors and promoted discussions amongst them. Applications to other rivers and coastal zones are expected. An application for regional water (quality) management issues is currently being developed.

SOBEK 1D2D – inundation module and functionality for water quality
Linkage of a one-dimensional model system for open branches and closed culverts with a two-dimensional model system for inundation of rural and urban areas was developed over the past several years. WL | Delft Hydraulics has developed the capabilities of the implicitly linked 1D/2D modelling software, SOBEK, to accurately analyse all water-related problems, including those affecting river flood plains, wetlands and urban areas. This successful technology has recently been extended to water-quality modelling.

Delft3D detailed modelling - Current Deflecting Wall
A relatively straightforward measure to reduce harbour siltation, resulting from a combination of in situ measurements, scale model and numerical simulation of a complex 3-dimensional phenomenon. Hamburg harbour served as a pilot and demonstrated a 40% reduction in siltation. An application is expected to be developed for the more complex situation which exists in the harbour of Antwerp. Cooperation with a third party which is the holder of the patent. PIANC has shown interest.
Flood Early Warning Systems
Operational FEWS for inland high waters due to rainfall and/or river discharges and for cyclone storm surges from the sea. The system combines in situ measurements, remote sensing data and meteorological information with forecast models. It is a GIS-based interactive system intended for decision support in crisis situations. Applied in India and England, other countries have shown interest.

Sediment-online
A new model concept has been successfully designed to simultaneously compute hydraulics, sediment transport and morphological changes. This method is superior to the former method of sequential computation of these components. It represents a breakthrough and reinforces the position of WL | Delft Hydraulics in morphological modelling. Considerable interest to utilise this knowledge has been expressed by public water managers and private companies.

Next-Generation Software Architecture
A software framework which enables the coupling of model systems of various sources and types. The idea is to accommodate software components of others in the WL | Delft Hydraulics software environment. It enhances the possibilities for import of the latest knowledge and for simulation at lower costs. Large organisations are interested in incorporating their own modules into this framework and in collaborating with WL | Delft Hydraulics.

Library of water quality and ecology modelling
The extensive WL | Delft Hydraulics processes library of water quality processes has been made accessible to users. Through a convenient user interface, users are able to add their own source code and processes to the library and thus include their own substances and processes, in concert with the existing Delft water quality processes. Each process-code is a “book” on the library bookshelf (.dll). Once tested and added to the library, the user only has to pull the “books” from the shelf, meaning that no computer programming errors can be made in setting up a model. The system facilitates the exchange of knowledge and software between scientists and practitioners.

HABITAT, flexible tool for habitat analysis
Spatial analysis and forecast tool for assessment of the availability and suitability of habitats and ecotopes based on GIS. This flexible tool has proven to be very useful in the description of existing systems and the effects of measures. For the successful implementation of the EU Water Framework Directive, Bird Directive and the Habitat Directive such a tool is a must. Users may include their own knowledge rules on the habitat requirements of species.
Portal for know how on coastal structures
Software knowledge system for the design of coastal structures, continuously updated with new available information on wave interaction with and stability of structures. State-of-the-art techniques, such as artificial neural networks, are used fill in the gaps. Substantial interest shown by national and international companies.

Facilities for testing of marine structures
Wave generation systems in flumes and basins are designed and applied in the facilities of WL | Delft Hydraulics and other institutes. Reflection compensation and second order panel steering are applied to produce state-of-the-art equipment for reliable model testing of marine structures. Frequent use of the facilities for national and international projects makes WL | Delft Hydraulics attractive to engineering firms and contractors active in marine structures.

Universal Coastal Intelligence Toolkit (UCIT)
Information system integrating available data on coasts, models and coastal state indicators (CSIs) in one user platform, with the aim to quickly combine this information for coastal zone managers and to focus coast-related research.
Marine & coastal systems

Marine & Coastal Systems at WL | Delft Hydraulics covers a range from marine and coastal zone management to marine and coastal infrastructure. Areas of expertise include hydrodynamics, hydraulic structures, morphology and environmental processes. Marine and coastal engineering focuses on harbour design, coastal and offshore engineering, including water intake and outlet systems for power and desalination plants. Both research and specialised consultancy projects are carried out for port and coastal authorities, plant operators, oil and gas companies, engineering firms and contractors. All stages of the project life cycle are covered from (pre)feasibility and conceptual design to detailed design and operational aspects.

In the field of marine and coastal zone management, multi-disciplinary research and development is conducted as it relates to the management of estuaries, seas and coastal areas. Special attention is focused on environmental action planning, feasibility studies, environmental impact assessment, fact-finding missions, and specialised technical assistance.

Research and development on marine and coastal systems is being conducted in a number of ways and on a wide variety of topics. In addition to theoretical investigations such as the development of new concepts for coastal zone management, experimental research and software development are being used to investigate and simulate processes relevant to marine and coastal infrastructure. The integration of these elements with one another and with data from other sources is a key strategic issue at WL | Delft Hydraulics. Illustrative examples may be found in the particular sections on experimental facilities and software systems.

Several R&D projects were executed under the umbrella of the Netherlands Centre for Coastal Research (NCK) and in co-operation with other institutes. The R&D programme 2004 for marine & coastal systems focused on various items.

Marine and coastal systems

Studies were continued related to analysis and support of water policy and management focusing on the Delta region of the Netherlands and the issues related to the EU directives (specifically the Water Framework Directive). The EU Catchment2Coast focusing on ecological interactions between freshwater catchments and coastal domains, and integrating biophysical and resource economics models in order to translate the impacts into urban and rural livelihoods was continued.

A study was conducted into the environmental flow requirements for sustainable delta development, resulting into a recommended approach. The EU DINAS Coast project was finalised in 2004 with the DIVA Tool, among others, which was developed for predicting the effects of sea-level rise on tidal basins and adjacent coasts.

The effects of shoreface nourishments were studied using a combination of a video-based monitoring system and Delft3D morphodynamic simulations. Coupling between Delft3D for details of coastal processes and UNIBEST-CL+ for an aggregated approach to these processes was tested.

The EU SANDPIT project was continued by a successful validation of a new transport formula in a 3D morphodynamic model.
The water and sediment quality processes in a new DELWAQ (module in Delft3D and SOBEK) have been calibrated, and produced good simulation results. In order to increase the suitability of semi-empirical long-term morphological models for estuaries and tidal lagoons, steps have been taken to explore and extend the applicability of ASMITA and ESTMORF. Improvements have been made to various model codes to enhance the use of morphodynamic simulations in coastal problems. A new method used for the synoptic monitoring of turbidity caused by resuspension of bottom sediment and spillage from dredging was demonstrated.

The EU HABES project was finished with the completion of a fuzzy logic technique-based expert system and applied in a Dutch coastal zone pilot project with promising results. The potential dispersal of eelgrass seeds in the Wadden Sea was studied to understand observed eelgrass recovery.

With the aim to arrive at better management of large complex marine water systems, an assessment of large-scale water circulations and pollutant transports in the North Sea was made in order to arrive at an integrated analysis of substances, water quality and aquatic ecology. The prediction of effects of natural disasters and technological accidents in marine environments is important in order to be able to reduce social, ecological and economic impacts. Suitable systems are developed to assist governmental bodies in taking the right actions when and where necessary.

**Marine and coastal infrastructure**

Long waves forced by short wave groups and the response of harbour basins, including moored ship motions, were studied. A new Boussinesq-type wave model (TRITON) is developed and comparison with an alternative non-hydrostatic model (TRIWAQ) is made. The BREAKWAT software for design of breakwaters was extended with a tool to produce uncertainty assessments in the computational output parameters.

Within the framework of the EU CLASH project a method has been developed to provide a conceptual design tool to estimate wave overtopping discharges for a wide range of coastal structures, using neural network modelling.

Pressures on dike slopes were compared with results from Navier-Stokes model SKYLLA, showing further improvements are necessary.

A great deal of coastal research has been conducted in cooperation with universities and other institutes; Netherlands Centre for Coastal Research has supported this cooperation since 1991.

- Integrated assessments
- Water Framework Directive
- Catchment2Coast
- Environmental flow requirements for sustainable delta development
- DINAS COAST
- Video monitoring and Delft3D morphodynamic simulations of shoreface nourishments
- Coupling between Delft3D and UNIBEST-CL+
- SANDPIT – Validation of a new transport formula in a 3D-morphological model
- Model development with regard to sediment-water exchange
- Long-term modelling of estuaries and coastal lagoons
- Remote sensing as a tool for scheduling and control of dredging (RESTCOD)
- Morphological expertise: Getting it ready for use
- Harmful Algal Blooms Expert System (HABES)
- The influence of dispersal of eelgrass seeds on eelgrass recovery
- Large scale water circulations and pollutant transports
- Safety- and risk-related topics in the marine environment
- Risk assessment of calamitous spills and development of exposure risk maps
- Advanced hydrodynamics for the accurate prediction of chemical pollution disasters in coastal areas
- Behaviour of long waves on coasts and in harbours
- Wave boundary conditions for harbours
- Non-hydrostatic flows
- BREAKWAT
- Neural network modelling of wave overtopping
- Wave pressures on dike revetments
- NCK
Integrated assessments

This project represents the continuation of several studies which had been conducted in previous years, all of which focused on the analysis and support of water policy and management. The current project focused on the Delta region of the Netherlands, and the specific issues related to the implementation of the EU Directives (specifically the Water Framework Directive). The project has been divided into 4 components, which have been conducted parallel to one another:

1. **The implementation of the Water Framework Directive in the Netherlands – implications for transitional and coastal waters**
   A literature study was conducted with respect to the Water Framework Directive, and was supplemented by several interviews with river basin coordinators in the Netherlands. Results are summarised in a paper which is ready for publication.

2. **Assessment criteria for the maintenance of a multi-channel system in the Western Scheldt estuary**
   An important step has been taken in the process of making the morphologic cell-concept for the Western Scheldt estuary operational. This now has the potential to provide clear management guidelines for the dredging, dumping and sand extraction policies for the estuary in a way that can guarantee the stability of the multi-channel system. A paper on the theory of the cell-concept has been finalised (ready for publication) and two additional papers on the 1) testing and 2) operationalisation in assessment criteria are currently still in draft form.

3. **Assessment criteria and an information system for a ‘Dynamic Delta’**
   With the recent vision statement ‘Delta Inzicht (Delta Insight)’ and the installation of the Deltaraad (Delta Council), serious attention is now being paid to a number of initiatives to return the dynamic conditions to the Netherlands Delta which had been absent since the completion of the Delta works infrastructure. To support the decision making process, a Delta information system, including a set of assessment criteria, is being developed in consultation with RWS. A first demonstration version and a vision for completion have been created (see figure).

4. **Ecologic screening tool for the Water Framework Directive**
   The WL | Delft Hydraulics’ software module BLOOM has been adapted for easy application as a screening tool for ecological assessment of water systems as required by the Water Framework Directive. A first version of the screening tool with user manual has been completed under this project and is ready for application. Further testing and reporting (publication) will take place next year in the context of the EU project REBECCA as well as a new R&D project.

For further information, please contact either Nicki.Villars@wldelft.nl or Henriette.Otter@wldelft.nl

Figure 1: Demonstration of assessment framework Delta

For further information, please contact either Nicki.Villars@wldelft.nl or Henriette.Otter@wldelft.nl

Financed by (a.o.) Ministry of: Transport, Public Works and Water Management
Water Framework Directive

The implementation of the Water Framework Directive (WFD) is progressing rapidly throughout Europe. The Netherlands is following suit through a number of activities varying from policy-related research, transposition of WFD goals in national legislation, the set-up of monitoring programmes and preparations for the development of river basin management plans. The purpose of this research was to take stock of the ongoing developments and to derive pertinent questions and challenges from these developments which confront the different stakeholders and management authorities involved. This description was mirrored against the present knowledge base and modelling capacity of WL | Delft Hydraulics. On the basis of this study we prepared a capability statement and dedicated website that demonstrates how WL | Delft Hydraulics can assist clients in meeting the various challenges presented by the WFD.

For further information, please contact Maarten.Kuijper@wldelft.nl
Catchment2Coast

The Catchment2Coast project (2002 – 2005) aims to provide an ecosystem scale understanding of the links that govern the economic dependency of tropical coastal resources on their associated river catchments. The core hypothesis of this project is that the most important biophysical interactions between freshwater catchments and coastal domains occur at the sub-seasonal event scale (days). This project integrates a number of numerical modules (coastal, river basin and ground water) with the required dynamic capability in order to implement a systematic approach to the functional dependence of coastal systems on river basin and ground water forcing. It focuses on a single but economically important coastal living resource of Maputo Bay (Mozambique), shrimp, and relates its productivity to the discharge pattern of the Incomati River. However, it must be generic enough to deal with other recognised impacts such as mining effluents, pathogens, eutrophication, erosion and silting. The project integrates biophysical and resource economics models to translate the impacts into urban and rural livelihoods.

In the second year of this project, WL | Delft Hydraulics' input focused on the development of a computational framework (DSS) for analysis. This framework provides a smooth integration and usage of model results in the subsequent stages of the project as well as for end users. A library of model runs forms the backbone of the framework. An essential element in this framework is a meta-database that provides essential descriptions of all models used and which enables the user to access the results of each model run.

During a special 5-day modelling workshop in Cape Town, SA, the set-up of the computational framework was successfully tested. Although reliable model results could not yet be retrieved since some models require additional calibration, the great advantage of the framework was that it brought all experts together to work on a common platform.

For further information, please contact either Marcel.Marchand@wldelft.nl or Chris.Sprengers@wldelft.nl
Environmental flow requirements for sustainable delta development – a review and recommended approach

In many of the world’s deltas, their natural link with the sea has been disturbed, which leads to water quality problems, sediment starvation, erosion and salinisation. Upstream discharge of pollutants as well as non-point pollution sources, water abstraction and storage reservoirs are at the root of these problems. These developments create a dire need to find ways to restore at least part of the original river-delta link. Environmental flow assessments can be helpful in finding the right balance between upstream developments and delta rehabilitation. This research project provides a review of comparative examples of delta restoration measures from different parts of the world. It appears that there are a number of well-documented methods for environmental flow assessment available which may be used. However, there still is quite a substantial lack of knowledge and scientific evidence concerning crucial river-coast cause-effect relationships, such as:

- What is the best strategy for restoring the sediment balance of the delta?
- How sensitive are estuarine species to the volume and timing of freshwater pulses and to the dynamics of salinity gradients?
- What is the ecological significance of the range of freshwater influence (ROFI) on the marine ecosystem of the delta?
- How can flow regimes be utilised in improving the water quality of the delta?

Until these questions can be answered, it will remain difficult to establish an environmental flow requirement which is capable of standing up to the viewpoint commonly held among developers that ‘every drop of freshwater running to the ocean is a loss.’

Procedure to assess relevant measures linked to river flow.

For further information, please contact either Marcel.Marchand@wldelft.nl or Bert.vd.Valk@wldelft.nl
DINAS COAST

The DINAS COAST project was finalised in 2004. The DIVA Tool is one of the main deliverables of the DINAS-COAST project. This tool combines the modules and data. The tool itself consists of an intuitive Graphical User Interface (GUI) from which input may be inspected and specified, the model calculation started and the results analysed. Maps, tables and charts support the inspection and editing processes. To make use of the help functionality while using the tool, a context-sensitive, HTML based help file has been created.

The DIVA Graphical User Interface underwent extensive development in 2004. The basis of the DIVA GUI is generic for all simulation models that connect to the model database. The model database consists of a collection of input/output and scenario files in the Delft Hydraulics HIS file format.

The actual model calculation is a sequence and feedback of modules focusing on different effects of sea level rise. The individual modules are being developed by the project partners. Delft Hydraulics contributed 2 of the 10 modules: River Effect Module and Indirect Erosion Module.

The River Effect Module calculates, based on the selected climate change scenario, the impacts on rivers (river impact length) under normal and storm conditions. An estimation of salt intrusion length and the (land) area influenced by this increased saline environment was also calculated. The database contains 115 rivers (worldwide).

The Indirect Erosion Module focuses on Tidal Basins. Based on the ASMITA (Aggregated Scale Morphological Interaction between a Tidal basin and the Adjacent coast) algorithms, new dynamic equilibria (sand balance) are being calculated for the selected climate change scenario. In total 200 tidal basins (worldwide) are included in the central database.

For further information, please contact either Gerben.Boot@wldelft.nl or Bert.vdValk@wldelft.nl
Video monitoring and Delft3D morphodynamic simulations of shoreface nourishments

Recent improvements in the Delft3D-model (e.g. inclusion of roller model and breaker delay concepts) combined with the implementation of the more advanced transport formulation of TRANSPOR2004, formed the impetus for an application of the upgraded Delft3D-Online model to investigate the effects of various nourishment designs on the nearshore morphology. The main purpose of this study was to illustrate the effect that various nourishment designs have on the nearshore morphology and to demonstrate the capabilities of the Delft3D-Online model in its present state. With the implementation of gradient boundary conditions (a so-called Neumann boundary condition) in Delft3D, Roelvink and Walstra (2004) demonstrated that a combination of tide, wind and wave-driven currents does not induce any visible boundary effects along the lateral boundaries. The obvious advantage of the Neumann boundary condition is that the model domain may now be focused more on the region of interest without having to worry about boundary effects which might negatively affect the model predictions. Furthermore, it was proven that Delft3D could be reliably run as a profile model by considering only one longshore grid cell. Based on the Roelvink and Walstra (2004) results, an innovative dual modelling approach was adopted in which Delft3D was applied as a 3D area model using parameter settings of a calibrated Delft3D 2DV profile model. This enabled a clear distinction between longshore effects such as leeside erosion, sediment trapping and cross-shore phenomena such as feeder effects.

The intercomparison of the investigated nourishment designs has shown that the design in which the nourishment was constructed in the trough between the outer and inner bar has the largest positive influence on the sand volume changes in the inner bar region and inter-tidal beach area. However, the construction height only had a small effect for the remaining alternatives in which the nourishments were constructed against the seaward slope of the outer bar. The design in which the length of the nourishment was varied did not lead to a significantly increased or decreased trapping of sand behind the nourishment for the long and short designs. The volume of the nourishment did have a relatively significant effect; a reduction of 50% in the nourishment volume (per unit alongshore length) resulted in a 75% reduction in the seaward migration of the MKL-position.

To further our insight into the morphological behaviour of shoreface nourishments, nourishment schemes may be evaluated in the field with the help of high resolution video monitoring techniques. A combination of Argus video imagery and inverse modelling techniques may be used to map bathymetric evolution in the surf zone. The Subtidal Beach Mapper (SBM-2DH) is a model that provides this type of bathymetric information. A state-of-the-art version of SBM-2DH can be used to conduct case studies on seasonal bed evolution from summer to the subsequent winter season as well as a case study on bed evolution at the storm time scale. This information can be used to analyse whether winter bathymetry differs significantly from the summer bathymetry. To analyse bed level variability during a storm in more detail based on video-derived bathymetries requires further improvement in the SBM-2DH model. Notwithstanding the latter conclusion, it is important to note that there is currently no alternative available for monitoring bathymetric change during a storm event.

For further information, please contact either Leo.vanRijn@wldelft.nl or Dirkjan.Walstra@wldelft.nl
Coupling between Delft3D and UNIBEST-CL+

Coastal impact studies often require analysis on various scales, ranging from a small scale (order 1 – 100 m) to a large scale (order 1 – 100 km). There are various engineering tools available that commonly focus only on a limited part of this scale range. Efforts to extend the range of analysis often focus on expanding a certain tool by including additional process knowledge, for example. This R&D project explored the possibility of combining the strengths of different existing tools. The main focus of the project was to determine if the WL | Delft Hydraulics models Delft3D, which models coastal processes in detail, and UNIBEST-CL+, which has a much more aggregated approach, could be combined to reinforce one another’s strengths.

The study concluded that by coupling UNIBEST-CL+ to Delft3D, a more realistic prediction may be obtained of the coastline evolution in the vicinity of breakwaters (at least in a technical sense) from UNIBEST-CL+. The strong erosion at the leeside of the breakwater, which is always observed for standard calculations using UNIBEST-CL+, disappears if the UNIBEST RAY-files are replaced by files generated by Delft3D results for the same stretch of coast. These Delft3D based RAY-files may be generated fully automatically with a MATLAB script from standard Delft3D output files.

Several questions remain however. It was observed that the equilibrium coastline orientation calculated using Delft3D is about 3 degrees off compared with UNIBEST-LT, even though the wave climate and cross-shore profile are identical. As a result, the alongshore sediment transport rate calculated by Delft3D is three to four times lower than the transport rate calculated using UNIBEST-LT. Because of the lower transport rates, the coastline response to a breakwater is less pronounced than for standard UNIBEST-CL+ calculations. Updrift accretion is much smaller, as a new equilibrium is achieved after only a small change in coastline orientation. The difference between the classic and novel approach is therefore not caused by modified RAY-files only.

