Deltares

Enabling Delta Life

Safety against flooding

Activity Report 2008-2009

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Keywords
Floods

Summary
This document reports the progress of Delft Cluster project CT04.30 "Safety against flooding" till June 2009.
Fundamental knowledge from the project has resulted in a large number of scientific publications, PhD theses and MSc theses. Work package A1 in particular has resulted in high-profile scientific publications, immediately awarded with high scores on the citation index. Furthermore, the project has provided education and training as scientists and practising engineers to a large group of PhD and MSc students.
Research knowledge from the project has been implemented in models, such as Delft3D, and has enhanced the expertise of staff of Delft Cluster institutes. For instance, Jos Dijkman has been appointed, as the only foreigner, in an American review commission under the National Academy of Engineering and the National Research Council, charged with the review of all post-Katrina studies by the Interagency Performance Evaluation Taskforce.
Applied knowledge from the project has been used and disseminated in various ways. Optical glass fibre cables from work package A1 provided the spinoff of a method to monitor groundwater upwelling at the toe of inner dike slopes. Consultancies (DHV, HKV) now routinely apply morphological models of work package A2 to PKB Room for the River measures. Work package A3 has established the probability of occurrence of super storm surges with greater accuracy by reconstructing storm-surge levels from the last 10,000 years using novel deposit dating methods. Findings from work package B are to be incorporated in guidelines for flood defence design and evaluation, thus affecting the evaluations for the "*Hydraulische Randvoorwaarden*". The system behaviour identified and analyzed in work package C turns out to be so important for the overall safety of dike rings, that it will inevitably lead to the need of adopting a new safety philosophy on a short term. Knowledge from work package A1 has been implemented in the hydrology curriculum of Delft University of Technology. Knowledge from work package A2 has been included in the PAO course on Room for the River.

References
Delft Cluster

Version	Date	Author	Initials	Review	Initials	Approval	Initials
	2009-06-26	Erik Mosselman		Kees Sloff		Annemargreet de Leeuw	AL
		Wim Luxemburg					
		Dimitri Solomatine					
		Cor Zwanenburg					
		Ton Vrouwenvelder					

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Contents

1 Introduction

1.1 Project set-up and work packages

The project set-up has been organised according to the *safety chain* shown in Figure 1:

- sources (work packages A);
- pathways (work package B);
- receptors (work package C).

The *sources* can be equated to the loads on flood defences and the natural phenomena that produce these loads. The *pathways* refer to the flood defences themselves, including the strength of these defences. The consequences of flooding occur at the *receptors*.

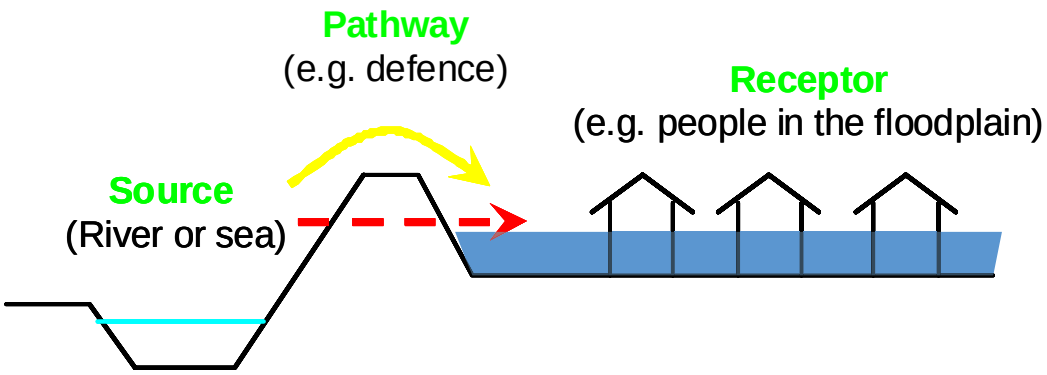


Figure 1-1. Safety chain as underlying structure for the set-up of the project.

The same flood safety chain was used in the European project FLOOD*site*, which was carried out in connection with the Delft Cluster project Safety against Flooding.