It is advisable to investigate the cause of the deviations in sediment transport calculations for Delft3D and UNIBEST-LT. It is also wise to examine the possibility to replace the coastline changes as evaluated with UNIBEST-CL+ locally with those determined using Delft3D. More local effects such as the reversal of sediment transport direction close to the breakwaters can then be accounted for.

The coupling in its current state was limited to academic test cases only. As a result, the approach is not yet operational for use by consultancy firms or governments. Nonetheless, the project resulted in an interesting alternative for dealing with the recurring issue of scales in coastal impact studies and with the problem of combining different model concepts. It enables a coupled use of UNIBEST-CL+ and Delft3D, the former being used for large scale analysis and the latter for a more detailed local analysis. One may wonder if an automatic coupling in real cases will be feasible or even desirable. Positive spin-off is more likely to come from more objective estimates for transmission coefficients around breakwaters etc. which are now mainly subjected to expert evaluation.

For further information, please contact either Mark.vanKoningsveld@wldelft.nl or DirkJan.Walstra@wldelft.nl
SANDPIT

Validation of a new transport formula (TRANSPOR2004) in a 3D morphological model

Coastal erosion is expected to increase in many European countries owing to a rise in sea level. This will lead to an increased demand for sand for the nourishment of beaches and dunes. Mining of sand from the middle and lower shoreface (depths of 10 to 30 m) in large-scale mining pits will be required to meet this increased demand in future. It is expected that large-scale mining through the dredging of artificial sand pits or the removal of existing sand banks will have a significant impact on the near-field and far-field morphology (increased coastal erosion). To this end, the Delft3D model was upgraded using state-of-the-art transport formulations and was verified using a number of field and laboratory experiments. These tests were used to establish the efficacy of morphodynamic models in predicting the behaviour of large-scale mining pits so as to contribute to improved coastal zone management. A typical validation result is shown below (simulation performed with default parameter settings).

![Figure 1 Performance of the upgraded Delft3D model for a laboratory experiment (Havinga, 1992).](image)

The validation results presented in this study have shown that the model is able to produce reliable predictions of the morphological development of pits and trenches in deeper water if the undisturbed transports are scaled to measured or realistic values. The Brier skill scores indicated that the performance of the model was “excellent” when TR2004 transport formulations were used. Furthermore, it was shown that the TR2004 predictors for bed roughness and the suspended sediment diameter resulted in accurate and robust predictions of the sediment transport (always accurate within about 50%). Although experience with the updated Delft3D-Online model is still limited, we concluded that at its present status, the model may be applied with confidence to model the morphological behaviour of pits/trenches and to assess the near field and far field impacts. However, sensitivity studies have shown that the final predictions may be significantly affected by small inaccuracies in the applied hydrodynamic forcing conditions and a number of model settings.

Sand extraction is often performed at sandbanks (tidal banks, shoreface connected ridges, head banks) due to their composition and their location. To assess the impact of such mining activities it is imperative to monitor abandoned sand extraction locations to investigate recovery of the sandbanks. However, the associated morphological time scales at which these recoveries typically take place are on the order of decades, which imposes a severe limitation for the implementation of regulations. It is therefore vital to improve and validate existing models to obtain insight into the reliability of the predictions made with numerical models. To this end, the Delft3D model was applied to an artificial sand ridge about 6 km off of the Dutch coast which has been monitored for over 20 years. The model was found to be capable of providing a good estimate of the observed morphological development.

For further information, please contact either Leo.vanRijn@wldelft.nl or DirkJan.Walstra@wldelft.nl
Model development with regard to sediment-water exchange

In previous years, a more generic version of the water quality model DELWAQ (module in Delft3D and SOBEK) had been developed. This version is different from the previous version due to the explicit modelling of sediment layers next to water segments. New process formulations were added and tested, in particular to improve the simulation of sediment diagenesis and sediment-water exchange. One unique set of process formulations is applied for water and sediment. The extent to which and the way in which these processes are expressed depend on local conditions such as the oxygen concentration.

Improved DELWAQ offers higher simulation accuracy, more detailed water quality simulation, and much higher flexibility with regard to the processes included and spatial schematisation in an application. These innovations are important for all users of DELWAQ and for all clients who are provided with advice on the basis of DELWAQ applications.

This year, the water and sediment quality processes in new DELWAQ have been calibrated in an application for the western Wadden Sea on the basis of the GEM configuration for processes and a grid containing approximately 100 sediment compartments with 9 to 3 layers each. The initial composition of the sediment and sediment forcing functions has been imposed on the basis of zoning. All compartments that belong to the same zone are assigned the same composition and forcing functions, so that justice may be done to spatial heterogeneity in an efficient way. Literature study and evaluation of values used in previous model applications delivered ranges and starting values for all of the process coefficients. The calibration resulted both in good simulation results and a new, consistent set of coefficient values.

To enlarge the potential for the use of the model, new process routines for consolidation and erosion of fine cohesive sediment have been integrated in DELWAQ. The influence of microphytobenthos and deposit grazers on sediment stability has been included. The coupling with a new submodule for microphytobenthos submodule has also been established; the result is that DELWAQ has now become a very comprehensive framework for the ecological modelling of surface water systems.

For further information, please contact: Johannes.Smits@wldelft.nl
Long-term modelling of estuaries and coastal lagoons

The objectives of this project are:

- To narrow the gap between the behaviour-oriented models and the process-based models.
- To explore and extend the applicability of ASMITA and ESTMORF.
- To develop guidelines for determining the model parameters of ASMITA / ESTMORF.

The ultimate objective is to increase the suitability of the semi-empirical long-term morphological models for estuaries and tidal lagoons, developed by WL | Delft Hydraulics, as a tool in the consultancy practice.

To achieve these objectives, the following activities were carried out in 2004:

1. By participating in the DEFRA-project EstSim (fundamental research project financed by UK government to create semi-empirical models for LT estuarine morphological development), research was conducted on long-term morphological modelling of the Humber Estuary in co-operation with UK institutes. From this research we learned that the nodal tide variation is very important for the morphological changes in this estuary. Because of the relatively small morphological time scale of this estuary (morphologically very active), a clear signal of the 18.6 year cycle may be detected in the data of morphological changes. The ESTMORF model appears to be able to reproduce the response of the estuary to the nodal tide variation. Even more interesting is that the semi-empirical models (ESTMORF & ASMITA) indicate a non-linear interaction between the response to the sea-level rise and that of the nodal tide variation. Due to the nodal tide variation, the estuary appears to adjust to an accelerated sea-level rise much more rapidly.

2. In an MSc-project (Davor Maas), the Venice Lagoon was modelled using ASMITA (Maas, 2004) at the Technical University Delft in co-operation with Padua University, Italy. Furthermore, a MSc thesis (of Mr. Nortier) was completed in early 2004. For the Venice Lagoon case it appears to be important to include the salt marshes as an additional morphological element in the model schematisation. Furthermore, the schematisation outside the inlet requires adjustment due to the specific situation.

3. Publications. Participated to the PECS conference and a presentation was given on the prediction of the dredging requirement in the Western Scheldt Estuary based on ASMITA-concept.

4. Participating in the discussion on the effects of gas-mining in de Wadden Sea. The ASMITA model concept has been used as basis for the determination of the limit of land subsidence in combination with sea-level rise.
Non-linear interaction between the morphological response to the sea-level rise and the response to nodal tide variation

For further information, please contact Zheng.Wang@wldelft.nl
Remote sensing as a tool for scheduling and control of dredging (RESTSCOD)

In recent years there has been increasing concern about the environmental effects of dredging in coastal waters, often performed in relation to large infrastructure projects. Of particular concern is the increased turbidity caused by resuspension of bottom sediment and spillage from dredging. In close cooperation with Argoss, NLR and the end user Van Oord NV, the RESTSCOD project was set up with the aim of demonstrating a new method for synoptic monitoring of turbidity, represented by Total Suspended Solids (TSS).

The method aims to optimise information from dredging operations, satellite remote-sensing data, water quality modelling of sediment transport and in situ data using new data-model integration (DMI) techniques. Using hindcast model simulations in combination with archived optical remote sensing and in situ data, the background TSS levels are modelled. Separately, the extent and concentration of dredging/disposal plumes is modelled using the Delft3D particle tracking model with a Graphical User Interface.

The Delft3D-PART graphical user interface – initial screen, showing example of modelled plume spreading overlaid on the map of dredging operations.

Using existing in-situ data, remote sensing reflectance images and flow and spreading models from the Penny's Bay area in Hong Kong where extensive dredging operations took place in 2002, the individual data sources were assessed on information content and the DMI methodology was further developed. An important part of this was the creation of the Graphical User Interface – a new software module that checks, interprets and processes the operational dredging data from the field into consistent and comprehensive information suited for modelling the plume spreading characteristics. This interpretation
tool was specified, developed and tested in close cooperation with dredging staff. Together with the industrial partners in the project, the prototype experiment was evaluated in terms of its generic applicability.

By means of DMI the three sources of data (in situ, remote sensing and model data) can be integrated in a structured way to obtain an optimal information product suited to the end user’s needs. The pre-operational Dredging Information System can presently be used in two ways:
1. During the tendering phases of dredging projects: assessment of initial effects caused by dredging and translation into the design of optimum execution methods that satisfy the environmental criteria and which are cost-effective (a so-called forecasting system);
2. Hindcasting of the turbidity field when information is required about a site after dredging works have been completed (a hindcasting system).

A proposed follow-up project will focus on extension into an operational near real-time system for carrying out compliance monitoring during the dredging operations (a nowcasting system). A diagram of the envisaged conceptual approach for the DMI techniques incorporated into the future Dredging Information System is illustrated in the figure below.

Diagram of operational monitoring of suspended matter related to dredging activities, based on optical Remote Sensing, operational dredging data, In Situ data, model data and data-model integration (DMI)

For further information, please contact either Sharon.Tatman@wldelft.nl or Herman.Gerritsen@wldelft.nl
Morphological expertise: Making it ready to use

This project aims at making improvements in model codes to enhance the use of morphodynamic simulations in coastal problems. The following activities have been carried out:

- Improvement of Delft3D behaviour as a small coastal model or profile model, prior to inclusion in the standard code. In particular, the boundary conditions in Delft3D were improved so that Delft3D may be easily applied to a small coastal area (order 2 km longshore by 1 km cross-shore), or as a full-fledged replacement of Unibest-TC. The method was published in Roelvink and Walstra (2004).
- Building in a simplified wave refraction algorithm based on Snel’s Law, which eliminates the need for a separate wave model for profile model applications.
- Redesign of the WAVE module, in support of R&D Delft3D-WAVE, to allow coupling of Delft3D-WAVE and FLOW in domain decomposition mode. The model now allows multiple nested SWAN runs to interact with multiple FLOW domains.

All of these developments are included in the standard release of Delft3D or will be included in 2005, thereby making them available to a wide range of users and researchers. The ability to run Delft3D in profile mode is very valuable in calibrating models, since the cross-shore profile behaviour may be calibrated efficiently before the overall calibration of large 3D models takes place. The combination of domain decomposition, online morphology and waves adds much flexibility to coastal morphodynamic models, since it becomes straightforward to apply local refinements, i.e. near structures under investigation.

The figure below illustrates the use of Delft3D in profile mode for a beach near Grays Harbor, Washington; courtesy of Peter Ruggiero, USGS and Dirk-Jan Walstra, WL | Delft Hydraulics.

For further information, please contact either Dano.Roelvink@wldelft.nl or Maarten.vanOrmondt@wldelft.nl.
HABES (Harmful Algal Blooms Expert System)

Primary production by phytoplankton forms the basis of most aquatic food-webs. However, some phytoplankton species may form blooms which result in harmful effects to the environment. Examples of harmful effects include toxicity in shellfish, mass mortality of (shell)fish in aquaculture, and nuisance foam on recreational beaches. During the HABES project (Harmful Algal Blooms Expert System), predictive models were developed for seven harmful algal species in Europe, with fuzzy logic. Fuzzy logic is a modelling technique based on knowledge rules instead of the mathematical formulas used by most other modelling techniques. In fuzzy logic models, empirical knowledge from measured data and existing knowledge from algae experts may be combined relatively easily.

The objectives of the project are 1) to create more understanding on the interaction between relevant factors, particularly the interaction between physical and biological factors and 2) to make the knowledge on the 7 key species accessible to stakeholders via the models and an Internet knowledge base. Stakeholders can then make optimal use of the existing knowledge on the interacting processes determining the fate of harmful algal blooms.

In the Dutch pilot project a fuzzy logic model is developed for *Phaeocystis globosa* and *Dinophysis* in the Dutch coastal zone. Not only was the presence of the algae species analysed but also the conditions which exist allowing them to become harmful. The aim is to predict when *Phaeocystis* blooms are likely to cause foam on the Dutch beaches and when *Dinophysis* blooms are likely to cause toxicity in shellfish. With the resulting models, the effects of climate change, eutrophication and other changes in the Dutch coastal zone can be evaluated. Existing knowledge provided by experts, the available literature and empirical knowledge have all been used. The empirical knowledge was derived from a large dataset of measured data obtained via data-mining techniques and traditional correlation analysis. The preliminary model results appear promising.

![Figure: Foam on the Dutch beach, probably caused by *Phaeocystis globosa*, observed by the video monitoring system ARGUS.](image)

We have worked on two papers, publishing research results on the modelling of harmful algal blooms in European waters. One paper focuses on the study of the algae *Phaeocystis* present in Dutch coastal waters. The other paper provides an overview of the results from the entire HABES project (Harmful Algal Blooms Expert System), which included the study on *Phaeocystis*. The latter paper focuses on the evaluation of the fuzzy logic modelling approach for modelling harmful algal blooms in European coastal waters. WL | Delft Hydraulics coordinated the HABES project, with 13 of its counterparts from several European countries. One person from each of the other institutes working on fuzzy logic modelling of harmful algal blooms will be a co-author of the overview paper.

For further information, please contact Anouk.Blauw@wldelft.nl
The influence of dispersal of eelgrass seeds on eelgrass recovery

The potential dispersal of eelgrass seeds from a 256 ha meadow in the Ems Estuary towards other parts of the eastern Dutch Wadden Sea was studied using computer simulation modelling. Flowering shoot density (peaking to 7.8 ± 5.4 m⁻²) and total seed production (1095 million seeds year⁻¹) of this meadow were determined in a field monitoring study and used as model input. Dispersal of floating generative shoots and rafts of plants dislodged by increased water turbulence during autumn was modelled using a 3D-transport model (Delft3D-WAQ). Transport of eelgrass seeds contained in floating reproductive shoots with the prevailing hydrodynamic regime revealed maximum dispersal distances of well over 130 km from the source of seed production. The effect of wind speed and direction on seed transport was assessed by applying a wind drag function (3% of wind speed) to surface currents in the model using actual wind data (hourly averages) from 10 consecutive years (1993-2002). The main direction of transport under average autumn wind conditions was north-eastward. Easterly winds (occurring at an average frequency of 15%) were responsible for some westward transport of eelgrass seeds (at densities >0.2 seeds m⁻²) up to 20 km from the mouth of the estuary. These results indicate that westward eelgrass colonisation of suitable areas in the Dutch Wadden Sea is limited by seed supply due to transport limitations imposed by the prevailing hydrodynamic regime. Extreme events, however, such as prolonged Eastern storms, might promote the transport of eelgrass seeds further westwards allowing for the possible natural recovery of former eelgrass vegetations in this area, which is supported by regular field observations of localised eelgrass patches as far as 40 km west of the estuary.
For further information, please contact Paul.Erftemeijer@wldelft.nl
Large scale water circulations and pollutant transports

The management of complex water systems such as the North Sea, the Wadden Sea and many large estuaries and coastal seas all over the world requires an assessment of the large scale water circulations and pollutant transports in order to arrive at an integrated analysis of dissolved and particulate substances, water quality and aquatic ecology. Integral numerical models comprise tools to support this management. The present research project aimed at realising an operational, tested, validated and published three-dimensional eco-hydrodynamic model. To this end, a model application to the southern section of the North Sea was targeted. This R&D project is a follow-up to the results of the 2002-2003 R&D project “3D-modelling of TSM, water quality and primary production.” The main activities involved the improvement of the real-time hydrodynamic forcing and the further elaboration of validation tools.

For further information, please contact either Jos.vanGils@wldelft.nl or Hans.Los@wldelft.nl

Figure 1: Contour plots showing the calculated surface salinity along the Dutch coast on 27 June 1989 from a reference simulation (upper left), a simulation with an optimised bathymetry (upper right), and a simulation with an optimised bathymetry as well as a refined calculation grid (lower left).

The project provided a clear insight into the factors determining the validity of the real-time hydrodynamic forcing. In part, the results confirmed experience from model applications elsewhere, in addition to new insights being gained. Even if it was already known that the model spatial resolution and the model bathymetry are important factors, the relevance of these factors for the correct representation of the Rhine and Meuse river plume had not been appreciated previously (see Figure 1).

The improvements realised in 2004 have been significant, however further research is still necessary. Clear recommendations to achieve this have been formulated. The validation of the three-dimensional eco-hydrodynamic model was further prepared by applying supportive techniques identified in 2003 to the North Sea model. These techniques allow a rapid, objective and reproducible quantification of the “goodness of fit” of the model (see Figure 2). Apart from the validation itself, these techniques also support a rapid comparison of different simulations, as well as an easier transfer of expert knowledge between team members or between team and client.

For further information, please contact either Jos.vanGils@wldelft.nl or Hans.Los@wldelft.nl
Safety- and risk-related topics in the marine environment

Like natural marine disasters, technological accidents can have significant ecological and socio-economic impacts. One example is the recent Prestige accident (2002) just off the coast of Spain which resulted in a shoreline that was heavily polluted by oil, a spill that extended for over hundreds of kilometres, causing one of the worst ecological disasters in European waters. Another essential safety issue concerns coastal flooding, which has become a very current topic as a result of the recent tsunami disaster in Southeast Asia. As a result of the devastating impact of the tsunami, the original natural and man-made protection level of the coastal areas from natural events occurring in the sea has been severely decreased. Building coastal defences for protection from flooding is required but the question must be asked whether this would be sustainable in future. Appropriate development strategy, coastal zone management accompanied by new flood prevention measures and warning systems are necessary. The third safety topic addressed is coastal morphodynamics related to natural coastal evolution and the impact of human intervention in the coastal system.

Within this study, a global inventory was performed on these three safety- and risk-related topics in the marine environment. As such, questions related to technical capabilities, (inter)national programmes involved, and ambitions for the near future were addressed. The results of this study can form the basis in guiding research work conducted in the near future through the identification of hotspot issues and gaps in required knowledge and understanding. In addition, the Spill Response Group Holland has been started. This group consists of government agencies, research institutes and commercial companies involved in oil and chemical policies, regulation, modelling, and the prevention of oil spills.

For further information, please contact either Johan.Boon@wldelft.nl or Deepak.Vatvani@wldelft.nl
Risk assessment of calamitous spills and development of exposure risk maps

Management and control of potentially calamitous spills rely on the knowledge and understanding of the causes, effects and behaviour of such spills. This requires the implementation of methods of environmental risk assessment and contingency planning which allow for the performance of an integrated analysis of the problem.

The main objective of this research is the understanding and implementation of stochastic elements of the risk assessment framework into a pollution transport and fate model. A practical method for generating synthetic wind time series based on wind rose information was implemented and a large number of these time series were applied within simulations. Tests have shown that the statistics of the synthetically generated wind time series are consistent with the original wind rose information. The present approach requires further refinements to improve the accuracy of all wind statistics of the synthetically generated wind data.

Oil probabilities maps, affecting receptor areas such as sensitive coastlines, were developed. Probabilities of the presence of oil, when released from multiple sources, were calculated and resulted in receptor risk maps. An example of this type of map may be found in Figure 1, in which a hypothetical probability map is shown depicting the risk of the presence of oil some time after an accidental spill at an unknown location in the Gibraltar Strait/Western Mediterranean Sea.

During the study, an initial application of reversed modelling for the development of source-risk maps has been performed. The latter has shown to be a very efficient way of generating source-risk maps.

Further research and development are required to obtain a fully operational tool. The reversed modelling in particular will require further development. The generation of synthetic wind time series requires a better statistical foundation as well. Moreover, the methods should be embedded in a GIS environment to achieve a fully operational tool that is suited to practical applications.

For further information, please contact either Frank.Kleissen@wldelft.nl or Johan.Boon@wldelft.nl
Advanced hydrodynamics for the accurate prediction of chemical (oil) pollution disasters in coastal areas

Spills of oil or other hazardous chemicals that are caused by mishaps at sea may result in significant impact on the marine environment and on the coastal communities which exploit these regions. Calamitous chemical (oil) spills as well as the chronic exposure of frequent small spills has a harmful impact on biota and economical issues. The threat of chemical (oil) pollution on vulnerable marine and coastal areas is of great concern to the responsible authorities and requires permanent, stand-by or temporary measures. Management and control of coastal pollution disasters requires knowledge and understanding of the dispersion and effects of such spills. Important parameters used in determining the chemical (oil) spill behaviour at sea are wind, waves, tidal motion, bathymetry, and the shape of the land-water boundary. Accurate hydrodynamic information is therefore essential for making reliable predictions of the dispersion and fate of chemical pollutions. This holds true especially in the vicinity of coastal structures such as long dams and harbour breakwaters where large scale horizontal vortices may be present. These horizontal turbulent motions have dimensions on the order of hundreds of meters and time-scales on the order of minutes. In the usual flow simulations in which the classical unsteady shallow water equations are numerically solved, these motions are not resolved. Therefore, a proper and advanced modelling technique such as HLES (Horizontal Large Eddy Simulation) is required which faithfully simulates the creation and evolution of eddies with horizontal dimensions significantly exceeding the water depth near coastal structures. In addition, high resolution curve-linear boundary fitted model grids are essential for an accurate representation of e.g. curved breakwater. In this paper we demonstrate the need for these kinds of advanced hydrodynamic modelling techniques by considering various contingency chemical spill scenarios in and nearby the IJmuiden harbour in the Netherlands. To accomplish this, a high resolution model of the harbour geometry inclusive coastal structures and the adjacent Dutch coastal zone has been defined to address the significance of hydrodynamic complexity. The results may provide valuable information to facilitate policy planning and the resolution of harbour management issues such as moving leaking ships in distress to a place of refuge.

For further information, please contact either Johan.Boon@wldelft.nl or Deepak.Vatvani@wldelft.nl
Behaviour of long waves on coasts and in harbours

The research focused on two aspects of the behaviour of long waves forced by shortwave groups. The first part of the research consisted of the analysis of data obtained in the Research Flume at the Technical University Delft. The long wave system was separated using a newly developed iterative procedure into an incoming long wave which propagates with a speed which is just slower than the group speed towards the beach, and an outgoing long wave which propagates with the shallow water speed in the offshore direction.

Physical and numerical modelling results were used to analyse the shoaling behaviour of the incoming long wave. It was verified that the shoaling rate is indeed a function of bed slope and group frequency. It was found that shoreline reflection is a function of the same parameter as well because in the direct vicinity of the shoreline, the long waves steepen up and break. This has ramifications for the reflection of long waves which until now has been assumed to be full from the shoreline.

The results of the research provide better insight into the behaviour of long waves and will contribute to a reduction of the uncertainties in the wave-induced time-varying set-up which are to this date accounted for with extra allowances on the dike levels. In future, these allowances can be better substantiated and possibly reduced, saving money in construction and maintenance.

The other area of study is the response of harbour basins to long waves which are generated in the nearshore region. Model-data comparisons were made using data from two actual ports: Tomakomai Harbor in Japan and Barber’s Point Harbor in Hawaii USA. In the first case, wave data as well as ship motions were measured during a Typhoon event. The combination of the Surfbeat model with the ship motion model BAS could successfully hindcast long wave motions and ship motions as well as the effect of increasing pretension in mooring lines and a line-breaking event during the storm. The wave motion inside and outside the second harbour has been monitored thoroughly and the data is used to show the effect of approximations in the frequency and directional spreading in the wind wave spectrum which are used as boundary conditions for the long wave model.

With the results of this research, harbour authorities and consultants will have a tool with which long wave penetration, amplification and mooring problems can be better understood and mitigating measures can be evaluated.


Figure 1: Time traces of the long waves at decreasing depth (top to bottom). The waves can be seen to steepen up and break

Figure 2: Reflection coefficient at the shoreline as a function of \( \beta \), a parameter dependent on beach slope and group frequency. The reflection is larger for steeper beaches and/or longer waves.

For further information, please contact Ap.vanDongeren@wldelft.nl
Wave boundary conditions for harbours

In order to assess hydrodynamic boundary conditions for the design and maintenance of coastal structures in harbours and coastal regions, a new Boussinesq-type wave model is developed.

An important aspect of numerical models is the treatment of boundary conditions. This also applies to the Boussinesq-type wave model TRITON. Two types of boundaries may be identified: open boundaries (also called seaward boundaries), necessary to limit the size of the computational domain, and closed boundaries, representing a beach, a dike, a revetment, a quay or a breakwater. Depending on the boundary geometry and wave field, waves reflect fully or partially at closed boundaries.

Because the model TRITON employs a Cartesian grid, closed boundaries often do not run parallel to the gridlines. Accurate and robust numerical treatment of such boundaries is therefore necessary. In order to achieve this, we have developed a new technique which is as accurate as frequently used cut-cell techniques yet much easier to implement. This new technique embodies the extrapolation of the boundary condition from the true, physical boundary to a boundary that fits the Cartesian grid (a staircase boundary). This method can, in principle, also be applied in other numerical wave models.

The implementation of the boundary conditions mentioned above is an essential step towards applications of wave modelling in harbours. An example is provided of an application of waves entering a harbour with two breakwaters.

Figure. Wave penetration into a schematised harbour (TRITON).

For further information, please contact either ivo.Wenneker@wldelft.nl or Marcel.vanGent@wldelft.nl
Non-hydrostatic flows

For time-accurate numerical modelling of short waves, among other applications, the following are important: non-hydrostatic effects must be taken into account; computational efficiency (since typical computations consist of long time series on fine grids); and the existence of little or no numerical dispersion and numerical dissipation. WL | Delft Hydraulics is studying whether the extension of Delft3D-FLOW with a non-hydrostatic module similar to the one in non-hydrostatic TRIWAQ (an R&D version developed by Zijlema (RIKZ)) is a good idea. In addition to this, WL | Delft Hydraulics has developed a Boussinesq-type wave model named TRITON which is expected to be launched on the market within a few years. Recent discussions regarding swell propagation in the Amelander Zeegat led to the need to compare TRITON to non-hydrostatic TRIWAQ. For this purpose, we studied a situation in both models which resembles a scenario frequently encountered in coastal areas: wave propagation on a sloping bar. The question addressed in this report is: What is required to compute propagation of waves (phase-resolved) over a large domain (several tens of wavelengths) with an acceptable degree of accuracy? Due to the fact that in non-hydrostatic TRIWAQ some hydrostatic elements are also different from those contained in Delft3D-FLOW, it was considered wise to also perform some Delft3D-FLOW computations to study the wave propagation characteristics of that model (even though it is a hydrostatic model).

The results may be summarised as follows:

- TRITON and non-hydrostatic TRIWAQ have similar resolution (spatial and temporal) requirements. Also, the computational performance of both models (two layers in non-hydrostatic TRIWAQ) is roughly the same.
- The standard method applied in Delft3D-FLOW and TRIWAQ to deal with open boundaries (prescribing Riemann or $\alpha$-boundary conditions at the outflow) appears to be insufficient for practical applications. Also partial reflection, typical for short-wave applications, is not yet included in these two models. TRITON does have accurate and robust modelling of open boundaries and partial reflection. Non-hydrostatic TRIWAQ makes use of absorbing boundary conditions at outflow boundaries by means of the sponge layer technique.
- In coastal areas, a suitable wave breaking model is required. If this type of model is not available, the simulated waves become too high and too steep, and lead to all sorts of unwanted numerical effects (numerical breakdown, waves trapped on the finest grid scales, large numerical dispersion).

In the event of high waves, a non-hydrostatic model such as TRITON or non-hydrostatic TRIWAQ is required even if the principal wave shows only a slight amount of dispersion. This is caused by the higher harmonics, whose presence is important and which contain a large amount of dispersion. This clearly illustrates the need for non-hydrostatic models.

For further information, please contact Leo.Postma@wldelft.nl
BREAKWAT

Many (mostly empirical) design formulae have been developed for the conceptual design of coastal structures. A number of these design formulae have been implemented in the software package BREAKWAT from WL | Delft Hydraulics. BREAKWAT is used by a large number of (inter)national parties such as (marine) contractors, engineering companies, universities, etc. The facility is widely applied as a tool to guide and assist in the design of many types of breakwaters.

The actual design formulae require several input parameters that describe the hydraulic environment (e.g. wave conditions) and the geometric properties of the structure. In practise, these input parameters are hardly ever known with a high degree of accuracy, and in design studies, decision-making and risk analysis, these uncertainties should be taken explicitly into account. So far this has not been done in a structured, quantitative, and statistically sound way, and in BREAKWAT applications little or no information is yet available about the uncertainty which must be assigned to the output parameters of design formulae.

In the present case an ensemble method was developed and implemented for uncertainty assessment for design formulae in BREAKWAT. The uncertainties in the input parameters must be specified by the user. This specification is based on elementary concepts of statistics which conveniently enable designers to take the effects of uncertainties into account, even if detailed information is missing. The user’s input is translated into analytical probability distributions for the input parameters. For a large number of randomly generated samples of the input parameters, the design formula is used to construct a so-called empirical distribution of the output parameter. From this distribution several statistical quantities may be derived, such as the mean value, spread, and quantiles. In this way estimates for the output parameter and its uncertainty (in the form of confidence intervals) may be derived. Apart from the actual uncertainty assessment, the methodology can also be used for a sensitivity analysis to gain insight in the effect of variations of input parameters on the output parameter.

The results of an application are shown in Figure 1. In this case a design formula to determine the dimensions of the rock material in the top-layers of a breakwater structure was selected. In practise this dimension of the rock material is an important parameter in the design of breakwaters. The output parameter, the nominal stone diameter \( D_{n50} \), depends on 8 input parameters, and realistic estimates for their uncertainties were assigned to all these input parameters. The probability distribution function defined for one of these, the wave height \( H_s \), is shown in Figure 1(left). On the basis of the design formula, an ensemble of estimates for the \( D_{n50} \) was generated, and the resulting identified distribution for \( D_{n50} \) is illustrated in Figure 1(right). A considerable spread can be observed for \( D_{n50} \), indicating a quite large uncertainty for this design parameter. In practise such a large spread should be taken carefully into account in the design process.

![Figure 1. Probability distribution function defined for the wave height, one of the input parameters, (left), and (empirical) distribution function identified for the nominal stone diameter, the output parameter, (right) in a design formula for the dimension of rock material in the top layers of a breakwater structure.](image)

For further information, please contact either Martijn.Coeveld@wldelft.nl or Henk.vdBoogaard@wldelft.nl
Neural network modelling of wave overtopping

Reliable predictions of wave overtopping are required for the design, safety assessment and rehabilitation of coastal structures. Several design formulae already exist for dikes, rubble mound breakwaters and vertical breakwaters. Nevertheless, suitable prediction methods are often not available for structures with non-standard shapes.

Within the framework of the European project CLASH, a method has been developed to provide a conceptual design tool to estimate wave overtopping discharges for a wide range of coastal structures. A single schematisation is used for all types of coastal structures, where not only dikes, rubble mound breakwaters or vertical breakwaters are defined, but also other non-standard structures are included. Additionally, not only is the effect of the most common parameters (i.e. wave height, wave period and crest freeboard) analysed in this schematisation, but the effect of many other wave/structural characteristics is also considered. The prediction method described is based on the technique of Neural Network modelling. For this purpose a data set obtained from a large number of physical model tests is used. Most of these data were provided by the partners involved in the CLASH project. Moreover, a method has been developed to obtain the confidence intervals around these predictions. The latter is a new essential step since the neural network model results in a tool that acts as a kind of black box for users. Therefore it is important that predictions are expanded with the addition of information regarding their reliability. The Neural Network for predicting wave overtopping will be made available so that it may be used by designers at consultancy and general contracting firms.
Fig. 1 Neural network modelling of wave overtopping at coastal structures

For further information, please contact Marcel.vanGent@wl.delft.nl
Wave pressures on dike revetments

The pressures on the slope of a dike that are caused by waves and wave impacts yield the forces that determine the stability of its revetment (see picture below).

In previous years, studies were conducted to determine whether these wave forces could be computed using the free-surface Navier-Stokes model SKYLLA. For short time series of regular waves or irregular waves, this appears indeed to be possible. In all nine cases with irregular waves which were considered where both the geometry of the construction and the time signal were varied, good agreement was found between measured and computed wave forces. Some examples of measured and computed wave impact pressures at the slope are given below.

Part of this investigation involved coming up with recommendations as to how SKYLLA could be made more suitable and further improved for the computation of forces due to irregular waves. To this end, additional simulations were performed for the two cases with the highest and steepest waves. This confirmed the conclusion reached in previous years that the problem of air bubbles getting locked up in the water needs to be resolved. This problem is due to the absence of a buoyancy mechanism in the present version of SKYLLA. It is a shortcoming of the Volume-Of-Fluid method, which is also used in SKYLLA. When wave breaking occurs, pockets of air get trapped repeatedly, as a result of which the amount of air in the water slowly increases. The results obtained for short time series show that, as soon as this problem is solved, SKYLLA would also be suitable for the simulation of irregular waves over longer periods.

For more information, please contact either Mart.Borsboom@wldelft.nl or Marcel.vanGent@wldelft.nl.
Netherlands Centre for Coastal Research

Coastal research is a topic of great interest for the Netherlands, since a large part of the country is located below sea level. The central part of the country is protected by an uninterrupted beach and dune system, whereas to the southwest, the coast is part of the estuarine system of the Rhine, Meuse and Scheldt rivers. Several inlets of this estuarine system have been closed or partially closed to better protect the Netherlands from flooding by the sea. To the north, the land-sea interface is formed by a large tidal lagoon area, the Wadden Sea, which is separated from the North Sea by a series of barrier islands. Knowledge of the natural processes influencing this coastal system is essential for maintaining a safe, productive and resilient environment. The coastal system should be managed in such a way that the Netherlands can safely contend with sea level rise for at least several centuries.

In 1991 the Netherlands Centre for Coastal Research was established, which now consists of the Delft University of Technology, NIOZ, NIOO-C EME, RWS-RIKZ, TNO-NITG, UNESCO-IHE, the University of Twente, the University of Utrecht and WL | Delft Hydraulics. The Centre aims to create a climate of excellence in education and research, to stimulate research of international standing, and to attempt to gain the widest possible appeal to attract young people with academic talent.

The task of WL | Delft Hydraulics in particular is to initiate new research in the form of writing up research proposals and to supervise MSc- and PhD-students in close collaboration with the NCK-university partners. This is realised through the deployment of WL | Delft Hydraulics' staff in these universities. In 2004 this led to:

- supervision of 15 MSc-students and 11 PhD-students,
- financing of four new research projects,
- publication of 12 papers (9 in refereed journals) and 1 book,
- preparation of some 20 new publications.

For further information, please contact either Han.Winterwerp@wldelft.nl or Ap.vanDongeren@wldelft.nl
RIVERS & INLAND WATERS

Rivers and inland waters involve interconnected physical, chemical and biological processes, which together constitute a diversity of water environments in which people live and work. Sometimes these water systems are natural, but more often mankind tries to shape them to suit its needs. Since fresh water is a vital source of life for people all over the globe, WL | Delft Hydraulics is involved in many aspects of research and development related to inland water systems. The expertise at WL | Delft Hydraulics covers five major areas: flood management and hydrology, river engineering and morphology, water quality and ecology, regional and municipal water management, integrated river basin management. Because complex problems often require integrated solutions, available expertise also includes policy analysis as well as planning and decision-making processes.

Several R&D projects were carried out under the umbrella of the Netherlands Centre for River studies (NCR) and in cooperation with other institutes. The R&D programme 2004 for rivers and inland waters focused on several areas. Policy analysis and public involvement in water management is a major issue in our field of work and was once again the subject of attention in 2004. The generation of instruments for public participation also plays an important role in the EU Harmoni** projects. To enable authorities to improve their river management, tools are developed, such as RIBASIM and tools for the EU Water Framework Directive.

In the hydrology-oriented project “distributed modelling techniques for rainfall-runoff,” a definite choice was made for Representative Elementary Watersheds (REW) and a case study was conducted. The coupling of groundwater (Alterra) and surface water (WL | Delft Hydraulics) models were tested. Special attention was paid to low flow hydrology as low flow situations result in important ecological and economical consequences. Downscaling of rainfall data for hydrological purposes was also studied. Filtering techniques were tested to improve the forecast of discharges. Extreme value analysis was once again the object of attention in a cooperative project.

Measures are taken based on consequences of flooding and as these consequences may be different from those observed many years ago, intervention might still be necessary. Refined possibilities to study the consequences were studied.

Poor lake clarity is a growing concern and measures are also imposed in this regard by the EU Water Framework Directive. The possibility of studying the complex processes using the DELWAQ model was analysed. Water storage in the wetlands might be necessary in future, in which case the multiple use of areas then becomes an issue. Models for the assessment of the eco-hydrology of such areas are studied. Research activities are linked with European projects, such as REBECCA and FLOODsite.

The operational management of urban water systems is changing as demands are rapidly increasing. An integrated approach is sought. Water quality in urban areas is of increasing importance and a guide was developed. An alternative method of dredging canals in order to prevent thick mud layers from forming was also studied.
Within the field of river engineering, various subjects were studied. An uncertainty analysis for 2D morphological models and the effects of these on practical problems, such as possibilities for shipping, were studied. The 2D river morphology study continued with the instrument to forecast the dynamic behaviour of river bifurcations, spiral flow effects in bends, the interaction between river morphology and vegetation, bank erosion processes.

The ship-induced water motion study proceeded with the development of an analytical model of the water motion and related aspects such as the prediction of erosion of bed materials. Scale model studies were performed in order to compare these results with numerical model results for complex flow near structures.

Many studies were conducted in cooperation with universities. The Netherlands Centre for River Studies provides a framework for these studies.

- Policy analysis and public involvement in water management
- Harmoni**
- Integrated river basin tool
- Instruments for the Water Framework Directive
- Distributed hydrological modelling
- Combined groundwater & surface water computations
- Low flow hydrology
- Downscaling of rainfall for hydrological purposes
- Extreme value analysis for complex hydraulic and hydrologic systems
- Particle filtering and Ensemble Kalman Filtering for runoff nowcasting using conceptual rainfall runoff models
- Serious consequences of flooding
- Issues involved in floods in urban areas
- Lake clarity
- Water storage in wetlands
- Ecosystem dynamics and processes of rivers and adjacent wetlands
- Integrated system for operational management of urban water systems
- Water quality in urban areas
- Alternative dredging in urban areas
- Uncertainty analysis for 2D morphological models of rivers
- 2D River morphology instrument
- Ship-induced water motions below the ship’s keel
- 3D Flow near structures
- Cooperation with universities on river engineerin
Policy analysis and public involvement in water management

This R&D project focuses on the perception and acceptation of flood risks along rivers, the implications for flood risk management policy making, and risk communication. Research questions include: How do people live with (flood) risk and how do they feel about it? What can be learned from this information and applied to communication and flood risk management? Is compensation for flood damage advisable?

Flood risk experts generally pay attention only to the technical aspects of risks (probability of an unwanted event and its consequences [casualties and damage]). However, lay people take other aspects into account when evaluating individual risks. Qualitative aspects, such as the (perceived) degree of free choice, equity, degree of control of the risk, but also expected benefits, are often decisive for risk acceptance. From this research, we have learned that there are large differences between how the government and experts view risks and how the public at large views risks. This knowledge is useful for drafting flood risk management policy, for communicating about risks, and for practical flood risk management.

The knowledge and insight gained within this research project contribute to the EU-subsidised projects Freude am Fluss and FLOODsite. As a result, the knowledge has become available during the discussions on the development of an EU policy on cross-border cooperation and integration of flood risk management strategies, initiated by the Dutch presidency. The results of the research project will prove to be particularly useful during participation in agenda-setting workshops and discussions with government agencies involved in the drafting of strategic flood risk management policies.

For further information, please contact either Paul.Baan@wldelft.nl or Frans.Klijn@wldelft.nl
Harmoni**

WL | Delft Hydraulics participates in a variety of projects in the Catchmod cluster, under the Key Action I (Sustainable Management and Quality of Water), sub I.1 (Integrated management and sustainable use of water resources at catchment/river basin or sub-basin-scale) RTD priority I.1.1 - Strategic planning and integrated management methodologies and tools at catchment/river basin scale of the DG Research 5th Framework Programme of The European Commission.

Within the cluster, WL | Delft Hydraulics participates in the following interrelated projects:
- HarmonIT - IT Frameworks (EVK1-2001-00037)
- HarmoniQUA - Harmonising Quality Assurance in model based catchment and river basin management (EVK1-2001-00071)
- HarmoniCOP - Harmonising Collaborative Planning (EVK1-CT-2002-00120).

HarmoniCOP analyses the role of modelling and information tools in public participative processes. The main output, to be completed in 2005, will be a handbook on public participation for the implementation of the Water Framework Directive.

HarmoniQUA focuses on quality assurance in relation to modelling studies. It develops a software toolbox to support the modelling process with guidelines (stored in a knowledge base), and a logging facility. By structuring the modelling process and recording the decisions being made, the traceability of model study outcomes will be improved. The toolbox is currently in its last test round and will be delivered in 2005.

Figure 1 Screen display of the Modelling Support Toolbox (in monitoring mode) as developed in HarmoniQUA.
While HarmoniQuA addresses the entire modelling process, BMW focuses on an important part of this process, namely the selection of a model with associated considerations. A protocol has been developed to structure the decision process on the application of a model through the use of a dialogue between modeller and water manager. This dialogue is supported by a model inventory database which focuses specifically on features relevant to the Water Framework Directive.