The contents of the project have been carefully tuned to the contents of the closely related Rijkswaterstaat projects SBW ("*Sterkte en Belastingen van Waterkeringen*") and VNK ("*Veiligheid Nederland in Kaart*").

The VNK project offers the framework of integration. It investigates the safety of 53 dike rings in the Netherlands. Load and strength statistics are used first to determine the probabilities of failure of individual dike sections. These probabilities are then combined, taking different interdependencies into account, to determine the probability of failure of a complete dike ring. The next step is the definition of relevant flooding scenarios and the corresponding probabilities and effects. This yields the total flooding risk for the dike ring considered. This approach allows identification of the weakest links in the defence system and assessment of the effectiveness of different types of measures. Meaningful application of the VNK framework requires good and validated models for the different threats (*sources*), failure mechanisms (*pathways*) and consequences (*receptors*). Such models are developed by the Delft Cluster project CT04.30 "Safety against flooding".

They deal with threats from rivers (work packages A1, A2 and A3), threats from the sea (work package A3), the resistance of dikes and hydraulic structures against failure (work package B) and the consequences in case of a failure (work package C). In turn, the results from VNK are used for WV21, disaster management, risk maps and the implementation of the European Floods Directive.

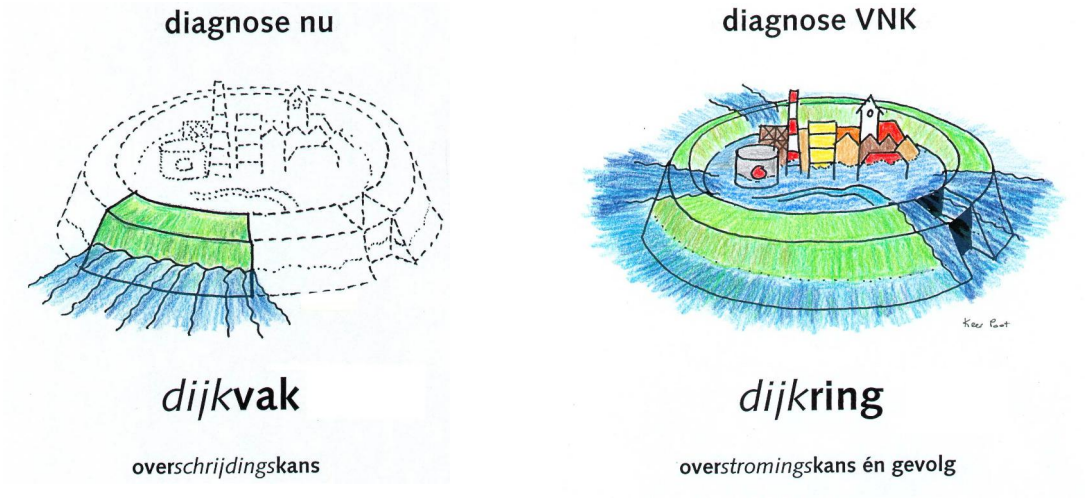


Figure 1-2. Integration framework of VNK project: consideration of the full safety chain (sources, pathways, receptors) and complete dike rings instead of mere dike sections.

Work package C about the consequences of flooding maintains the primary links with the Bsik projects LmW (Leven met Water: Living with Water) and OmO (Omgaan met Overstromingen: Dealing with Flooding). In practice, many more links exist through personal relationships, as key researchers of the Delft research community on the safety against flooding are involved in several projects and meet regularly in different contexts.

Rijkswaterstaat has deliberately selected research questions for the Delft Cluster project that are not on the critical path for ongoing projects. Rijkswaterstaat uses the Delft Cluster project for fundamental and strategic research that will yield products for practical management on a longer term. Hence Rijkswaterstaat does not see delays in product delivery as a problem. The VNK framework allows easy adoption of new knowledge and methodologies from the Delft Cluster project as soon as they are ready for implementation.

Two important features of the project, agreed at the start with all parties involved, are its fundamental and strategic character, implying that no strict specifications and deadlines have been defined for the products to be delivered, and its integration in the framework of VNK, implying that the project itself will not interlink its work packages. Despite the original agreement, however, these two features became a major source of criticism by Delft Cluster's Scientific Advisory Board. This has led to the arrangement that Deltares had to take over the direction of the project from the Delft Cluster Management Bureau.