Since integrated water management requires that many processes be taken into account, one must typically deal with a variety of models that need to be linked together. HarmonIT is developing an international interface standard for online links between models. The specification of this standard, OpenMI, has been completed and is available on the web (www.harmonit.org). The associated software implementation will be released in early 2005 as open source software. WL | Delft Hydraulics will launch its first OpenMI compliant software components as a ²-functionality in the SOBEK 2005 release. Progress is ongoing on other software products both within and outside of WL | Delft Hydraulics.

For further information, please contact either Peter.Gijsbers@wldelft.nl or Simon.Groot@wldelft.nl
Integrated river basin tool

The objective of the project is to develop an integrated computational system for the analysis of water allocation problems in river basins and the assessment of the impacts of interventions or changes in land use on the demand and distribution of water in the basin. The core of this computational system will consist of the existing model RIBASIM (River Basin Simulation model). The main topic of this research project is how to further develop this RIBASIM tool. These further developments include the development of required additional modules for RIBASIM (e.g., to determine the agricultural water demand and habitat requirements for ecological sustenance), the integration of RIBASIM with other models and tools (such as SOBEK and HYMOS) as well as the transformation of the IT-structure of the computational system in order to facilitate the integration with other computational systems.

In 2004 a reconnaissance was conducted into the emerging developments with respect to basin planning. Request for support of operational management of river basins led to the development of a ‘DEWS (Drought Early Warning System)’ comparable with the ongoing developments in Flood Early Warning Systems (FEWS). Technological developments include the increased availability of earth observation data and Information Technology (IT) developments which enable better integration of models and data (e.g., Delft-FEWS and OpenMI). To improve the applicability of RIBASIM in Integrated Water Resources Management (IWRM), links with more ecological and economic oriented tools are required.

A reconnaissance study was also conducted to determine how to include Environmental Flow Requirements (EFR) in RIBASIM applications. A review was performed of the available methodologies on the basis of which recommendations were made with respect to the most appropriate methodology for tools such as RIBASIM. The development of EFR-tools will take place in actual applications of RIBASIM in basin studies.
In the report year, work was continued on three modules which should be included in the computational framework, i.e. a new agricultural demand module, a damage module and 'Topowizard.' The last two modules are generic and not related to RIBASIM alone. The new agricultural demand module will replace the old AGWAT and WADIS modules of RIBASIM and include components for crop planning, irrigation demand and allocation and yield prediction. The generic damage module provides a post-processing framework for models such as RIBASIM, SOBEK and DELFT-FLS to determine damages (and benefits) that result from certain conditions (water allocation, water levels, etc.) as calculated by these models. Users can specify their own damage functions. Topowizard is a tool that manipulates raster data of a DEM (Digital Elevation Model) into input data for hydrological models such as HBV and Sacramento, and, with some additional data, for RIBASIM as well. It can also be used to derive first versions of model schematisations for RIBASIM and SOBEK.

Finally, in 2004 initiatives were taken to start the development of version 6.40 of RIBASIM. This version 6.40 will include a simple water quality module and the new agricultural demand module mentioned above. Moreover, IT developments will be implemented to ensure better integration with other modules and to safeguard the quality of the software (test bench and code review). The release of version 6.40 is expected in the spring 2005.

The developments described above will improve the capabilities of the users of RIBASIM to apply the model in actual problem situations. The first applications of the developments already took place in 2004 in WL | Delft Hydraulics projects in Egypt, Iran and Taiwan. The resulting software has been transferred to our clients as well as to our cooperating partners in these projects (Netherlands consulting engineers).

For further information, please contact Eelco.vanBeek@wl.delft.nl
Instruments for Water Framework Directive

The objective of this project is to develop knowledge and methods for the implementation of the Water Framework Directive and other EU directives such as the Bird Directive and the Habitat Directive. In cooperation with the Directorate-General for Public Works and Water Management, WL | Delft Hydraulics worked on the development of a spatial analysis tool for ecological assessment: HABITAT. In this project, the applicability of Habitat for the implementation of the WFD and Bird and Habitat Directive was explored further. One of the possible applications which were examined is the use of Habitat to assess possible and feasible measures to achieve the environmental objectives.

In order to search for possible applications of HABITAT and demonstrate how it may be used, a case study was conducted in cooperation with the national Institute for Inland Water Management and Waste Water Treatment (RIZA). For IJssel Lake, the potential occurrence of the Zebra mussel (*Dreissena polymorpha*) was modelled based on maps of environmental conditions. The results correspond reasonably well to the actual occurrence. The abundance of the Zebra mussel is one of the objectives of the WFD. An imaginary objective to be set as the exact objective for heavily modified waters has not yet been established. Using HABITAT, a spatial image was created of the limiting environmental conditions such as water level, soil type, and orthophosphate concentrations. Measurements should focus on improving conditions resulting in the largest suitable area. However, this example also demonstrated that some conditions cannot be changed as a result of unrealistic measures and consequent failure to achieve the objectives. This information can help policymakers with the formulation of environmental objectives. Based on this example, a document was written and other EU Directives (Figure 1) studying the possible applications of Habitat for the WFD. This document has been sent to several water managers.

A second case study focused on the river IJssel. In a discussion with RIZA, several steps which must be followed to meet the environmental objectives have been formulated and assessed for the possible application of HABITAT. In this case we studied whether a set of measures resulting from the project ‘Room for the River’ would bring us closer to achieving the ecological objectives in and along the river IJssel. To perform this case study, the HABITAT tool has been filled with habitat-models for

Figure 1. Possible opportunities for the application of HABITAT in the steps towards implementation of the Water Framework Directive.
macrophytes and fishes. A description of the hydro-morphological conditions was derived from simulations with the WAQUA model for the IJssel. However, this model was calibrated for extreme hydrological situations through which the final results deviate from the actual situation. We propose to make these types of models suitable for the simulation of average hydrological conditions as this mainly determines the ecological conditions which make these models useful in the process of selecting effectiveness measures.

Finally, another conclusion from the case studies is that more knowledge rules are needed with regard to impact-effect relationships. The current assessment method for Dutch water bodies presently exists of a large number of species. It is probably not feasible to create knowledge rules for all these species. Therefore, we propose to select indicator species or group species and set knowledge rules for these groups.

Figure 2. Habitat suitability (higher values and darker colours indicate higher suitability and larger change in the occurrence) for the Zebra mussel in the IJssel Lake area in the current situation (left) and after taking measures (on the right).

For further information, please contact Marjolijn.Haasnoot@widelft.nl
Distributed Hydrological Modelling

In 2004 the project Distributed Hydrological Modelling focused on the selection of a concept which WL | Delft Hydraulics will use in distributed hydrological modelling. The concept selected is that of Representative Elementary Watersheds (REW) introduced by Reggiani et al. [1998, 1999, 2000].

REW is an integrated hydrological modelling approach based on the discretisation of a watershed into spatial units. Global balance laws were formulated at the spatial scale of a REW by integrating the point-scale conservation equations over particular control volumes. The choice of the control volumes is subject to the specific flow behaviour to be described, and is dependent on the hydrological characteristics of the spatial regions. These include the unsaturated subsurface flow, groundwater flow, overland and channel flow. The REW scale balance laws constitute generally valid governing equations for environmental flows encountered in hydrological systems and are applicable, in contrast to point-scale equations, independently from the chosen spatial and temporal scale of representation. The project presents a first application of the REW approach to a complex hydrological system and shows how a theory, which has so far only been used for synthetic cases, is applicable to real-world situations. In this context the most challenging research effort remains the formulation of appropriate closure schemes for mass, momentum (and energy) fluxes at the REW scale. It is recognised that the schemes proposed for the closure of the fluxes are subject to limitations, but sufficient to expose the philosophy and the essential working principles. The advantages of the particular spatial discretisation and the current limitations of the closure schemes are highlighted. In this context an indication is provided for the direction future research should take in order to consolidate the REW approach as a more general and scale-independent modelling philosophy for hydrological systems.

Within the scope of the project, a case study was carried out at the Tanshui basin in Taiwan.

Figure 1. Possible opportunities for the application of HABITAT in the steps towards implementation of the Water Framework Directive.

For further information, please contact either Marc.vanDijk@wldelft.nl or Paolo.Reggiani@wldelft.nl
Combined groundwater & surface water computations

For specific problems it is important to simulate the interaction between the ground water system and the surface water system in a dynamic way. Alterra Wageningen and WL | Delft Hydraulics conducted a research project on simultaneously connecting the SIMGRO ground water model and the SOBEK surface water model.

In this project we defined the way of couple the two models according to the Open-MI standard, we modified the software structure of both models and developed the software for coupling the models. Finally, a small test was performed to couple the models. In 2005 the development of coupling the models will be completed.

The SOBEK model with its structures. The SIMGRO segments are also visible (in green).

For further information, please contact Hans.Hakvoort@wldelft.nl
Low Flow Hydrology

For the project Low Flow Hydrology, a number of studies were performed which are a continuation of studies of issues which had already been raised during 2003. The following topics were studied:

1. Possible alternative modules for the simulation of low flow (baseflow) on rivers, with emphasis on the Rhine basin;
2. Assessment of the return period of low flow discharges which had been determined during the study performed in the year 2003 as being critical values for a number of water users on the Rhine river in the Netherlands, such as navigation, public water supply, agriculture and water for cooling of power generation;
3. Continuation of the study of the relationship between anomalies in the major circulation patterns in the North Atlantic and the seasonal forecasting of drought in North-Western Europe.

In topic 1, a number of special modules were studied which might form alternatives for the present rainfall-runoff model HBV used in the Rhine basin. This model has been developed, and calibrated, specifically for flood forecasting and it is not clear yet whether this model is also the most suitable one for the simulation of low flows (baseflow) in the Rhine basin. There are a number of special models which were developed specifically for baseflow simulation and those models have been described in detail and their characteristics compared to those of HBV. The conclusions state that:
- Groundwater components of the evaluated Tank models are generally of the same level of complexity as the groundwater component in HBV. The use of one of these alternative groundwater components, will not add extra value to the HBV model.
- The groundwater components of the physically based models add detail, but using one of these groundwater components would mean having to calibrate many more parameters for each subbasin of the Rhine catchment.
- The models to separate the baseflow from the fast runoff component can prove useful in determining the characteristic baseflow curves of the Rhine subcatchments. These models may also be used to determine if the Rhine catchment at Lobith shows a characteristic baseflow curve.

In the year 2005 some of the most promising modules will be used to simulate the baseflow of some of the major tributaries of the Rhine River and compare the results.

For topic 2 the return period was determined for the water user affected most during low flows: navigation. As a measure for critical low flow for navigation in the Netherlands the OLR is applied, which means: “Overeengekomen Lage Rivierstand” (Agreed Low River level). For navigation this means that for the Waal, for example, the depth below this water level is 2.5 m, which is the target level for navigation (width is 150 m). The OLR corresponds with an OLA: “Overeengekomen Lage Afvoer” (Agreed Low Discharge). Since 2002 this discharge has been set at 1020 m$^3$/s in the Bovenrijn at Lobith, which implies a discharge of 818 m$^3$/s in the Waal, 30 m$^3$/s in the Nederrijn and 172 m$^3$/s in the IJssel. These values have been used to assess the return period of such low discharges. Both frequency analysis and run analysis were used.

The annual maximum continuous period of discharges below 1020 m$^3$/s has been selected from the results of the run analysis. In the period of 1901 – 1997, a minimum discharge less than or equal to 1020 m$^3$/s occurred in 46 years.

In the following figure the frequency graph is shown for yearly discharges with durations less than 20 days left censored. The 20 days is based on the average number of days with a low flow situation equivalent to a water depth on the Waal branch of 2.5 m.
Using the latter analysis, the frequency of a duration equal to 20 days/year is 1:4 years.

In Topic 3 on the relationship between NAO and seasonal forecasting of drought, new publications have been included in the study which had already been conducted in 2003. Especially the study for the relationship between climate in Scandinavia and the NAO shows that such a relationship may be relatively high, with values of $r = 0.6$, but evidently it is not yet possible to arrive at a deterministic relationship between NAO and the occurrence of drought.

For further information, please contact Ron.Passchier@wldelft.nl
Downscaling of rainfall for hydrological purposes

The spatial and temporal resolutions of hydrological models are generally different from resolutions used in meteorological and climate models. This means that a translation is required from one scale to the other. The intensity of exchange processes such as precipitation and evaporation are by no means constant within the grid size of meteorological forecasting models (typically ~ 20 km). Also, within a single time-step, whether this is a month, day or hour, the intensity of precipitation in particular can be highly variable. Downscaling of precipitation is of particular interest for flood forecasting, operational management and climate change assessment studies. A fundamental aspect for downscaling rainfall is that the predicted rainfall is not exact but is often presented through a probability density function.

The present project is initiated to test downscaling techniques for rainfall, and to assess the benefit to the water management field in terms of improved system performance. We limit ourselves to the assessment of the information supplied by KNMI’s Limited Area Numerical Weather Prediction Model HIRLAM for the benefit of the water management within the water boards.

13 months of HIRLAM precipitation forecasts in representative grid points were compared with five measured rainfall time series for the Rijnland district water board. Using 3 hours of rainfall forecasts and 10 rainfall classes, the comparison was made by applying the FBI, ETS and TSS skill scores. The results were very similar for the five representative stations. They show a very high percentage of false alarms, which could be halved if 24-hour aggregated forecast data were used, while on the other hand heavy rainfall is clearly underpredicted. It is likely that the forecast skill for extreme rainfall can be more satisfactory, however, in cases where NWPs are tuned to more extreme situations, or effective downscaling techniques are used.

For further information, please contact either Jaap.Kwadijk@wldelft.nl or Albrecht.Weerts@wldelft.nl

[Figure 1: Comparison of predicted versus measured rainfall (per 3 hours) for Rijnland measurement location Lijnden, showing that the rainfall forecasts tend to underpredict heavy rainfall.]
Extreme value analysis for complex hydraulic and hydrologic systems

In this research project various methods for deriving extreme value statistics are being analysed, developed and applied. The methods being investigated vary from straightforward direct extrapolation of measurements to more complex methods in which statistics are based on results of large numbers of simulations with physically based models. A case study concerning exceedance probabilities of water levels of the IJssel Lake (the Netherlands), is being executed to explore and quantify differences between four different methods: [1] direct extrapolation [2] numerical integration, [3] principal component analysis and [4] Monte Carlo analysis. For each method, several variants have been applied. All methods and variants have been compared in terms of practical applicability and resulting statistics. The analysis gives a valuable insight in the pros and cons of each method and consequently can serve as a guideline for future extreme value analysis.

Furthermore, a study was performed on the possible regulation of the various guidelines and directives that exist in regional Dutch water systems, such as the Water Framework Directive, GGOR and regulations regarding protection from extreme conditions. These regulations are sometimes conflicting, so the analysis focused on how to best approach these matters in an integral manner. A list of measures was presented and evaluated to find out in which sense it serves or conflicts with each of the guidelines/directives.

Finally, an existing study on the functioning of a river system during extreme flooding conditions was continued. The main focus was on the reducing effect of flooding on flooding probabilities at downstream locations.

The results of the research are presented in 2 reports and 5 papers.

Partners:

For further information, please contact Ferdinand.Diermanse@wldelft.nl

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Particle Filtering and Ensemble Kalman Filtering for runoff nowcasting using conceptual rainfall runoff models

Flood forecasting is a key issue in hydrology. The two factors which have the most significant effect on a flood forecast are the quantitative precipitation forecast and the rainfall-runoff nowcast. The quantitative precipitation forecast is normally derived from weather forecasts. The runoff nowcast is normally derived using measured or estimated evapo-transpiration and measured rainfall and the conceptual hydrological model, and may be improved by assimilating measured discharge data. Therefore, two particle filters, sequential importance resampling (SIR) and residual resampling (RR), and an Ensemble Kalman (EnKF) filter which is capable of handling dynamic non-linear/non-Gaussian models are compared to obtain an optimal runoff nowcast with a conceptual rainfall-runoff model HBV-96. All three methods are easy to implement in real flood forecasting systems.

Under normal circumstances, the residual resampling algorithm RR and EnKF performed equally well. SIR performed the least satisfactorily. With all three filters, the model error on the rainfall could be estimated during a twin experiment (Figure 1).

Both SIR and RR may degenerate temporarily, characterised by many identical particles. SIR and RR do not involve state updating, which may lead to significant overestimation of the runoff as a result of snow pack formation and later release of snow melt. This can be avoided by decreasing the role of these filters in favour of the forward model through temporary strong reduction of the rainfall uncertainty, e.g. when the temperature drops below 3°C. Given its state updates, EnKF forecasts adhere more closely to the data (Figure 2), regardless of a much smaller ensemble size.

![Figure 1. Ensemble mean forecast for EnKF (blue), SIR (magenta) and RR (red) and true synthetic runoff (black drawn line). The case study is the HBV model application for sub basin Nahl, a part of the hydrological model of the German part of the Rhine basin and the Mosel river developed by the Federal Institute of Hydrology in Germany (BfG, 2001), for the Institute for Inland Water Management and Waste Water Treatment in the Netherlands (RIZA).](image-url)
The error with respect to the evaporation could not be estimated since it acts on the same states as the rainfall, and the rainfall error was dominant in this case. Further research on the effect of the assumptions on model uncertainties and measurement uncertainties is recommended.

For further information, please contact either Albrecht.Weerts@wldelft.nl or Ghada.Elsafy@wldelft.nl.
Serious consequences of flooding

Apart from the number of people living in flood-prone areas, the strength of the structure of houses and other buildings has a large effect on the number of casualties to be expected in the event flooding occurs. During the flood in 1953 in the western part of the Netherlands, over 1800 people drowned. In 1953, many houses were made of single-stone walls causing many deaths since houses constructed with single-stone walls are less sturdy and tend to collapse more easily when flooded than cavity wall houses. These days, most houses are built with concrete walls or cavity walls. Due to the increased strength of the structure of the houses and other buildings, the expected percentage of people living in flood-prone areas who may be killed by a flood has decreased since 1953. Other factors which are important when considering the risk of fatalities as the result of floods include the stream velocity, the rate of water-level rise, available escape time and the presence of escape routes. With this knowledge the available flood models can be improved which in turn means that the number of casualties and the total damage may be predicted more accurately and reliably. This is essential for all flood risk management studies.

Together with this R&D project, a project for the province of South Holland was carried out aimed at minimising potential flood damage in a low-lying polder where there are plans for new home construction.

The solid colours indicate possibilities for the collapse of houses computed with a 2D flooding model and functions to compute the collapse of different types of building structures. The hatched colours indicate the percentage of houses that collapsed during the flood of 1953.
Figure 1 The relationship between collapse of houses and % of casualties determined from data for Goeree and Schouwen Duiveland for the flood of 1953, taking into account the effect of warning and possibilities for escape.

This graph shows that a clear relationship exists between the collapse of houses and the number of inhabitants killed, but that the effect of an advance warning is substantial as well.

For further information, please contact Nathalie.Asselman@wldelft.nl
Issues involved in floods in urban areas

The ultimate aim of the study “proefopstelling” is the development of an on-line decision support system (dss) for the regional water management in the Netherlands. The dss should include tools to:

- Predict the system load on the basis of the available weather forecast data;
- Derive control actions for pumping stations;
- Analyse “what-if” questions with respect to the constructive measures and control strategies.

The Rijnland storage basin serves as a case study. The basis of the dss is formed by the existing flood early warning system (FEWS) developed by WL | Delft Hydraulics. Next to the processing of data a major effort was put into the implementation of a water basin control module named “Integrale Regalaar” in the dss. This module has been developed at Delft University of Technology and was tested within the simulation environment for the Rijnland storage basin.

The paper for the International Conference Urban drainage Modelling 2004 describes some results of the PhD study of Elgard van Leeuwen, more specifically the derivation of control rules for the near optimal control of urban drainage systems during system failures. The paper is entitled: Control Rules for the operation of pumped urban drainage systems – Adequate operation during system failures. The proceedings may be viewed on http://www.tu-dresden.de/UDM04. Control rules based upon the aforementioned doctoral thesis study were successfully implemented in the Rotterdam urban drainage system by Siemens Nederland.

For further information, please contact Elgard.vanLeeuwen@wldelft.nl
Lake clarity

Between 2004-2007 ‘Helderheid meren (Lake clarity)’ focuses on activities for the implementation of the Water Framework Directive. We want to expand the knowledge on ecological relationships and methods to quantify these relationships, in order to describe and understand the interactions between the biological quality elements of lakes and hydromorphological conditions and water quality parameters.

The project has two final products:
1. calibrated and validated implementation of macrophytes in the Delft Systems DELWAQ and HABITAT
2. knowledge database of habitat requirements of aquatic flora and fauna species relevant for the WFD (indicator species)

This year (2004) a macrophyte module was implemented in the DELWAQ process library and the existing model MACROMIJ of RIZA, together with an HSI model for Chara vulgaris which has been implemented in HABITAT. In the coming years, these modules will be validated and calibrated and higher trophic levels will be taken into account since the existence of an interaction between macrophytes and water quality has long since been acknowledged.