Table 1-1 shows for each work package the partners involved. A major part of the research is carried out by PhD students. Many of them work across different institutes as these institutes offer office space, facilities and support in the framework of the project.

Table 1-1. Work packages and partners.

Link in chain	Work packages	Partners
Sources	A1: Genesis of floods	Delft University of Technology (lead) UNESCO-IHE Deltares
	A2: River morphology	Deltares (lead) Delft University of Technology UNESCO-IHE TNO Utrecht University (in collaboration with Alterra) University of Twente
	A3: Data driven methods	UNESCO-IHE (lead) Delft University of Technology TNO
Pathways	B: Strength and loads of flood defences	Deltares (lead) Delft University of Technology UNESCO-IHE TNO
Receptors	C: Consequences of flooding	TNO (lead) Delft University of Technology Deltares Alterra

1.2 Valorisation

Fundamental knowledge from the project has resulted in a large number of scientific publications, PhD theses and MSc theses. They are listed in Chapter 7. Work package A1 in particular has resulted in high-profile scientific publications that were immediately awarded with high scores on the citation index. Furthermore, the project has provided education and training as scientists and practising engineers to a large group of PhD and MSc students.

Research knowledge from the project has been implemented in models, such as Delft3D, and has enhanced the expertise of staff of Delft Cluster institutes. For instance, Jos Dijkman has been appointed, as the only non-American, in an American review commission under the National Academy of Engineering and the National Research Council, charged with the review of all post-Katrina studies by the Interagency Performance Evaluation Taskforce.

Applied knowledge from the project has been used and disseminated in various ways. Optical glass fibre cables from work package A1 provided the spinoff of a method to monitor groundwater upwelling at the toe of inner dike slopes. Consultancies (DHV, HKV) now routinely apply morphological models of work package A2 to PKB Room for the River measures. Work package A3 has established the probability of occurrence of super storm surges with greater accuracy by reconstructing storm-surge levels from the last 10,000 years using novel deposit dating methods. Findings from work package B are to be incorporated in guidelines for flood defence design and evaluation, thus affecting the evaluations for the "*Hydraulische Randvoorwaarden*". The system behaviour identified and analyzed in work package C turns out to be so important for the overall safety of dike rings, that it will inevitably lead to the need of adopting a new safety philosophy on a short term. Knowledge from work package A1 has been implemented in the hydrology curriculum of Delft University of Technology. Knowledge from work package A2 has been included in the PAO course on Room for the River.

The project actually results in a myriad of products for national and international audiences, ranging from fellow scientists to practitioners and the general public. It has been decided that these products will not be displayed in a summarising final Delft Cluster report, but that the highlights will be presented in a non-specialist article and a general booklet.

The ***non-specialist article*** will be about four pages long. Journalist Peter Juijn will write this article on the basis of the present activity report, end-user interviews and the general booklet described below.

The ***general booklet*** will present the full range of expertise at Deltares regarding safety against flooding. It will hence be broader than a mere presentation of the findings from the Delft Cluster project. It will be issued in September 2009, containing about 20 to 30 pages. The following highlights of Deltares expertise and achievements will be included:

- Safety philosophies, with the recent shift from design hydrodynamic conditions at dike sections to risk assessments for dike rings (VNK) as well as the future shift to including river system behaviour (work package C of the present project);
- Flood forecasting, with the Flood Early Warning System developed for the Environment Agency in the UK and the successful prediction of a rare sea flood in Jakarta;
- Reconstruction of storm-surge levels from the last 10,000 years using novel deposit dating methods in order to determine the probability of occurrence of super storm surges with greater accuracy (work package A3 of the present project);
- River morphology and its importance for the safety against flooding (work package A2 of the present project);
- Systematic periodic verification of safety against flooding, with lines for future improvement;
- Strength and failure mechanisms of dikes (work package B of the present project, IJkdijk, wave overtopping simulator);
- The dike inspection game as a successful application of serious gaming;
- New insights on dune erosion during storm surges, including experimental research;
- The Maeslant storm surge barrier, for which Deltares carried out the physical model studies, adapted the design to suppress vibrations due to hydrodynamic action and developed the software for its operation;
- Flood protection strategy optimisation on the basis of multiple cost-benefit analyses for different strategies and scenarios;
- Inundation modelling and evacuation;
- The Planning Kit for te selection of Room-for-the-River measures;
- Involvement in post-Katrina studies for New Orleans (work package C of the present project).