The implementation of the macrophyte module in DELWAQ was started by making a base-line model of the alternative steady states in shallow eutrophic lakes (a clear water state vs. a turbid water state) using Excel. Sensitivity analyses were used to determine the most important factors causing changes in the ecosystems on long time scales (over several years). The functional design of the macrophyte module will use this knowledge in the coming years, and focused this year on the growth and decay of macrophytes in relation to the most important chemical processes in shallow lakes.

For more information, please contact Ellis.Penning@wldelft.nl
Water storage in Wetlands

One of the solutions for current and future periods with an excess or shortage of water is the storage of water in flood control areas for example and in the case of high water, in the large rivers. In all of these cases, more room is needed for water (temporarily). As room is scarce, policymakers look for multiple use of the same areas, namely by combining water storage and nature. To implement these ideas, it is necessary to research the effects of inundation of surface water on terrestrial vegetation.

The development of vegetation is influenced by many environmental factors. The abiotic conditions which eventually determine which type of vegetation will grow are called site factors. In 2003 and part of 2004 a literature study was conducted to determine the effects of flooding on site factors. At the moment, there is primarily only information available with regard to average situations. In other words, the relationships are based on conditions which occur during a long period (often 20 years). An important difference in the knowledge needed for the assessment of the effects of water storage is that in cases of water storage, it is not an average situation but more an occasional event. The collected knowledge in the literature study has been described in a concept article.

In 2004 we also worked on the preparation of this knowledge in ecohydrological model systems, such as HABITAT. This was done in cooperation with the Sava-project. The objective of this study is to assess different flood control strategies for the Lonjsko Polje detention area with regard to safety against floods, ecosystem development and nutrient trapping. For these purposes, a vegetation succession model was developed. The methodology is based on ecohydrological knowledge rules demonstrating a relationship between the local inundation duration, land use and vegetation succession rate. Several flood control scenarios were explored to determine their effect on the vegetation development. This resulted in a recommendation for flood management of the central Sava river basin. Results are described in the article: “Flood detention, nature development and water quality in a detention area along the lowland river Sava, Croatia”.

Furthermore, this project contributed to the EU 5th project ECOFLOOD by contributing to the guideline on how to combine water storage and flood control “Ecoflood”, towards natural flood reduction strategies.”

Lonjsko Polje nature park area flooded after controlled water storage to diminish high water levels at the Sava River.

For further information, please contact Marjolijn.Haasnoot@wldelft.nl
Ecosystem dynamics and processes of rivers and adjacent wetlands

Due to recent EU policies and regulations, such as the Water Framework Directive, Habitat Directive and Bird Directive, river basin managers must take measures to improve the ecological quality and functioning of rivers and adjacent wetlands. Water quality improvement and restoration of hydro- and morphodynamic conditions are inevitable in order to achieve those objectives. Moreover, river managers emphasised the need for measures to reduce the flood risks by increasing the conveyance capacity on the one hand and improving the ecological quality of the rivers and floodplains on the other in order to meet the environmental requirements of EU policies and regulations.

A research project was set up to (a) develop knowledge on the interactions between hydro- and morphodynamic processes, physio-chemical processes and ecological processes and (b) to implement this knowledge in the Delft modelling software.

To improve and validate the quantified relationships between floodplain vegetation and hydro- and morphodynamic processes in Delft3D, the following activities were carried out:

- Simulation of flume experiment on sediment transport on a vegetated bed. A thorough quantitative comparison of the simulations with the data of the flume experiment is pending.
- Improvement of analytical formulae for the hydraulic resistance of vegetation and for the bed shear stress on a vegetated bed. Three different expressions for the vegetation resistance were developed and compared with the modelled data from 1-DV model for different types of Dutch floodplain vegetation and combinations of water depth and bed roughness. Surprisingly, the results show that the simplified equation of the complex analytical formula provided the best agreement. Moreover, the test results of the new analytical formulae for bed shear stress show an improvement. Based on the results of this analysis, the formulae for hydraulic roughness of vegetation and bed shear stress in Delft3D and SOBEK are / will be improved.

To provide underpinning for one of the key principles on which the Water Framework Directive is based, research activities were initiated to quantify the relationships between the biological quality elements and the physio-chemical and hydromorphological quality elements. Research activities focused on (a) chronic toxic pressures from contaminated soils and (b) hydromorphological requirements related to availability and suitability of habitats for fish species. Research activities are linked with European research projects: REBECCA and FLOODSITE. The first results will become available in 2005.

The applicability of the recently developed ecological modelling tool HABITAT was tested in different case studies. For example, HABITAT was applied for the Taquari River, Brazil, to analyse the habitat availability for characteristic fish species, such as the Piranha. In this case study HABITAT was applied in combination with SOBEK2D.

For further information, please contact Harm.Duel@wldelft.nl
**Integrated system for operational management of urban water systems**

**Scope of the project**
The public interest in urban drainage and water supply is very high, and each year large investments are made in urban water systems. However the functions of urban water are changing. The demands on the urban water system are rapidly increasing. The role and functions of urban water as well as the number of parties involved have increased. Techniques to make an area suitable for building have changed, new types of water infrastructure have been developed, the role of water in urban design and spatial development has changed, etc. The change in all of these interests calls for a more integrated approach to urban water management.

**Aim of the project**
The aim of the project is to develop an integrated approach for designing and controlling urban water, including the accompanying design and modelling instrument. The development of the approach and the instrument will focus on the water fluxes inside as well as in between the different parts of the urban water system: rainfall-runoff, surface water, groundwater and the sewer system. Especially important are the coherence and the interaction of these fluxes. The instrument will be tailored to provide insight into urban water systems, quantitative as well as qualitative, to support civil engineers, urban designers and operation and maintenance in performing their duties.

![Figure 1 Overview of the water fluxes in an urban area](image)

**Present developments**
The completion of the total project is scheduled for the end of 2008. However the development will lead to a large number of tools which will be ready for use long before this date. At present we are in the process of developing an urban rainfall runoff module, which in principle can handle all the interacting water fluxes, and which has the capability to interact with surface water, groundwater and the sewer system, both under normal and under extreme conditions (flood). This year the concept for this module was developed. The first prototype of this concept has been built into SOBEK-RR. This prototype will be finalised and tested during the first half of 2005.
In addition to this, we are in the process of developing a previously tested concept for the linking of rainfall runoff– surface water– and groundwater models, using Harmon-IT like techniques for the necessary data transfer. The concepts are based on a closed water balance. The concepts were first tested for a simple part of a Dutch polder. After that, the concepts were applied in a phreatic area in Luxembourg. Both tests produced satisfying results. In order to optimise these concepts for application in urban drainage problems, it is necessary to make some changes in the programs that are used. This linking process is scheduled to be completed before the summer of 2005.

For further information, please contact Toine.Vergroesen@wldelft.nl
Water quality in urban areas

Water is of increasing importance in the design of new residential areas in The Netherlands. In addition to the need for water retention in urban areas, people generally prefer to live near open water. The water quality of the newly designed urban water systems is subject to uncertainties. In recent years, WL | Delft Hydraulics has been commissioned to provide water quality advice with regard to this issue to several engineering companies. For this reason, a guide was developed which supports the water quality research of new urban water systems. A thorough uncertainty analysis of urban water systems forms the basis for this guide.

The guide starts with a general description of problems and points of attention for the water quality of new urban water systems. Subsequently, the guide provides detailed information on several specific topics, such as the water quality of urban runoff and the internal loading of pollutants from the sediment. Finally, the guide provides recommendations for the best strategy for dealing with uncertainties in future water quality issues.

It is advisable to develop the guide further and to include practical experience with the design of a new urban water system and the resulting water quality.

For further information, please contact joost.icke@wldelft.nl
Alternative dredging in urban areas

The project focuses on the birth and prevention of thick mud layers in the canals of the Dutch Water Board’s Schieland district. An alternative dredging method will be tested in one of the canals of this area, which focuses on early removal of the young mud layer which is known as Sapropelium. In order to do so, the following activities have already been or will be carried out:

A. Inventory and analysis of mud accumulations in the canals of Kralingen and Capelle: A study has been conducted to explain local mud accumulations in the canals of Schieland. These accumulations appear to be situated near culverts. Several reasons for this have been found. In addition, steering parameters are described which may be used to influence local mud accumulations.

B. Research on the source and supply of materials that cause mud. For this topic WL | Delft Hydraulics conducted a literature survey on the characteristics of Sapropelium. Additionally, WL | Delft Hydraulics acted as an advisor for the development of a measuring method in order obtain samples of materials that settle over time in the water column. WL | Delft Hydraulics designed the prototype of this measuring tool. The actual measurements will be performed by the Schieland District Water Board.

A. Test with the alternative dredging method: The tests will be performed by a local Dutch contractor. WL | Delft Hydraulics acted as an advisor for the design of the alternative dredging method and the actual location of the test site. The tests still need to be carried out.

For further information, please contact either Chris.Stolk@wldeflt.nl or Simone.VanSchijndel@wldeflt.nl

Velocity, silt concentration and silt transport profiles (Source: Van Rijn, 1993)
Uncertainty analysis for 2D morphological models of rivers

The management and control of water systems is often based on the results of hydraulic or morphological models, for example. Although based on physical principles, these models contain several uncertainties, even if these models are well calibrated. The relevance of uncertainties and the effect they may have in practice on decision-making processes is becoming increasingly more recognised. It is often difficult, however, to obtain accurate and quantitative estimates for these uncertainties, especially in the case of complex, computational intensive numerical models. Using a case study, a specific aspect of this problem has been addressed, dealing with the uncertainties in model predictions due to uncertainties in the model’s input(s) or external forcings.

In this case study, a 2D morphological model based on Delft3D was applied to a reach of the Upper Rhine (Figure 1). The discharges at the upstream boundary were considered as an uncertain input for the model and the effect of this uncertainty on the river bed was estimated. This was done using a Monte Carlo (MC) method. The uncertainties in the upstream discharge were described through the use of a statistical model, and a set of 100 random discharge series of 3 years was generated. The morphological model was evaluated for each of these synthetic discharges. Figure 2 shows an example of the information that may be obtained from the ensemble of morphological changes which was found: the 90% confidence interval of the shipping width in a section of the modelled river reach. This type of information can help a river manager to decide where problems might occur for shipping. For example, the figure suggests that particularly the section of the reach near location 855 [Rkm] is critical, since a large part of the confidence interval is below the threshold width of 170 m.

A standard MC method, as applied in this case study, has the disadvantage that quite a large number of simulations is required to obtain sufficiently accurate estimates for the uncertainty in the model results. Alternative sampling methods have been developed to improve the efficiency of standard MC-methods, and in the present case the performance of a so-called Quasi Monte Carlo (QMC) method was examined. The results of preliminary tests are promising and on this basis it may well be feasible to refine and improve the present uncertainty analysis significantly. More generally, such QMC techniques may provide important new opportunities for uncertainty analyses to other complex and computationally intensive numerical models.

Figure 1: Overview of the morphological Delft3D model.
Figure 2: The lower and upper limit of the 90% confidence interval of the shipping width based on a minimum water depth of 2.8 m during OLR (standardised low water level) conditions.

For further information, please contact Hanneke.vdKlis@wldelft.nl
2D River morphology instrument

This project aims to develop an instrument used to answer river morphological questions. With regard to the Dutch rivers, these issues arise as a result of management questions related to navigability during low flows, morphological developments after flood-plain restoration and morphology near constructions. Apart from the last subject, for which a lack of knowledge still exists with respect to hydrodynamics, these problems are translated into research-questions with respect to transport of sediment and related morphological developments.

Within this project, river morphological issues are studied in relation to the theme “dynamics of river bifurcations” of the Morphological Triangle (which is a knowledge platform for river-morphological research in the Netherlands). Questions which are treated include: how does the interaction of several sediment fractions contribute to large-scale morphological development, how does this coincide with the large observed dynamics of the bed forms, and how may these effects be modelled efficiently for practical applications.

Also related questions regarding large-scale water movement relevant to morphology (such as spiral flow in bends), the interaction between morphology and vegetation, and processes such as bank erosion, belonging to a more natural planning of the river area (secondary channels) are some of the subjects being considered within this project.

Over the past several years, the development of more extensive boundary conditions, input options, alluvial and vegetation roughness formulations, bank erosion, graded-sediment modelling, and modelling of spiral flow effects in sharp bends have been important topics involved in this project. The modelling system Delft3D is used as the foundation for these developments, where it is applied in 2-D (depth-averaged) flow mode. In 2004 a connection was also made with Baseline, which is a GIS-based data management system used for the Dutch rivers. In addition, the activities for integrating the graded-sediment approach into a new Delft3D morphology module were started up in 2004. The objective of this integration is to allow for combined modelling of gravel, sand and (cohesive) silt mixtures while returning the effect of grain-sorting processes and dune development on bed roughness.

The application of the newly developed 2-D graded-sediment functionality for the Pannerdensche Kop river bifurcation (in cooperation with the Morphological Triangle) and for several rivers in Japan (in cooperation with J-Power, Japan) has demonstrated both the benefits and limitations of this new approach. Also, new developments for bank erosion are now being tested for field cases, aiming at validation and setting the program for further improvements. The outcomes of this research meet the demand for more detailed and accurate modelling approaches, and the regular Delft3D-software users are expected to benefit from these improvements.

For further information, please contact either Kees.Sloff@uldelft.nl or Bert.Jagers@uldelft.nl.
Ship-induced water motions below the ship’s keel

The ship-induced return current below a ship’s keel may affect the stability of the bed of navigation channels and the present structures, such as bed protections. The return current depends on the keel clearance and the ship speed, among other factors. The goal of this research project is to develop a prediction method for the return current velocities below the ship and their effect on the bed morphology and stability of the material protecting a pipeline crossing the canal, for instance. In 2003 a literature survey was conducted and an inventory was taken of the possibilities of existing numerical models. Subsequently, the research was continued in 2004 with the development of an analytical method. This resulted in a set of formulae to predict return current velocities below a sailing ship. Also formulas are summarised to predict erosion or stability of bed material or bed protection material given the return flow velocities. In 2005 the project will be finalised with a further improvement of the method, a sensitivity analysis and validation with the available data of laboratory and field measurements. The final result will be a method to predict ship-induced flow velocities below a sailing ship, allowing consultants and authorities to improve their designs and management tasks.

For further information, please contact either Henk.Verheij@wldelft.nl or Chris.Stolk@wldelft.nl
3D Flow near structures

The aim of the present research project is to develop generic knowledge on the numerical computation of flow about hydraulic structures. Important questions include: how can the flow best be simulated given a certain geometry, which simulation model is appropriate and which properties should this model have, how should the simulation results be interpreted, what is the accuracy of the computations, and what are the shortcomings of the simulation?

The local flow near hydraulic structures usually has strong three-dimensional properties; standard flow simulation models with depth-averaging or a hydrostatic pressure assumption cannot be applied. Variables such as the lay-out and geometry of the structure, the surrounding geometry, the hydraulic roughness of walls and other flow boundaries, and the properties of water (viscosity, density) strongly affect the local flow about the structure. Important hydrodynamic aspects are: the development of the free water surface, the development of boundary layers on walls and bottom, the formation of flow separation points on structures, the formation of free boundary layers in the fluid, vortex generation, spreading of turbulence and damping, expansion of the flow and eddy formation, effects of turbulence on velocity profiles and stream patterns, energy losses, and effects caused by density differences.

In the year 2003 an exploratory study was conducted into the present status of the simulation of flow around structures. Attention has also been paid to computational grids and their properties. In the year 2004 flow velocity measurements were taken in a scale model of a section of a groyne (in a related research project). The flow was also simulated using the CFX® code and the Delft3D code. These simulations were aimed to check the numerical results on aspects such as the effect of the turbulence model on flow pattern and flow velocity profiles, the effect of wall roughness modelling, the effect of water surface modelling (in CFX). Two basic problems were encountered in the CFX simulations: the construction of a suited grid, and the modelling of very rough walls. The present CFX models still have a moderate convergence and do not yet fully reproduce the actual flow over the groyne. Also the results of the Delft3D simulation with Z-layers are not yet sufficiently satisfactory.

For further information, please contact either Dirk.Schwanenberg@wldelft.nl or Bert.Jagers@wldelft.nl
Cooperation with universities on river engineering

WL | Delft Hydraulics has invested in following developments at universities in the field of river engineering and morphology:

- “Sediment distribution at river bifurcations”. Mrs. Van der Mark (MSc, Delft University of Technology) has performed a theoretical analysis of river bifurcations. Based on extensive computations using Delft3D as well as existing experimental data, she has derived a simple design formula for the distribution of sediment at river bifurcations.

- “Stochastic modelling of river morphology”. Mrs. Van Vuren (PhD, Delft University of Technology) is extending her originally one-dimensional analyses to two dimensions. Furthermore, she is developing methods to translate Monte Carlo results from morphological Delft3D computations into aggregated information for river managers.

- “Dynamic roughness in rivers during floods”. Mr. Paarlberg (PhD, University of Twente) has started his research by conducting a literature survey, detailing his research plan and collecting data. He has managed to retrieve the valuable measurement data from the old TOW research programme at WL | Delft Hydraulics which had previously been considered lost for a long time.

- “River width adjustment: from mega-scale to local-scale”. Mrs. Mengoni (PhD, University of Florence, Italy) has analysed the water flows, morphological changes and bank erosion processes in a bend of the Cecina stream near Pisa, Italy, by using field data and Delft3D computations. Her meticulous analysis reveals that some of the common wisdom regarding bank erosion processes needs to be re-considered.

- The results of the Albufera project in Spain have been used to describe the innovative approach with SOBEK-1D2D for simulation of hydrodynamics combined with transport and sedimentation of suspended materials.

For further information, please contact either Erik.Mosselman@wldelft.nl or Frans.vdKknap@wldelft.nl
5 Industrial & closed conduit flows

Companies using liquids in their processes or those who perform activities in open waters strive for an operation that is economical, safe, reliable and controllable, and for the (adverse) effects from their activities on the environment to be as few as possible. WL | Delft Hydraulics offers expertise and modelling techniques to assist in achieving these goals. A broad definition of “industry” applies here, since various distinct categories may be defined.

Transport in pipeline systems with pumps, long conduits, flow meters, valves and outlets is an issue in many cases. The offshore industry is faced with questions regarding the effects of forces on structures during extreme environmental conditions and the stability of foundations on sandy soils, pipeline landfalls, oil spills, etc. The dredging industry has interests in the dredging process near the bed, and in the dredger and its influence on the environment, the slope stability of trenches, morphological effects of dredging and pollution control possibilities. Once the technology had been improved, tunnel boring in soft earth layers began to boom in the Netherlands, due in part to the assistance provided by WL | Delft Hydraulics.

The R&D programme 2004 for industrial systems and offshore industry focused on various items.

In 2004 the research was continued on horizontal directional drilling, and addressed topics of industrial flow technology. Understanding and manipulation of slurry behaviour is an essential aspect of the capabilities of Dutch drilling contractors.

Various studies were conducted with respect to 2-phase flow. An unsteady friction module was developed in the model system of pressurised flow in pipelines WANDA; a numerical model for compressible, homogeneous two-phase flows was developed and implemented in WANDA; free surface flow in WANDA were made; the matrix solver in WANDA was improved; a check valve model was developed and will be implemented in future also in WANDA.

A numerical model which simulates the transient flashing in horizontal pipelines was designed in Matlab®.

For wastewater sewer systems, a research programme was initiated in order to limit the frequently experienced malfunctioning in these systems due to gas-water phenomena.
• Horizontal Directional Drilling Research
• Slurry technology
• Tactical
• 2-Phase flow
• CAPWAT
Horizontal Directional Drilling

Within the framework of the research that has been conducted by the participants of the Horizontal Directional Drilling Research Association which restarted in 2001, several studies were completed and finalised in three reports.

The first report dealt with the issue of “good practise in monitoring.” This topic is of considerable importance to consultants and contractors because a majority of the transfer of newly gained process knowledge and risk assessment from the last several years in joint research takes place in their fields of expertise.

The second completed research initiative concerns the verification of process knowledge in an actual prototype test project. In this study, the dynamics that govern the maximum pressure in bore holes were checked and consecutively funded with a method to calculate and thus predict this.

The third evaluation submitted by the participant concerns an overall evaluation of the new research conducted in the last few years. This was established as a principal effort of the Delft University of Technology with the support of WL | Delft Hydraulics.

Last but not least, there was a substantial contribution to the relevance and review of the tunnel boring projects executed within the Betuweroute project and the High Speed Railway line. As with the Horizontal Directional Drilling study, these addressed the topics of industrial flow technology.

Mini Rig boring (HDD-) installation in Hardenberg enabling process research for the participants in the Horizontal Directional Drilling Research project in 2004.