1.3 PhD students

One of the guiding principles of the project is that PhD research is the main vehicle for innovation and major steps forward. About 50% of the original project budget is used for this. Other activities within the project are centred around the PhD research. Table 1-1 lists the PhD students in the project.

Table 1-1. PhD students in Delft Cluster project CT04.30 "Safety against flooding"

WP	PhD student	Topic
A1	A.M.J. Gerrits	The role of interception in the hydrological cycle
	M.C. Westhoff	High-resolution temperature sensing in hydrology using fibre optic technology
	G.P. Zhang	Improved catchment modelling with interception and subsurface storm flow
	F. Fenicia	Parameterisation techniques for improved hydrological modelling in mesoscale catchments
A2	M. Abdu Nabi	Subaqueous dunes using detailed hydrodynamics
	A.P. Tuijnder	Roughness and bedforms under partial mobility conditions
	N. Hobo	The sedimentary dynamics of embanked floodplains
A3	G.A. Corzo Perez	Hybrid data-driven and conceptual models in operational hydrological forecasting
	M. Siek	Predicting sea levels and surges in the coastal zone
	M. Nejad M. V. Cong	Multivariate, extreme-value and bayesian statistical models in flood risk analysis
B	B. Stalenberg	Urban riverfronts: flood protection and more
C	B. Jonkman	Model for estimating casualties in floods

1.4 Internationalisation

The scientific conferences attended and the peer-reviewed publications listed in Chapter 7 have a clear international dimension, but are at the same time a trivial form of internationalisation. This section provides examples of internationalisation beyond the context of scientific conferences and journals:

- *United States of America:* One of the PhD students within the project, Bas Jonkman, collected data on the consequences of flooding in New Orleans immediately after the occurrence of the Katrina disaster. His data are now a valuable source of information that is also used by other researchers within the project. The previous leader of the project, Jos Dijkman, is the only foreigner in an American review commission under the National Academy of Engineering and the National Research Council, charged with the review of all post-Katrina studies by the Interagency Performance Evaluation Taskforce. In this capacity, he has first-hand access to all major academic and engineering studies currently undertaken in the USA. The work package C reseach team remains involved in post-Katrina analyses;
- *Japan:* River morphologists of work package A2 participate in the Japan-Delft Research Co-operation on River Hydrodynamics and River Morphology. The last workshop in this framework was held in Delft on September 24, 2007. One of the PhD students within the Delft Cluster project, Mohamed Nabi, carried out part of his research in this framework at Hokkaido University in Sapporo;
- *Europe:* Deltares, Delft University of Technology and UNESCO-IHE participated in FLOOD*site*, which was the largest ever European Commission (EC) research action on flood risk management, with an EC "grant to the budget" of nearly ten million euro. FLOOD*site* delivered key knowledge and instruments for the new EU Flood Directive for the reduction of flood-related risks to human health, the environment and economic activity. Deltares was one of the leading partners, along with HR Wallingford. Researchers of the Delft Cluster project were involved in FLOOD*site* as well. Interactions between project partners provided lots of knowledge on flooding risk research and management in other countries of the European Union;

- *France:* Deltares researchers of work package B collaborate with geotechnical researchers of Cemagref and other institutes in France. The research of this co-operation regards piping and the stability of flood defences;
- *France:* The project leader, Erik Mosselman, lectured on urban flooding risks at a post-graduate summer school of the Ecole des Ingénieurs de la Ville de Paris ("Le risque d'inondation en milieu urbain: construction durable et exemples du Rhine et du Rhône", Université d'été: La ville durable; urgences et utopies, Ecole des Ingénieurs de la Ville de Paris, 25 August 2008, Paris, France);
- *France:* The project leader, Erik Mosselman, presented climate change adaptation in the Netherlands (including the Commission Veerman recommendations) to an audience of French Members of Parliament, mayors and flooding risk professionals ("Les changements climatiques dans la gestion hydraulique aux Pays-Bas", Invited presentation, Assemblée générale de l'AFPCN, Assemblée Nationale (Palais Bourbon), Paris, France, 9 June 2009);

Figure 1-3. Internationalisation: Invited presentation of climate change adaptation in the Netherlands (including Veerman) to French Members of Parliament, mayors and flooding risk professionals in Assemblée Nationale, Paris.

- *Germany:* One of the PhD students within work package A2, Arjan Tuijnder, has carried out laboratory experiments at the Leichtweiss Institute in Braunschweig, exchanging knowledge with the local research group;
- *Luxembourg:* Researchers of work package A1 carry out field measurements in the Alzette catchment and co-operate with the Centre de Recherche Publique Gabriel Lippman;
- *Italy:* The project leader, Erik Mosselman, discussed Room-for-the-River flood mitigation measures in the Netherlands and Italy with a delegation from the Po River Basin Authority (Messrs Piero Tabellini and Andrea Colombo, 23 August, 2007);
- *UK:* Work package C is involved in research on time-dependent reliability and risk estimation procedures at University of Newcastle upon Tyne and HR Wallingford;

- *Various countries:* PhD student Bianca Stalenberg compared urban strategies of dealing with floods in Tokyo (Japan), Dhaka (Bangladesh), Venice (Italy), Germany and the Netherlands through field visits in co-operation with local experts;
- *Various countries:* Routine international exchange of information takes place through involvement of foreign MSc and PhD students of UNESCO-IHE;
- *Various countries:* Routine international exchange of information takes also place by providing technical support and specialist advice abroad, mainly in projects of Deltares.

1.5 Finance

Financial aspects of the project are reported in separate documents. Substantial budget reductions were imposed during execution of the project. This has resulted in the need to cancel certain project components, as well as in severe financial losses for the participating partners.

2 Work package A1: Genesis of floods

2.1 Objectives and Content

The research question reads: *Can an improvement in discharge prediction modelling be achieved by hydrological concepts that focus on describing the non-linear threshold behaviour of the heterogeneous sub-surface in hillslope regions?*

The aim is to reduce the uncertainty in flood forecasting.

Methodology:

A. Detailed study and quantification of relevant processes that require improvement in modelling;
B. Incorporation of relevant processes in models;
C. Optimisation techniques for parameter estimation in modelling;
D. Upscaling to medium-sized catchments.

End products:

- Improved knowledge on hydrological processes;
- Concepts describing the non-linear threshold behaviour of the heterogeneous sub-surface in hillslope regions;
- Assessment of capabilities of existing hydrological models;
- Tools for operational flood forecasting;
- Tools for assessment and planning of changes;
- Integration of knowledge into university curricula;
- Involvement of young scientists through MSc and PhD work;
- Publications in international peer-reviewed journals and conference contributions.

Table 2-1 shows names, topics and periods of engagement for the PhD students involved in the project.

Table 2-1. PhD students in work package A1.

Category	Topics	PhD student	Delft Cluster time	Start date	End date
Hillslope processes	Evaporation and interception	Gerrits	0.5	Jun 2005	Dec 2008
	Flowpaths, tracers, residence times	Westhoff	1	Dec 2006	Dec 2008
Rainfall-runoff model development and upscaling	REWASH modules	Zhang	1	Apr 2006	Oct 2006
			-	Oct 2006	-
	REWASH, HBV, Alzette	Fenicia	-	-	Oct 2007