For further information, please contact either Johan.Pennekamp@wldelft.nl or Arno.Talmon@wldelft.nl
Slurry technology

The following progress was made on the basis of research conducted by WL | Delft Hydraulics:

The geotechnical static consolidation phenomenon was introduced into the fluid mechanics of high concentration solid-liquid mixtures (clogging problems). Potential applications which come to mind include problems resulting from clogging within the food industry (such as carrot transports, potato peels), sanitary system sludge, transportation of fluidised excavated soil. A publication describing this study was prepared.

In 2004 our first publication on concentrated slurries in Trenchless Technology by an international journal specialised in Tunnelling (TUST) saw the light of day.

In 2004 a publication followed on the fluid mechanics of solids transport by Non-Newtonian fluids. Data and video material obtained in Carrousel experiments dating back several years was brought to the attention of international experts. Specifically the existence of gelled bottom layers in pipes and bore holes which provide an important means of solids transport was highly appreciated.

WL | Delft Hydraulics’ data on the settling of solids being transported by Non-Newtonian fluids was also brought to the attention of the international scientific community (presentation at T&S conference). It was well-received and enjoyed a surprising broad based support.

The year 2004 saw the publication of WL | Delft Hydraulics’ conclusions regarding the cause of unsteady sand transport in long distance dredging pipelines presented before the international dredging community (WODCON congress).

Density Stratification Effects in turbulent pipe flow have been modelled with 1-D theory and validated with laboratory experiments. The conclusion is that in two-phase flows stratification effects might be stronger under field conditions than under those created in the laboratory.

For further information, please contact either Arno.Talmon@wldelft.nl or Johan.Pennekamp@wldelft.nl.
Tactical drilling

The project organisation HSL-Zuid commissioned GeoDelft and WL | Delft Hydraulics, as partners in Delft Cluster, to conduct research concerning the grouting process at the Groene Hart Tunnel. The Groene Hart Tunnel is part of the High Speed Railway Link between Amsterdam and Paris. The research focuses on the grouting of the annular space created by the tunnel boring machine (TBM). The grouting process is of importance with respect to (sub)surface settlements of the soil and the structural integrity of the tunnel lining. At some selected locations, the tunnel lining segments have been equipped with pressure sensors.

In 2004, WL | Delft Hydraulics’ contribution to the project consisted of:
1) Bilateral cooperation with industry partners within the COB–research committee “Tunnel construction”.
2) Analysis of grouting pressures and consolidation at a tunnel passage in the Noordplaspolder.
3) Design of a laboratory experiment on the interaction between the movement of the tunnel lining and reaction forces from the grout.
4) Publications have been prepared for international conferences ITA, TC28 and ICSMGE. The subjects include: beam-action of the tunnel lining, calculation of grout pressures around tunnel linings (see also WL | Delft Hydraulics’ website), thickening and resistance of mixtures in Earth Pressure Balance Tunnel Boring Machines,
5) Different aspects of monitoring, measuring and data acquisition during the construction of bored tunnels.

For further information, please contact either Arno.Talmon@wldelft.nl or Johan.Pennekamp@wldelft.nl
2-Phase Flow

The R&D efforts in the year 2004 were carried out within the framework of two-phase and dynamic flow modelling.

Unsteady friction model
An unsteady friction model was developed in WANDA. Based on a quasi-steady flow approach, the existing friction models lack a damping of pressure waves (figure 1). Unsteady friction models predict damping much better and thus give more realistic transient flow calculations, ultimately allowing the design of safer and more cost-efficient pipe systems. Unsteady friction is particularly relevant in scenarios where the initial transient initiates a second transient which occurs during the damping phase of the first transient (examples are air valve slam, damped check valve closure or ESD control events). After implementation and validation, the model will become available in the commercial WANDA version.

Compressible and Multiphase flow in WANDA
A numerical model for compressible, homogeneous two-phase flows was developed in which the classical waterhammer theory (practically incompressible fluids) is combined with gas dynamics theory (compressible fluids). The system of equations which describe conservation of mass, momentum and energy, is solved by the method of characteristics. Due to the variable wave speed of the flow mixture, an interpolation procedure must be performed on a fixed computational grid. As a first step, the compressible flow equations are implemented in WANDA. Two test cases are run and compared with results from literature: the so-called Riemann shock tube problem (figure 2), and a case from WL Delft Hydraulics consultancy work. The next step involves the implementation of the homogeneous two-phase model in WANDA, including two-phase valve and compressor models.

Free surface flow improvements, part I architecture of WANDA pipe models
A start was made on the redesign of the architecture of the pipe models in WANDA, to handle the variety of different mathematical models with their specific computational methods, such as Fluid Structure Interaction, Free Surface Flow and Two-Phase Flows. The main strategy is to include the pipe models in the same object-oriented structure as the non-pipe components (which form the boundary conditions of the pipe models). At the same time, the data communication between the computational core and user interface is redesigned to facilitate the (future) addition of new models with their specific input and output quantities.

Sparse matrix solver in WANDA
An investigation was performed into the effectiveness of a sparse matrix solver to replace the existing full matrix solver which is based on a Gauss elimination method, which performs poorly on sparse matrices. WANDA makes use of matrices for the solution of the steady state system of equations as well as the nodal set systems of equations in unsteady state. After proven success, the solver was implemented in WANDA. Ten cases from engineering work revealed a significant reduction of the CPU times (by a factor 10 or more) as well as the memory usage.

Check valve model
A check valve model was developed which is exclusively based on steady flow and dynamic characteristics, as known from standard tests on undamped check valves. The model may be used to simulate the closure and opening behaviour of both undamped and damped check valves, and replaces the existing model which simulates the closure behaviour of undamped check valves only. As a next step the model will be implemented in WANDA and validated against experiments.

Flashing model
A numerical model has been developed in Matlab®, which simulates the transient flashing in a horizontal pipeline, including thermodynamic non-equilibrium flashing, pipe elasticity, liquid compressibility and heat transfer to the subsoil. This development contributes to the safety of critical pipe system, in which flashing cannot be neglected. The model has been applied to assess the total mass flow and vapour flow from a pipe system into a blow down tank.
Most of the models developed will be implemented in WANDA, and as such become available to the WANDA users.

For further information, please contact either Arno.Kruisbrink@wldelft.nl or Ivo.Pothof@wldelft.nl
CAPWAT

In the Netherlands, wastewater is collected in the mostly combined sewer system and pumped to the WWTP through pressure mains. These pressure mains are a part of the system which has not received very much attention lately with respect to the monitoring of performance and maintenance. For this reason, these mains’ state of operation is often unknown. Failure of operation is only noticed when, during storm conditions, the capacity of the system remains under the supply, resulting in undesirable discharge to the surface water.

An inventory of the system conducted recently showed that half of the pressure mains demonstrate increased pressure loss for no apparent reason. A reduction in the system’s nominal capacity may be caused by many factors, such as increased wall roughness, scaling and occurrence of free gas in the pipeline. Free gas may result from the degassing of dissolved gas, but also by air entrainment at the pumps’ inlet or at air valves.

A research study was been started which will be conducted during the period from 2003 to 2005. This study concentrates on three main areas:
1. a description of the gas-water phenomena in wastewater pressure mains with respect to transportation and dynamic hydraulic behaviour,
2. a method to diagnose gas problems, and
3. to overcome future problems by either applying remedial measures or improve the design of wastewater pressure systems.

The study is being conducted by the University of Delft and Delft Hydraulics in collaboration with the majority of the district water boards in the Netherlands. In 2004, the design and construction of an experimental facility was performed which comprises a transparent DN200 test section. Furthermore, preliminary tests have been carried out which led to a better understanding of the mechanics involved in visual observation and an initial start was made in a quantitative description of the resulting head loss and critical velocity to transport gas.

At the end of 2004, the design was created for a second experimental facility with a length of over 600 m. The purpose of this facility is to develop a method to diagnose gas problems and to assess the location and quantity of air in the system.
A
air bubbles moving through the bend

B
bubbles moving downstream

C
air pocket moving upstream

For more information, please contact either Christof.Lubbers@wldelft.nl or Kees.Kooij@wldelft.nl
6 Experiments & data management

Hydraulic research methodology requires a specific balance. Synergy between all of the available tools is necessary as a result of the increasing complexity of the topics of hydraulics research; often it is only an integrated approach which uses every available method of research that will result in the correct answers. Experiments in the laboratory or in situ are intended to deliver useful data to validate or calibrate mathematical modelling techniques, or to gain insight into insufficiently understood phenomena. This involves natural phenomena, as well as responses to human activities. Physical scale modelling has long been dominant within WL | Delft Hydraulics, yet this has gradually come to be substituted by numerical modelling in recent decades. However, physical experiments are and will remain necessary for a long time to come, particularly in specific cases related to complex flow and morphological phenomena, forces on structures and responses, but also for closing knowledge gaps in mathematical modelling of water quality aspects and studies to ascertain the proper design of expensive innovative structures.

Several projects were carried out within the framework of the 2004 R&D programme.
A physical modelling programme was defined and conducted to provide systematic information on sea bed scour around spud cans, as a lack of information on this important subject was detected in the literature.
A series of tests with a moored ship were performed in the multi-directional wave basin to validate methods developed in recent years used to calculate forces on moored ships.
Flow pattern studies with a section model of a groyne were performed to collect data for calibration and validation of numerical computation of flow about such structures.
Remote sensing data is increasingly important and an overview was prepared of the information content of the various data types.
Evaluation of data is made easier by alternative presentation possibilities. In general, data model integration was the object of continued attention.
Three projects were conducted, namely: validation of confidence intervals by coverage rates, ensembles of synthetic time series, and synthetic time series of wind speed fluctuations.
- Scour around spud cans
- Wave-induced forces on moored ships
- Flow patterns near submerged groynes
- Use of remote sensing data for modelling inland water processes
- Remote sensing & GIS
- Quantitative model evaluation approaches and tools
- Validation of confidence intervals by coverage rates
- Ensembles of synthetic time series
- Synthetic time series of wind speed fluctuations
Scour around spud cans

The assessment of scour development around spud cans is an important issue in jack-up rig operations in areas with erodible seabeds. Excessive scour around spud cans might lead to settlement, tilting of legs or even stability problems. In order to avoid damage to the legs, scour protection measures are often applied. As these measures are very time-consuming as well as being costly, there is a need for a better understanding of scour processes near spud cans and for adequate predictions of expected scour development.

Given the above considerations and the lack of information on scour around spud cans in literature, a physical modelling programme was defined and conducted to provide systematic information on this subject. Physical modelling was carried out in our Scheldt basin which is capable of simulating combined waves and currents required to represent relevant offshore conditions. A total of ten model simulations were carried out, each providing simultaneous information on scour development for twelve schematised spud cans, covering three main spud can shapes (schematised).

The 2004 offshore scour research focused on the model execution and data collection. The data will be analysed and published in 2005.

For further information, please contact Klaasjan.Bos@wldelft.nl
Wave induced forces on moored ships

In recent years research has been focused on the development of methods to calculate forces on a moored ship from wave model data. For the validation of these methods, a series of tests were performed in the multi-directional wave basin. In 2004 the measurements were reported in a memo and the data have been archived. Two methods for calculating forces on a ship due to waves were verified with these data.

One of the methods which were verified is the combination of DPRA (in the time domain) and transfer functions (theoretical relation between wave and force) in the frequency domain. DPRA uses time signals from a number of wave probes to derive the required information for the wave field. Revising the code (making it applicable for the present use) and the application/verification of it based on the measured conditions has resulted in increased insight regarding the (future) operational application of this method.

Additional tests with DPRA were performed based on calculations with the TRITON model (separate from the work described in the following paragraph). These tests showed that good results can be obtained provided a number of prerequisites are met. An abstract based on the results obtained in 2004 has been submitted for presentation at the WAVES 2005 conference in Madrid to be held in July of 2005.

The verification of the second method for calculating wave forces on a ship, the coupling of TRITON (WL | Delft Hydraulics) and Delmulti (TUD), was completed in 2004. Good agreement was found between the measured and the calculated forces on the ship for the studied cases. The results from this year and results obtained on this topic in previous years have been integrated into one report.

In 2004 the cooperation with the TUD in a Ph.D. project continued. The Ph.D. student is W. van der Molen of the Department of Hydraulic Engineering (Prof. Ligteringen), of the Faculty of Civil Engineering at Delft University of Technology. His project is entitled “Behaviour of Moored Ships in Harbours.” The cooperation consists of taking part in the project’s user committee and providing additional information/data where required and possible.

For further information, please contact either Otto.Weiler@wldelft.nl or Mart.Borsboom@wldelft.nl.
Flow patterns near submerged groynes

The main rivers in the Netherlands are equipped with groynes, which aim to improve the conditions for shipping in the navigational channels. There is a growing interest to adapt the groynes in such a way that flood levels are reduced in the river. To this end, the flow resistance of the groynes should be made relatively small at the high water level, but at the same time the flow resistance should remain high enough to maintain the flow in the main channel when the water level is low (water level just above the crest of the groyne). The flow resistance depends on the local flow pattern, which in turn is affected by the geometry of the groyne (upstream and downstream slope, crest level) and surface roughness.

In the related research project '3D-flow about hydraulic structures,' which aims to develop generic knowledge on the numerical computation of flow about structures, the case of a flow over a submerged groyne was selected for research purposes. The present research project supported this case study and provided data for calibration and validation. In a scale model of a section of a submerged groyne, which was protected with rockfill, the local flow pattern was observed and vertical profiles of the flow velocity measured (using laser techniques). A distinction was made between the time-averaged flow velocity component and the dynamic component (turbulence). The surface roughness of the groyne was varied as well as the angle of the downstream slope. It was clearly evident that the flow over the groyne could be influenced by a variation of the slope and the surface roughness. The scale model study did not yet include the flow about the side edge of the groyne. The obtained data (including water surface and discharge) are available in digital form.

Flow over groyne (scale model test)

For further information, please contact either Tom.Jongeling@wldelft.nl or Chris.Stolk@wldelft.nl
Use of remote sensing data for modelling inland water processes

The information provided by remote sensing data is increasingly important to the studies and projects in the field of freshwater systems; see Figure 1.

Figure 1 Spatial distribution of remotely sensed Chlorophyll-a observations for Lake IJsselmeer for April – September 2003. Composite fortnightly images for the surface, mapped onto a numerical model grid for comparison and guiding three dimensional model simulations (images courtesy of IVM)

This research project focused on increasing insight into the existing expertise available on the use of remote sensing data for inland water studies, creating an overview of the information content of the various data types, and the availability of these data.
A series of interviews have been conducted to gain an overview of available knowledge, past expertise in using remote sensing data in inland water projects, and the views on the present potential of remote sensing data in combination with modelling for analysis and solving inland water problems. Finally a network plan was set up proposing several activities necessary to obtain a broader network within the remote sensing world.

For further information, please contact either Karin.Stone@wldelft.nl or Pascal.Boderie@wldelft.nl

Figure 1 Spatial distribution of remotely sensed Chlorophyll-a observations for Lake IJsselmeer for April – September 2003. Composite fortnightly images for the surface, mapped onto a numerical model grid for comparison and guiding three dimensional model simulations (images courtesy of IVM)
Remote Sensing & GIS

In recent years, the amount, quality and resolution of earth observation data which has relevance for hydrology has increased. Under the name Global Data sets (free/via the internet accessible GIS/remote sensing data sets with global coverage), this research project identified, defined and assessed the applicability of those spatial data sets using GIS tools. The outcome of the research and its case study applications was very positive. The quality of the data sets was better than expected and the amount of data and the range of data types are impressive. The data sets facilitate rapid analysis at the beginning of a study and allow the production of high quality models. This is a major advantage when compared to current practice in which the collection and validation of local data often results in a model with less quality which typically becomes available at the end of the project.

It was concluded that the proper usage of those data sets can improve the implementation of overseas projects. In 2005, the lessons learned from the case studies will be formalised into guidelines designed to improve the applicability of those spatial data sets within a GIS-environment.

For further information, please contact Aljosja.Hooijer@wl.delft.nl
Quantitative model evaluation approaches and tools

Methods to evaluate flow modelling results quantitatively have been standardised on the basis of practical cases. This helps to improve the validation of complicated 3D flow models and makes the evaluation more objective, easier to reproduce and explain to the parties commissioning the studies.

Traditionally, flow modelling results are often evaluated purely in graphic terms; see the example in Figure 1. In this case, the salinity distribution by tidal motion and vertical and horizontal mixing modelled by Delft3D-FLOW (red and magenta curves) is compared to the salinity measured at positions along the physical scale model in Delft Hydraulic’s Tidal Flume (green and blue curves).

In cases where salinity profiles are measured by vertically moving salinity probes, the visual evaluation of modelled and the measured salinity profile can be made intuitively, see Figure 2. The salinity probe systematically measured the vertical salinity distribution by moving periodically in five vertical steps from the top to the bottom measurement level (indicated by dots).
Quantitative evaluation of modelling results requires that suitable acceptance criteria to be formulated, given the intended use of the model. In the present case the parameter is salinity intrusion, and the acceptance criterion is that the maximum RMS salinity difference at given locations does not exceed an agreed percentage of the local measured dynamic salinity range.

Table 1 presents an example of the quantified results. The RMS error at this measurement point (0.36 ppt) is 5.5% of the dynamic range of salinity over the flume (6.5 ppt), which is within the accepted range.

<table>
<thead>
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<th>observation</th>
<th>simulation</th>
<th>mean</th>
<th>st. dev.</th>
<th>RMS</th>
<th>max</th>
<th>min</th>
<th>observation range</th>
<th>simulation range</th>
</tr>
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<td>BEZO/Temp/EMS-60-1</td>
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<td>0.35</td>
<td>0.36</td>
<td>0.74</td>
<td>-0.76</td>
<td>5.83</td>
<td>5.62</td>
</tr>
</tbody>
</table>

Table 1. Example of quantified differences of modelled and measured salinity

For further information, please contact either Arnout.Bijlsma@wl.delft.nl or Herman.Gerritsen@wl.delft.nl
Validation of confidence intervals by coverage rates

The management and control of water systems is often based on the results of numerical models and/or a statistical analysis of observed data. Model predictions and/or statistical estimates may contain several uncertainties and in analysis and decision-making processes, these should be taken carefully into account. Specifically, this requires quantitative and accurate estimates for uncertainties in modelling results. Uncertainties are often quantified by means of a confidence interval (of 95% for example). Several methods have been developed for the computation of confidence intervals. Validation of methods for the estimation of confidence intervals may be done using so-called coverage rates. This is illustrated here within the context of frequency (or extreme value) analysis.

In a frequency analysis, observed extremes of several hydraulic or hydrological quantity (e.g. wave heights, discharges, water levels, etc.) are used to identify the parameters and quantiles of a probability distribution that describes the statistics of these extreme values. The Q'th quantile \( (0 < Q < 1) \) is defined as the level that is not exceeded by probability \( Q \), and these quantiles are important parameters in design procedures and risk assessments. In the present case, a three parameter Weibull distribution is chosen for the statistical model of extremes, and its parameters and quantiles are estimated with the MPS method (Maximum Product of Spacings). Compared with other estimation techniques, MPS has important advantages when it comes to one-sided and J-shaped distributions. Confidence intervals were produced with a Bootstrap resampling procedure. The actual coverage rates used to validate this method for confidence intervals were computed from a large number \( K \) of “twin experiments.” In each experiment, a (new) random sample of fixed size \( N \) was drawn from a parent Weibull distribution (with fixed parameters), and the MPS-estimation and Bootstrap procedure was applied to identify the confidence intervals (for one or more confidence levels, e.g. \( \gamma = 95\% \)) for a set of quantiles \( Q \). The results of an application are plotted in Figure 1 where quantiles (actually the associated probabilities of non-exceedence \( Q \)) are positioned along the abscissa, and coverage rates along the ordinate. The solid curves denote the identified coverage rates for the quantile’s confidence intervals for three variations (90, 95, 99%) of the confidence level. These confidence levels are represented by the horizontal dashes. The coverage rates were observed to agree reasonably well with the ‘true’ confidence levels. This agreement is extra remarkable because of the rather critical conditions in this test. In fact, the shape parameter in the parent Weibull distribution was set at , leading to a J-shaped distribution. For these types of distributions, many estimation techniques (other than MPS, however) often fail to produce consistent estimates and/or accurate confidence intervals.

The preceding illustration demonstrates the practical suitability of the present Bootstrap procedure for creating consistent confidence intervals in frequency analysis.

Figure 1. Coverage rates for quantiles for three confidence levels.