2.2 Activities and results achieved in December 2007 – June 2009-06-26

The PhD students Gerrits (PhD due 2009) and Westhoff (PhD due 2010) worked on hydrological hillslope processes. Gerrits demonstrated and quantified the importance of interception in hydrological processes under different climatological conditions and for different vegetation. She applied direct measurements, indirect measurements through tracers and the energy balance. Westhoff developed methods to determine and quantify the hillslope processes. The completely new method of distributed temperature sensing (DTS) using an optical glass fiber cable was extensively explored. As a spinoff of this research, DTS has found several other applications in detecting temperature anomalies in land and water systems (e.g. groundwater seepage in polders, landslide studies, illicit connections in sewage systems). Potential applications include the possibility of monitoring groundwater upwelling at the toe of inner dike slopes, thus providing another link to the safety against flooding. The remainder of Westhoff's work concerns field experiments and further detailing of subsurface runoff. The question as to "How water starts to get going" in the subsurface appears to be a key issue. This is referred to as the issue of connectivity. It is affected by both threshold behaviour and preferential flows in the subsurface at hillslopes. This links to issues of old water responding to rain events measurable from observing tracers (e.g. O^{18}), giving average resident times of several years rather than days.

The PhD students Zang (PhD completed 2007) and Fenicia (PhD completed 2008) worked on rainfall-runoff model development and upscaling. Their development of various model structures was motivated by the recognition that different processes play different key roles in different catchments and sub-catchments. This has eventually resulted in the FLEX model by which, first of all, the relevant hydrological structure of a catchment is determined through parameter identification. The procedure has been applied extensively to three Rhine small-scale sub-catchments, comparing its performance with HBV modelling. Hydrologists at Deltares recognized the advantages of the procedure. Delft University of Technology will take initiatives in the future to continue with the FLEX model approach, extending the scales and making the codes publicly available. Fenicia and Adveeka (temporary researcher DUT) have demonstrated, in a FLEX like approach, that inclusion of historic forestry development can considerably improve the runoff modeling for the Meuse catchment at Borgharen.

Work package A1 has been particularly successful in producing high-profile scientific publications that were immediately awarded with high scores on the citation index.

The work package has provided education and training as scientists and practising engineers to a large group of PhD and MSc students. Results and conclusions from the work package have been incorporated in the following courses of the Water Management course programme at Delft University of Technology: Hydrological modelling (CT4431) and Hydrological measurements (CT4440).

The following instruments have been installed for continued field experiments and monitoring:

- New equipment in the Huewelerbach catchment to make an energy balance model of the forest floor (operational since May 2008);
- Two new forest floor interception devices in Harare, Zimbabwe (operational since November 2007);
- Fourteen piezometers and sixteen in-situ logging temperature devices in the Maisbich experimental catchment.

A flood wave experiment has been executed in the Maisbich experimental catchment. A hillslope sprinkling experiment has been planned in the course of 2009.

Presentations in the period December 2007 – June 2009 were delivered at the EGU 2008 conference in Vienna, Austria, at the Hydropredict 2008 conference in Prague, Chech Republic, at the ERB conference in Cracow, Poland, at the NCR Days in Dalfsen, the Netherlands, and at the AGU Fall Meeting in San Francisco, USA.

3 Work package A2: River morphology

3.1 Objectives and content

Realising that erosion and sedimentation are key elements in the safety against flooding, the work package River Morphology has the following objectives:

1. To improve knowledge and prediction of the morphological behaviour of river bifurcations, because this morphological behaviour affects the design water levels (MHW) along the Dutch Rhine branches and because this morphological behaviour will be affected by measures to increase the safety against flooding. Details of sediment transport processes and bed-form development in the case of sediment mixtures are of critical importance for this behaviour.
2. To improve knowledge and prediction of morphological processes during floods, because they affect the conveyance capacity and the hydraulic resistance, and hence the flood water levels under design conditions (MHW).
3. To improve knowledge and prediction of interactions between Room-for-the-River measures in the floodplains (lowering, dike set-back, nature development, secondary channels) and sediment transport, erosion and deposition, because Room-for-the-River measures induce a combined response of vegetation growth and morphological evolution in the floodplains that affects the durability and sustainability of the measures. Detailed knowledge on these processes allows optimisation of maintenance strategies (cyclic rejuvenation).

After closure of the Delft Cluster project, Rijkswaterstaat will continue research on river morphology for safety against flooding within the SBW project.