For further information, please contact Henk.vdBoogaard@wldeft.nl

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Ensembles of synthetic time series

Observed time series are used in nearly every (hydraulic, hydrological, ecological, etc.) case study for the monitoring, analysis, or statistical description of the system’s state. Alternatively, observations are often also used for the initialisation of and/or integration with numerical models. In practice, observed time series are often incomplete due to missing values, gaps, or measurement errors. Equally, the duration may be too short, or the spatial/temporal sampling too sparse. For the (re)construction of a time series, some form of interpolation or extrapolation must be used. To obtain a meaningful interpolation, the physical and statistical properties of the underlying processes must be taken into account carefully. An algorithm has been developed to generate such synthetic time series. The algorithm is in the form of an optimisation procedure where physical/statistical properties and observations (if present) are prescribed by means of constraints. In cases where the observations are missing, a fully synthetic time series may be generated. Figure 1a, and in greater detail, Figure 1b, show this type of fully synthetic time series found in an application where the marginal distribution function (red solid curve in Figure 1c) and the series’ auto-covariance function (red marked symbols in Figure 1d) were prescribed. Note the very special/complex form of these functions (bimodal marginal distribution and auto-covariance function with a weak periodic component; physically these may be related to a two-state system with some quasi-periodic time evolution), for example. The estimates of the marginal distribution and auto-covariance function derived from the identified time series (black curves in Figures 1cd) agree accurately with what was prescribed.

Figure 1. Example of a fully synthetic time series based on user-prescribed statistics

An important feature of the present algorithm is that it allows ensembles of synthetic time series to be produced. Each individual time series in the ensemble satisfies the same prescribed statistical properties and/or observations, while the several individual series are mutually different, however. This confirms that the results of an interpolation need not be unique. In fact, an ensemble reflects the uncertainties in an interpolation, and in practice these uncertainties can prove important when interpolated/synthetic series are used in uncertainty and risk analyses, control, and/or decision-making processes.

Another contribution within this “R&D 2004 Annual Report” will treat an ensemble of synthetic time series for wind-speed fluctuations.

For further information, please contact Henk.vdBoogaard@wldelft.nl
Synthetic time series of wind speed fluctuations

In open water systems, water levels, flows, transports, mixing, etc. all depend on gravitational, external-mechanical, and external-thermodynamic forcing. In practical applications of hydrodynamic numerical models, and especially when an accurate representation is desired for relatively small spatial and temporal scales (order of 1 km or less, and 10 minutes or less, for example), it has often proved to be impossible to obtain data of this external forcing with a sufficiently detailed resolution. As a result, these data must be interpolated appropriately to the much finer spatial and temporal grids of the numerical model.

Recently a method was developed for the construction of synthetic time series. In this method physical/statistical properties can be prescribed within an interpolation of observed samples. In this way, a synthetic/interpolated time series is highly consistent with the actual physical process. A special feature of the method is that ensembles of consistent synthetic series can be generated and the variability in such an ensemble represents uncertainties.

In this case, the suitability of the method was tested for the interpolation of wind speed fluctuations. To obtain statistic properties of these fluctuations, an observed data set with 1-minute wind-speed samples was statistically analysed. The wind-speed fluctuations were identified as the residuals of a regression model for the long(er) term temporal variations. Figure 1a shows the original wind-speed time series (in black), its slowly varying component (in blue) and the resulting fluctuations (in red). The statistical analysis revealed that these fluctuations can be modelled as a random process (close to Gaussian) with an exponential auto-covariance function. The marginal distribution and serial auto-covariance function derived directly from the ‘observed’ fluctuations are shown in red in the Figures 1bc, while the estimates of these quantities based on a calibrated analytical model for the fluctuations are plotted in black.

The resulting (analytical) model which has been identified for the observed wind speed fluctuations was used to generate an ensemble of synthetic time series. Together with the marginal distribution and auto-covariance function, a sparse subset of observations was prescribed as well. In this way the situation is emulated in which the original time series of 1 minute samples must be reproduced from a sparse subset of 10 minute samples. Figure 2a shows the original wind speed fluctuations (the time series of Figure 1a, though shifted in time) with its samples that were selected as observations marked by an asterisk in black. Figures 2bc illustrate two different synthetic time series from the identified ensemble. We note that they accurately satisfy the prescribed observations (as well as the prescribed marginal distribution and auto-covariance function, not shown here), these two synthetic series and the original series can be significantly different but for the new time points. Figures 2de show some ensemble statistics. In Figure 2d the ensemble mean is presented as function of time, while ensemble quantiles (10, 50, 90%) can be found in Figure 2e. Note that these quantiles are shown for a subinterval to provide a better perspective on their temporal properties.
The present results suggest the feasibility of the present method for physically/statistically consistent interpolation issues. For a wider applicability, the technique must be extended even further using the appropriate facilities to deal with multi-variate time series and/or spatially dependent data.

Figure 2. Time series of synthetic wind speed fluctuations and ensemble statistics

For further information, please contact either Henk.vdBoogaard@wldelft or Rob.Uittenbogaard@wldelft.nl
7 Software systems

The transfer of knowledge and technology via software systems continues to receive considerable attention at WL | Delft Hydraulics. Both internal experts and external clients from around the world are involved in the development and application of a range of Delft software systems used in research and specialised consultancy.

In-depth knowledge and expertise of the processes involved usually provides the basis for the continuous development of our software products. Advanced software engineering technologies, appropriate hardware system architectures, and accurate as well as solid numerical techniques are used to further improve and modernise the Delft software systems. Maintenance and customer relationship management services are carried out by a skilled staff of dedicated professionals.

Whenever possible and feasible, results obtained from computer simulations are validated against experimental investigations and field observations. In this way, WL | Delft Hydraulics is able to establish a rich suite of software systems and to continuously improve and expand the embedded process formulations. The resulting suite of Delft software systems may be viewed as a particular means of arriving at electronic knowledge encapsulation which in turn supports the work of both internal users and external clients alike.

Several projects were carried out within the framework of the 2004 R&D programme.

In cooperation with TNO-NITG, a pilot study was conducted to connect WL | Delft Hydraulics’ 1D surface water model system with the groundwater model MODFLOW. A new database server that is sufficiently generic in order to accommodate all existing users and database systems has been incorporated into HYMOS (hydrological information system). The feasibility of input correction using Ensemble Kalman Filtering in rainfall-runoff models was studied.

Various projects to extend and improve SOBEK functionality were performed: modelling of water movement over excessively coarse line objects, SOBEK 1D2D-Functionality was improved on various aspects and the modelling of flow through vegetation also received attention. In addition, a broad spectrum of different functionalities in SOBEK-Rural/Urban and SOBEK-River were implemented. The application of the SOBEK modelling system for compound channels was studied and compared with a data set (Aberdeen experiment). The WL | Delft Hydraulics’ Flood Early Warning environment (FEWS) was expanded with the addition of generic and automated calibration tools. A Message Passing Interface (MPI), an international standard for the communication of data between processes, was integrated into the Open Modelling System (OMS). For Delft3D, a User Interface for the Open Process Library for water quality modelling was developed and Ensemble Kalman Filtering was implemented as part of a generic data assimilation toolbox and applied in a test case.
A data drive approach of sediment transport in vegetated channels was investigated. Water quality modelling to assess eco-engineering measures for the restoration of a shallow eutrophic lake was combined with a cost-benefit analysis to inform decision-makers. 

The applicability of the modelling paradigm of cellular automata (CA) to ecological engineering was investigated. Combined data mining and numerical modelling for hydro-morphological analysis of observed changes of coasts and river banks were also studied. Uncertainty analysis and risk management tools were tested on observed dam break events.

The application of Constraint Logic Programming (CLP) was demonstrated through application to two cases related to flood prevention measures.

- Combined analysis of surface water and groundwater in project areas
- HYMOS 5
- Input correction in rainfall-runoff models using Ensemble Kalman filtering
- SOBEK
- SOBEK 1D2D-Functionality
- Evaluation of physically based and evolutionary data mining approaches for modelling resistance due to vegetation in SOBEK with 1D2D-Functionality
- SOBEK-Rural/Urban
- SOBEK-River
- Modelling compound channels with SOBEK
- Integration of generic automated Calibration Tools in FEWS
- Open Modelling Systems (OMS)
- Delft3D – implementation of new developments
- Application of Ensemble Kalman Filtering in Delft3D-Flow
- Modelling sediment transport rate within submerged vegetated channel – a data-driven approach
- Cellular automata and artificial intelligence in ecohydraulics modelling
- Water quality modelling to assess eco-engineering measures for the restoration of Wuli Lake in China
- Uncertainty analysis and risk management in dam break modelling
- Combined data mining and numerical modelling for hydro-morphological analysis
- Constraint logic programming and flood prevention I
- Constraint logic programming and flood prevention II
Combined analysis of surface water and groundwater in project areas

For certain issues, it is important to simulate surface water flow in a dynamic and detailed way in addition to performing ground water modelling. In cooperation with the Dutch Institute of Applied Geosciences (TNO-NITG), WL | Delft Hydraulics has conducted a pilot study on sequentially connecting the outflow of a MODFLOW-groundwater model to a SOBEK-channel flow model.

Using state-of-the-art techniques, it is possible to derive a very detailed surface water system using GIS-information. This very detailed surface water system has been input in the MODFLOW-model as well as the SOBEK-model, resulting in many connection points between the two models.

We have managed to build the models in this way and to perform simulations (which are numerically stable and have limited computation-time).

In all likelihood, this type of connection of models in a detailed manner will be used in extensively in new projects of engineering offices, water boards, provincial and municipal authorities and drinking water companies.

The detailed SOBEK-model. Each yellow node represents a connection point to the MODFLOW-model.

Cut-out of the SOBEK-model

For further information, please contact either Hans.Hakvoort@wldelft.nl or Toine.Vergroesen@wldelft.nl
HYMOS 5

HYMOS, an information system for water and the environment, is a software package with a very long history. Starting in the mid-1970s, the system has been widely used in the Netherlands and abroad. The system essentially comprises a database for the storage of time series of water-related information, both quantitative and qualitative, and an extensive function library for data analysis.

Notwithstanding the unrivalled performance of the HYMOS proprietary database, the development of a generic database server connecting HYMOS to all ODBC compliant databases was required. The challenge was to design a database server that is sufficiently generic in order to accommodate all existing users and database systems, without sacrificing too much in terms of performance, and to maintain sufficient flexibility in the setup of the data model.

Research initiated in 2003 into the development of database server for large datasets resulted in a database server design that seemed promising. A test implementation for primarily performance testing showed that it was possible to meet performance criteria, and in 2004 the final database server was implemented. Figure 1 illustrates the new structure.

The new database server has been incorporated into HYMOS version 4.5. With this version, current HYMOS users will be much better equipped to meet the requirements of the Water Framework Directive, as this will allow users to combine all water-related information in a single, consistent database. With this version users will also be able to perform combined analyses of qualitative and quantitative parameters.

For further information, please contact either Bob.vanKappel@wldelft.nl or Erik.Ruijgh@wldelft.nl.
Input correction in rainfall-runoff models using Ensemble Kalman Filtering (EnKF)

For the prediction of river floods, WL | Delft Hydraulics uses numerical models, known as Flood Early Warning Systems (FEWS). Rainfall-runoff models (RR-models) are important components in FEWS. RR-models often contain large uncertainties, which are due to model imperfections such as:
- Model errors, for example due to a lack of physical knowledge, or simplifications in the model to avoid high computation time.
- Errors in the input data of the model, i.e. uncertainties in predicted or observed rainfall or evapotranspiration.

Data assimilation is an efficient and often-applied method used to reduce uncertainties in models and thus improve the model’s performance. Data assimilation means that models and observations are integrated in some (optimal) way. The Kalman filter (KF) is a well-known example of a data assimilation technique that is often used in practice. The standard KF was developed for linear dynamic systems. However, in practice most physical systems and models are not linear. In order to apply Kalman filtering to these models, the algorithm must be appropriately adjusted, extended or approximated. The ensemble Kalman filter (EnKF) may be mentioned as one such alternative algorithm. One of the main advantages of the EnKF is that it is a generic method, i.e. it can be applied to virtually any dynamic model in discrete time.

The feasibility of the EnKF for input correction in RR-models was investigated within the scope of this project. The EnKF was applied to several RR-models, varying from very simple approaches to models with a more realistic representation of the physics. The final realistic case dealt with an application of the EnKF to the HYMOD RR-model. A sensitivity analysis was performed by varying the parameters in the model to assess the best statistics for the representation of the uncertainties in the rainfall and evapotranspiration. The results of this research indicate that the EnKF offers a valuable method for input correction in RR-models.

This project was executed in cooperation with Technical University Delft (MSc study).

For further information, please contact Arthur.Mynett@wldelft.nl
SOBEK

In the Overland Flow module, so-called 2D limiters (e.g. the Conservative MinMod limiter and a Dike-height limiter) were implemented in the v2.06 main development version in 2004. Using these 2D limiters, the water movement over excessively coarse schematised vertical line objects (such as dikes, roads, railroads) may be modelled with a much higher degree of accuracy. During the extensive testing programme, some imperfections in the implementation of the 2D limiters were established, which are anticipated to be analysed and fixed in early 2005. In addition, the requirements (e.g. required architecture) for enabling distributed hydrological modelling in SOBEK were studied. Distributed hydrological modelling refers to the interfacing of the Overland Flow module (rectangular 2D gridcells) with, for instance, distributed rainfall-runoff models, evapo-transpiration models, and groundwater models such as MODFLOW. Further work on this topic is projected for 2005.

For further information, please contact either Adri.VERWEY@WLDelft.nl or Edward.MELGER@WLDelft.nl
SOBEK 1D2D-Functionality

In 2004, the 2D Water Quality module (now only available as a special SOBEK development version) was made even more suitable for official release in the near future. An extensive test programme/plan was formulated. In line with this test plan, several tests were performed and imperfections which resulted from these tests were corrected. For the final release of the 2D Water Quality module, some existing features regarding line boundaries as well as the functionality to produce so-called fraction simulations (determination from which part of the catchment particular flow originates) will be incorporated. Additionally, developments occurring within the framework of the OSIRIS project were made available in the SOBEK 1D Water Quality module. Specifically, this involves improved formulations regarding the reaeration of oxygen at weirs and the decay of organic material and ammonia, as incorporated in the TEWOR+ water quality model (effects of sewerage outflows). The findings from the OSIRIS project are now available in the external released SOBEK v2.09 version.

For further information, please contact either Adri.Verwey@wldelft.nl or Edward.Melger@wldelft.nl
Evaluation of physically based and evolutionary data mining approaches for modelling resistance due to vegetation in SOBEK with 1D2D-Functionality

Modelling flow through vegetation is of great practical and scientific importance, especially when one considers the modelling of wetlands and vegetated floodplains, which are essential in wetland restoration and flood risk assessment projects. SOBEK 1D-2D is particularly useful for such modelling, since it combines 1D modelling of rivers and channels with 2D overland flow modelling. However, the resistance caused by vegetation is difficult to model: it is included in the bed friction term through a constant ‘equivalent resistance (or ‘roughness’)’ coefficient which is incapable of representing the resistance at all water depths.

Three different approaches were considered to obtain such coefficients, namely: 1DV model, theory-based formulae and empirical formulae using genetic programming (GP). It was found that the combination of the theory-based formula for un-submerged vegetation and the GP-obtained formula for submerged vegetation has great potential, given its simplicity, ease of use and accuracy, especially when vertically uniform vegetation is considered.

With the implementation of water-depth dependent resistance coefficients, SOBEK 1D-2D acquires some of the benefits of 3D-computation through the relationship between water depth and resistance coefficients, while maintaining the advantages of 2D simulations. In this way, a typical closure coefficient, usually determined by comparison with values that worked well in previous similar situations, is replaced by a theory-based coefficient, which can be directly related to the floodplain vegetation characteristics.

This project was executed in cooperation with UNESCO IHE Delft (MSc study).

For further information, please contact either Vladan.Babovic@wldelft.nl or Arthur.Mynett@wldelft.nl
SOBEK Rural/Urban

In 2004 a broad spectrum of different functionalities were implemented. In Urban Flow it is now possible to import DHI Mouse (SVK19 file format) schematisations into SOBEK. Additionally, it is possible to determine in the schematisation process the amount of water stored in a sewerage system or in parts of the sewerage system. In the Overland Flow module (currently only outside the graphical user interface), it is possible to define the roughness of particular ecotypes as a function of water depth, while these ecotypes may spatially vary over the 2D grid domain. This functionality is of importance in modelling water quality and sedimentation processes in, for instance, lakes, wetlands and flood plain areas. In Urban Flow, different concepts for introducing energy losses in Manholes were implemented. For steep areas (Dutch province of Limburg and abroad), the energy losses in Manholes can be considerable and, therefore, may not be neglected. Further refinement of the concepts is foreseen for 2005. In addition, many recent developments in the v2.06.000.39 main SOBEK development version were made available for the v2.09 SOBEK external version. This means that many functionalities/developments implemented in 2003 and 2004 are now available for commercial SOBEK users.

For further information, please contact either Adri. Verwey@wldelft.nl or Edward.Melger@wldelft.nl
SOBEK-River

Within the framework of SOBEK developments, the 3rd Rural Integration project was carried out in 2004. This project was conducted by assignment of the Joint Venture in place between RIZA (Ministry of Public Works in the Netherlands) and WL | Delft Hydraulics. Specifically, the project concerns the implementation of functionality as available in the SOBEK RE product line into the new SOBEK-Urban/Rural product line. In its totality, the new SOBEK product line has more functionality (Urban Flow, Rainfall Runoff, Real Time Control, Overland Flow, 2D Water Quality etc) than the SOBEK RE product line. In addition it has a much more user-friendly graphical user interface (GUI). The implementation of five new structure descriptions (i.e., River weir, Advance weir, General structure, River pump and Database structure); a compound structure comprising several of the aforementioned structure descriptions; six controllers (i.e., Time controller, Relative-time-controller, Relative-from-value (time) controller, Hydraulic controller, Interval controller and PID controllers); and three triggers (i.e., Time triggers, Hydraulic triggers; and Time & Hydraulic triggers) has more or less been completed. In addition, the implementation of the possibility to control the previously mentioned structures by the Real Time Control Module of SOBEK was initiated, which will tremendously increase the possibilities to control these structures in a user-defined way and is scheduled to be completed in early 2005. Also the implementation of morphology options as available in SOBEK RE was begun, with special attention focused on the graded sediment option. The functionalities mentioned significantly extend the modelling possibilities of the SOBEK-Urban/Rural product line. It is anticipated that once all relevant SOBEK RE functionalities are incorporated into the SOBEK-Urban/Rural product line, the SOBEK RE product line will no longer be supported by WL | Delft Hydraulics.

For further information, please contact either Adri.Verwey@wldelft.nl or Edward.Melger@wldelft.nl
Modelling compound channels with SOBEK

In nature, most river reaches tend to be compound channels as well as meandering. For the management of rivers and floodplains, it is important to understand the behaviour of flows within compound channels. The stage-discharge curve is essential for risk management and flooding damage assessment. This study dealt with the application of the SOBEK modelling system for compound channels. Developed by WL | Delft Hydraulics, SOBEK is an integrated numerical modelling package used to simulate hydrodynamics of one-dimensional river/channel network and two-dimensional overland flow. It is based on the 1D De Saint Venant Equation and the 2D Shallow Water Equations, using an implicit scheme known as the Delft Scheme.

Two different kinds of models were set up in SOBEK to test against the laboratory data of the Aberdeen experiment from Database on Conveyance in River/Floodplain Systems, set up by the University of Glasgow. One is a 1D2D coupling model, in which the main channel consists of a 1D network and the floodplain of a 2D grid. Another one is a full 2D model, in which both the main channel and the floodplain are treated as 2D grids.

Sensitivity analyses were performed on three parameters: the Manning roughness coefficient of the floodplain, the longitudinal slope of the flume, and the sinuosity (meandering) of the main channel, in order to analyse and compare the behaviours of these two models. In general, close agreement between the laboratory data and the SOBEK results were obtained from both the 1D2D coupling model and the full 2D model. The Full 2D model shows a better performance on the overbank section, whereas the 1D2D coupling model shows a better behaviour on the inbank flow. Both models seem to underestimate the effects of longitudinal slope and sinuosity of the main channel.

This project was executed in cooperation with UNESCO IHE Delft (MSc study).

For further information, please contact Arthur.Mynett@wldelft.nl
Integration of generic automated calibration tools in FEWS

In practical case studies, aggregated and/or integrated numerical models are commonly used for the simulation and prediction of hydraulic, hydrological, ecological, etc. processes. These models usually contain one or more application-dependent parameters or coefficients, even in cases where these models are based on sound physical principles. Such uncertain model parameters often represent non-measurable quantities and they must be estimated using calibration, i.e. they are adjusted until the model’s response agrees as closely and consistently as possible with the corresponding observations. Examples of efficient automated and generic calibration techniques which have been developed and applied at Delft Hydraulics in the past include the DUD-method (an efficient derivative-free, though local minimisation method, based on least square criteria) and SCE (Shuffled Complex Evolution; a global minimisation technique for more arbitrary calibration criteria, but at the cost of much more computation time).

In the present project, WL | Delft Hydraulics’ Flood Early Warning environment (FEWS) was expanded with the addition of generic and automated calibration tools. An important issue involved in this development is that these tools must be applicable for virtually any numerical simulation model that is (or will be) linked to the FEWS environment, such as, for example, hydraulic models (SOBEK-Rural, SOBEK-River, Delft3D, ISIS, etc.) and rainfall-runoff models (e.g. HBV-96 and MCMR). Because of its proven skill in the past, the DUD-method was the first calibration method that was made operational within the FEWS-environment. Using dialogue boxes, the user can identify the specific model application and select the model parameters for calibration. In the same flexible way, the calibration run options are set and results are presented. The implementation and performance were successfully tested by means of a calibration of runoff parameters in an MCMR model of the Severn catchment (Midlands, UK), dealing with the prediction of the river flow at Rhos-Y-Pentref. Figure 1 presents the model selection for this calibration. Figure 2 presents the calibration results in terms of the runoff at the control station for the 5th iteration, plus the performance index.

In a second application DUD was applied for the estimation of bed roughness parameters in a hydraulic SOBEK-Rural model included in a model suite for the Tanshui basin in Taiwan.

Figure 1: Dialogue screen for the selection of the specific module and the data that will be used in the evaluation of the iterative calibration process.
Figure 2: Calibration results. Modelled runoff and target runoff at the control station for the 5th iteration, including the present value of the least squares performance index.

For further information, please contact either Albrecht.Weerts@wldelft.nl or Henk.vdBoogaard@wldelft.nl
Open Modelling System (OMS)

The aim of the OMS project is to migrate the current modelling systems SIMONA of Rijkswaterstaat and Delft3D of WL | Delft Hydraulics to a single Dutch Open Modelling System (OMS). Furthermore, this integration must meet the future demands of users with respect to functionality, flexibility, accessibility, modularity and performance.

An important objective of the OMS project is to offer a framework in which programs (or better components) which are used in SIMONA and Delft3D may be combined into a new application. This framework is referred to as the OMS backbone and is a communication software system which may be used for running and coupling software components. In 2004 the emphasis was on the development of an MPI version of the OMS backbone. MPI stands for Message Passing Interface and is an international standard for the communication of data between processes. With this MPI functionality the backbone now supports both “within application (also known as “in memory”)” communication and “between applications” communication.

The new functionality of communication between applications was tested extensively. For example, a WAQUA – SWAN coupling was implemented by using backbone functions. Furthermore, the hydrodynamic (water levels, velocities, turbulence) functionality in Delft3D-FLOW was coupled with the morphology functionality in Delft3D-FLOW via the backbone. The figure below contains an illustration of this coupling.

The OMS backbone is closely related to other projects and activities concerning open modelling systems and software architectures. This involves e.g., HarmonIT and Generic Framework (Water). An integration of the backbone with the OpenMI concept of HarmonIT is projected for 2005.

For further information, please contact either Erik.deGoede@wldelft.nl or Jan.Mooiman@wldelft.nl.
Delft3D – implementation of new developments

New functionalities are continuously being developed for the different modules of the integrated modelling system Delft3D. In 2004 the emphasis was not only on adding new functionality to Delft3D, but also on the improvement of the usability of Delft3D. New functions were made available to all users by implementing research versions into the operational (standard) version of Delft3D.

In 2004 an important issue was the development of a User Interface for the Open Process Library of Delft3D-WAQ. The WAQ processes library is an extensive library with over one hundred substances and over 500 processes that act on these substances. In spite of this, there is a continuous need for further developments, such as for new toxic substances and new ecological processes. Up until now, these new developments were incorporated into new releases of the process library by Delft staff. However, Delft3D-WAQ users would like to expand the library themselves. For example this demand was expressed by many university staff members who would like to allow students to develop their own processes and in this way make a contribution to the knowledge base of the faculty or institute. This so-called “Open Process Library” which was developed in 2004 and will be released in early 2005, offers just such a functionality.

The “Open Process Library” is very similar in appearance to the User Interface of the existing process library. The only difference is that at every level (substance groups, substances, processes, variables and fluxes) an additional button “add/modify” appears which allows the free addition to and/or modification of the existing processes library. In this way, users can define their own subset of substances and processes and can switch per application.

For further information, please contact either Rene.Brocatus@wldelft.nl or Bert.Jagers@wldelft.nl
Application of Ensemble Kalman Filtering in Delft3D-Flow

Numerical models of a water system are always based on assumptions and simplifications that may result in errors in the model predictions. Such errors can be reduced through the calibration of the model to in situ and/or satellite measurements of the system’s state through the integration of models and data. Use of the Ensemble Kalman Filter (EnKF) with recent measurement data in operational forecast situations will significantly improve the success rate of the forecasts. The EnKF is a generic data assimilation method which has the advantage that its algorithm is relatively simple to implement and is also well-suited for highly non-linear models. An EnKF software module was implemented and applied successfully to SOBEK-River hindcasts for a section of the Rhine in 2002/2003 (El Serafy, 2003). In the present work, the EnKF was implemented as part of a generic data assimilation tool box and applied in combination with a Delft3D-Flow model of Osaka Bay. This test case provided more insight into EnKF performance with real-world operational forecasting systems for two and three dimensional flow regimes.

The primary driving force for the circulation in the Osaka Bay is tide, which is mainly diurnal, with spring range on the order of 2 m. In the northeastern section, five rivers discharge into Osaka Bay. Varying wind and river discharges drive the local salinity variations and leads to a locally salinity stratified three-dimensional circulation system. The aim of the application of EnKF is to improve the daily operational forecasts of salinity and current profiles for engineering activities in this stratified basin.

Due to operational constraints, a full EnKF was computationally too demanding, thus a simplification was chosen. This steady state Kalman filter (SSKF) was calibrated for the Osaka Bay model by assimilating hourly salinity and velocity components in two locations and four different vertical levels for the period 13-28 of Feb. 2002. The results of the simplified calibrated filter and its forecasting ability are shown in Figure 1 for the period of 18-20 February, 2002. The performance of the SSKF for improving the salinity and velocity components during the first 24 hours forecast is illustrated. It may be observed that using data assimilation, the model’s predictions are better than those seen in the model without data assimilation, with the update effect disappearing over time. With newer measurements and new forecasts, this forecast window moves with time.

The present results show the practical feasibility of EnKF for data assimilation and are promising for application of EnKF to all sorts of other models used in hydrology and hydraulic engineering, for example water level, wave or run-off forecasting. Due to the simplicity and generic properties of the algorithm, these extensions can be realised with a limited amount of effort.

Co-funding of the present research by Kajima Technical Research Institute in Japan is gratefully acknowledged.
Figure 1: Time series of Measured, Deterministic, KF-hindcast, and KF-forecast of the Salinity, North and East velocity components at Station 3 (1 m below surface water) for the period 16-20 February, 2002.

For further information, please contact either Ghada.Elserafy@wldelft.nl or Herman.Gerritsen@wldelft.nl
Modelling sediment transport rate within submerged vegetated channel – a data-driven approach

Vegetation in floodplains and seasonal channel beds plays an important role in the fate of sediments, acting as a trap as well as reducing the channel’s sediment carrying capacity. While sediment transport in natural channels without any intervention is already a stochastic process, it becomes more non-deterministic in the presence of vegetation in the channel bed. Not much research has been conducted so far into determining the sediment transport rate within vegetated channel flows. On the basis of flume experiments carried out at WL | Delft Hydraulics in the year 2002, this study focused on adding new insight using a data-driven modelling technique.

Previous studies showed that turbulence could effectively pick up sediment as sand bursts. Although bursting is not a new concept in sediment transport, when it comes to flow through vegetation, these bursts seem to have a different source of energy, since it happens before the bed-shear stress exceeds the threshold value for initiation of motion. To trace out the actual mechanism of sand bursts and to quantify whether bursts were dominating the transport volume, the problem was approached by integrating data mining techniques into available theory and recorded data.

When plotted in polar coordinates, the available data showed distinct orientations of the combined force of instantaneous horizontal and vertical velocity components, all pointing towards a particular direction along the entire plant section, most prominently in the immediate vicinity of the plant top layer. The progression of a large amplitude wave (monami) over the submerged plants was seen inducing periodical pumping effects on the bed. Sand bursts are apparently the result of these pumping actions. The existence of coherent structures discovered in this study is not only useful for sediment transport modelling but also will provide new insight into modelling hydrodynamics within vegetation. This project was executed in cooperation with UNESCO IHE Delft (MSc study).

For further information, please contact either Vladan.Babovic@wldelft.nl or Arthur.Mynett@wldelft.nl
Cellular automata and artificial intelligence in ecohydraulics modelling

In order to achieve sustainable solutions for protecting valuable ecosystems, simulation methods and decision support systems are being developed within the framework of Ecohydraulics and Environmental Hydroinformatics. Ecohydraulics is an interdisciplinary subject which couples hydrodynamics and ecodynamics. Research fields cover water quality, environmental flows, eutrophication effects, algal blooms, river / lake restoration and wetlands dynamics. In these fields, WL | Delft Hydraulics is working closely together with UNESCO-IHE and with TUDelft, as well as with Wageningen and Amsterdam University and various research institutes abroad. The special interest in this PhD research was on developing software instruments and tools for modelling eutrophication and aquatic ecosystem dynamics.

The research focused on exploring possible alternative modelling paradigms and simulation techniques, such as the applicability of cellular automata (CA) to ecological modelling. In order to derive the local evolution rules from the often limited data available from in-situ measurements, techniques such as fuzzy logic rule-based systems were explored, combining data with expert knowledge received from biologists and ecologists. Case studies on algal bloom prediction in Taihu Lake, China and along the Dutch coastal waters demonstrated that fuzzy logic can be a useful technique in ecohydraulics modelling, especially if only limited data are available.

The fuzzy logic technique developed within this thesis was integrated into the cellular automata model to formulate ecological rules; the resulting integrated Fuzzy-CA module is then coupled with the hydrodynamic module of Delft3D. The application of the resulting model along the Dutch coastal zone showed promising results. From this, the general conclusion was reached that it seems feasible to integrate numerical techniques with data analysis procedures and knowledge base systems, leading to the creation of practical tools in ecohydraulics modelling.

This project was executed in cooperation with UNESCO IHE Delft (PhD thesis Mr. Chen).

For further information, please contact either Qiuwen.Chen@widelft.nl or Arthur.Mynett@widelft.nl
Water quality modelling to assess eco-engineering measures for the restoration of Wuli Lake in China

Wuli Lake is part of the Taihu Lake in Western China, and may be categorised as a eutrophic lake with excessive nutrient content. The main reasons for this are: 1) the very high domestic waste loads from Wuxi City discharging into the Lake, and 2) the long-term accumulated background concentration of contaminants both in the water and in the sediment.

In order to reconstruct the aquatic eco-system in the Lake, the proposed restorative measures should follow a proper sequence. Obviously, the external contaminants entering the Lake should be reduced both for point and non-point sources. Once the external pollutants are under control, dredging can eliminate the hidden dangers of internal nutrient release from the sediment, which will retard the recovery of the eco-system. Developing the macrophytes vegetation should wait until the sediment has resettled to the bed, otherwise the light limitation would cause the new-planted vegetation to collapse.

Based on data from field monitoring and model simulations, once the external pollutants are controlled and dredging is initiated, the concentrations of the Oxygen group already reach the grade b! of National Standards. In studying ways to achieve the desired water quality standards, modelling is the first choice, because it is generally a rather inexpensive and flexible way of exploring alternative measures to be taken. Delft 3D-WAQ is a very powerful modelling tool for water quality issues in shallow lakes. The graphic post-processing tools can provide the decision-maker with a clear and direct idea of what really happens if measures are taken in the Lake. Combining this information with the cost-benefit analysis, the decision-maker can make the correct choice, i.e. achieving maximum profit at a minimum cost.

This project was executed in cooperation with UNESCO IHE Delft (MSc study).
For further information, please contact either Leo.Postma@wldelft.nl or Arthur.Mynett@wldelft.nl
Uncertainty analysis and risk management in dam break modelling

This research aims at contributing to the understanding and modelling of dam break events, with a specific focus on dam breach analysis and the simulation of dam break flows in the area near the dam, accounting for uncertainty associated with these processes, as well as risk assessment, and the development of early warning systems. Clearly, the construction of dams in rivers can provide considerable benefits such as the supply of drinking and irrigation water as well as the generation of electric power or flood protection; however, the consequences which would result in the event of their failure could be catastrophic. They vary dramatically depending on the extent of the inundation area, the size of the population at risk, and the amount of warning time available.

Predictions of potential flood conditions resulting from the partial or complete failure of a dam are useful for the development of emergency plans, risk assessment, control development of areas potentially prone to flooding, as well as for the estimation of insurance compensation for property. The capabilities of existing computational modelling systems are continuously advancing, while nowadays, data-driven techniques are also becoming available for solving problems which are not yet fully understood.

The accurate prediction of flood wave propagation is fundamental to reliable dam-break simulation. Data taken from some real cases of dam failures shows that the magnitude of sediment transported during dam break floods might reach the same order of magnitude as the volume of water released from the failed dam. That means that sediment transport is one of the issues which should be considered during dam break analysis. However, it is recognised that when sediment transport is included, a different set of equations may be more appropriate and this should be investigated further.

This project was executed in cooperation with UNESCO IHE Delft (PhD thesis Mrs. Zagonjoli).
For further information, please contact Migena.Zagonjolli@wldelft.nl or Arthur.Mynett@wldelft.nl
Combined data mining and numerical modelling for hydro-morphological analysis

Located in the central part of the coastal region of Bangladesh, the Meghna estuary is that body of water through most of the combined flow of the GBM system is discharged into the Bay of Bengal. A complicated interplay between the forces of the river, tide and the waves creates a complex pattern of sediment displacement in the estuary, which causes morphological changes starting from a time frame of just a few hours to years or even to decades. The Bhola, the largest of the islands of Bangladesh, is located in the western part of the estuary and is subjected to numerous problems to which the estuary is also subjected. Among them, bankline shifting is the major issue which has been relevant for quite some time.

Numerical modelling in combination with satellite images can prove to be a strong foundation for exploring the bankline shifting trend as well as the hydro-morphological analysis of rivers and estuaries if the uncertainties are minimised. The objectives of this study were to enhance the knowledge of complex morphological processes and to develop a qualitative relationship between long-term observed and simulated changes around Bhola Island, Bangladesh. Three methods were explored: literature review, planform analysis and numerical modelling.

Six satellite images taken at an interval of about six years and available for the period from 1973 to 2002 were collected from CEGIS and analysed around Bhola Island both with and without the consideration of sedimentary features. The major factors responsible for the morphological changes in the Meghna Estuary were explored using different long-term modelling tools, scale issues and computational methods using the Delft3D-FLOW model. It was found that the uncertainty ranges of the numerically simulated changes are much higher for the model parameters than the effects of upstream water level variations. The large uncertainty ranges could be reduced if more field data were available for calibration and model verification.

This project was executed in cooperation with UNESCO IHE Delft (MSc study).

For further information, please contact Arthur.Mynett@wldelft.nl
Constraint Logic Programming and flood prevention - I

The power of Constraint Logic Programming (CLP) is in its ability to deal with combinatorial complexity. While simulation calculates the effects of measures, CLP generates good sets of measures that comply with the set of constraints and goals set for the problem. CLP and simulation may be considered complementary.

The intention of this application is to support decision-making in flood prevention by deriving appropriate measure sets from targets and goals to be achieved in a system. It generates good combined measure sets from a database of precalculated effects of measures.

Another project description shows the use an alternative CLP approach to design flood prevention measures.

Although the application deals with the consequences of extreme river discharges, the principles of the approach have a much wider scope.

Stacking up measures

Using a simulation model of the Dutch branches of the Rhine River, the effects of hundreds of measures were calculated. Our CLP application uses these calculated effects. Each measure lowers the water level in a part of the river but none of them is individually capable of compensating for the violations of the Maximum Water Levels (MWL, set by law) that occur under extreme discharge conditions. Any solution, therefore, must consist of a combination of measures.

Our CLP application generates sets of measures that together maintain the water levels everywhere under MWL. The heart of this application is the cumulative constraint that ensures that the sum of effects of measures in every section of the river should be greater than or equal to the amount of the violation. As a result, any solution generated is by definition consistent with this constraint. Moreover, the constraint applies “forward-looking” strategies to direct choices from the remaining possible measures, to disable possibilities or to backtrack on choices made previously.

In cooperation with constraint propagation that maintains consistency between constraints and possible values for the variables (this is called a domain), intelligent search strategies select appropriate measures to include in the set. Finding a solution is followed by a new search for a solution with lower costs than the last one. In this way solutions are improved until the given search time is exhausted, or until the optimality of the last solution is proven. The proven optimality message indicates that better solutions can only be found after changing constraints or goals. Of course, an overly strict definition of a problem will generate a message that the problem is not solvable.

Solutions are generated rapidly by the application, especially after improvement of the solver in 2004. For a river branch having 166 sections and 54 possible measures, it takes about 20 seconds (on a 1 GHz processor) to find a first solution, while the third solution appears after about 2.5 minutes. This one is proven optimal. The performance would be improved considerably if more information about the characteristics of the measures and more elaborate constraints on the wishes with respect to the solutions were available.

The software may be applied to other rivers by changing the data set.

For further information, please contact Hans.Goossens@wldelft.nl
Constraint Logic Programming and flood prevention - II

The power of Constraint Logic Programming (CLP) is in its ability to deal with combinatorial complexity. While simulation calculates the effects of measures, CLP generates good sets of measures that comply with the set of constraints and goals set for the problem. CLP and simulation may be considered complementary.

The intention of this application is to support decision-making in flood prevention by deriving appropriate measure sets from targets and goals to be achieved in a system. It generates good combined measure sets from a database of precalculated measures. Although the application deals with the consequences of extreme river discharges, the principles of the approach have a much wider scope.

Designing measures

This application applies a constraint which directly represents the hydrodynamic equation. It guards the relation in a river section between cross sectional area (A), roughness (N) and the head difference (dH) over the sections length. The essence of the application is that any reduction of the freedom in one of these three variables directly propagates to the domains of the other variables. So, limiting the possible values for the dH directly translates into limitations of A and N, and vice versa. The values in the domains are thus always consistent with all posted constraints.

The goal is to find values for A and N that are consistent with water levels within the allowed range. Optimisation is directed towards the smallest excavation volume of the river banks, necessary to enlarge A to the required values. This constraint is used in cooperation with the continuity constraints at the section boundaries. The structure of the model is sketched in figure 1. This constraint network causes very effective propagation of information.

![Figure 1. constraints guarding consistency between water levels, cross sectional areas and roughness in sections in a river.](image)

As a result, the resulting water level is given for every section, as well as values for cross sectional area, excavation depth and roughness. Solutions are generated quickly (10-20 seconds), but there is much freedom in the problem as it is stated here. More information about realistic limits to cross sectional areas, excavation depths, roughnesses, and some global preferences with respect to scattered or adjacent excavations, etc. would improve the efficiency considerably and would also improve the suitability of the obtained solutions.
The approach allows for “playing” with management goals in a problem, almost interactively, while the application takes care of the complexity of the problem by maintaining consistency at all levels, including the global one. Its decision-making support is a welcome complement to the solution testing done with simulation packages.

For further information, please contact Hans.Goossens@wldelft.nl
8 Procedures & financing

The Annual R&D programme 2004 was set up in close collaboration with representatives from the various Dutch ministries involved. The proposed programme was reviewed by the Scientific Advisory Board at WL | Delft Hydraulics and formally approved by the Board of Directors and the Supervisory Board in December 2003.


Based on the annual R&D programme 2004, detailed project plans were formulated and submitted to the Director of Science & Technology at WL | Delft Hydraulics for approval, prior to being started and carried out. The format of these project plans is specified in accordance with the internal management and quality system, based on ISO 9001 procedures frequently audited by Lloyds Registrar Certifying Agency.

Financial contributions to the Annual R&D programme 2004 were provided by the Ministry of Education, Culture and Science (euro 1.2 M), the Ministry of Transport, Public Works and Water Management (euro 3.7 M) and the Ministry of Economic Affairs (euro 1.6 M). Detailed overviews of the financial realisation of all projects involved were reported to the contributing ministries in February and March of 2005.

The present annual report R&D 2004 aims to provide an overview of the content of each project and a contact person who may be approached by those interested in further details.
9 Publications

In order to increase the accessibility of results of the various research and development projects and to further interaction with the international scientific community, the policy of WL | Delft Hydraulics is to stimulate publication as much as possible. These activities range from publication in peer-reviewed scientific journals to contributing to specialised conferences, workshops and seminars. Where appropriate, documents may also be published in popular magazines, scientific newspaper articles or weekly journals.

At present, special emphasis is being placed on making (titles of) research reports, conference contributions and scientific publications directly available via the Internet, which increases accessibility even further. In this section of the annual report a compilation is provided of the publications which resulted from the 2004 R&D programme.

A total of 170 papers were registered; 45 of which were published in or submitted to international scientific journals, 83 were contributions to congresses and symposia, 8 were book contributions, one was a PhD thesis and the remaining 33 were contributions to international and national magazines. Of this total of 170 papers, 28 were produced within the NCR-framework and 44 within the NCK-framework.

For further information on specific publications, please contact the individual authors directly or via e-mail to info@wldelft.nl
For information on the latest publications, please visit our website www.wldelft.nl

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