The partners in the work package carry out the following activities:

Deltares:

- Co-ordination of Delft Cluster work package on river morphology (originally WL | Delft Hydraulics);
- Guidance, support and temporary working space with computer infrastructure for university researchers (originally both WL | Delft Hydraulics and TNO-NITG);
- Implementation of newly developed knowledge in operational numerical models (originally WL | Delft Hydraulics).

Delft University of Technology:

- Physics-based modelling of ripples and dunes, focusing on detailed hydrodynamics and sediment transport submodels that account for lag effects and turbulent fluctuations (PhD Mohamed Abdu Nabi).

UNESCO-IHE Institute for Water Education:

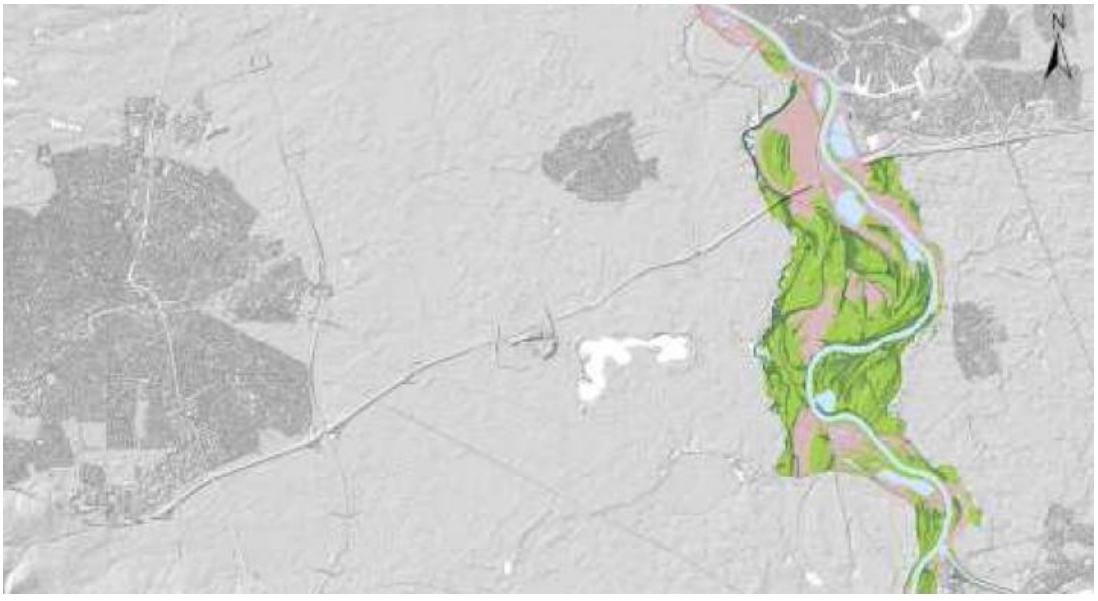
- Relation between bankfull discharge, floodplain sedimentation and bank erosion (MSc A.T. Urquieta Quiroga);
- Modelling the effects of riparian and floodplain vegetation on river patterns and flow dynamics (MSc May Samir Saleh);
- Modelling the influence of vegetation cover on floodplain sedimentation rates (MSc Alejandro Montes Arboleda);
- Modelling the morphological and flow patterns long-term response induced by the implementation of the Pilot Project Meers (Common Meuse River), including the growth of different vegetation on the floodplain (MSc Jairo Alberto Villada Arroyave);
- Modelling the morphological aspects of cyclic rejuvenation of the Ewijkse Plaat along the Waal River in the Netherlands (MSc Elena Facchini).

University of Twente:

- Laboratory experiments on bedforms, roughness and sediment transport in the case of widely graded sediment mixtures and partial transport. The research particularly focuses on conditions with finer sediments being transported over immobile coarse layers (armour layers) and supply-limited bedforms (PhD Arjan Tuijnder);
- Theoretical analyses of elementary morphodynamics of rivers with sediment mixtures using various concepts for sediment transport, vertical sediment exchange and sorting, to assess the validity range and the robustness of numerical models (postdoc).

University of Utrecht in co-operation with Alterra:

- Floodplain sedimentation on decadal scale, for planning of re-landscaping and cyclic rejuvenation of floodplains as well as for sediment mining (brick) industry (PhD Noortje Hobo).



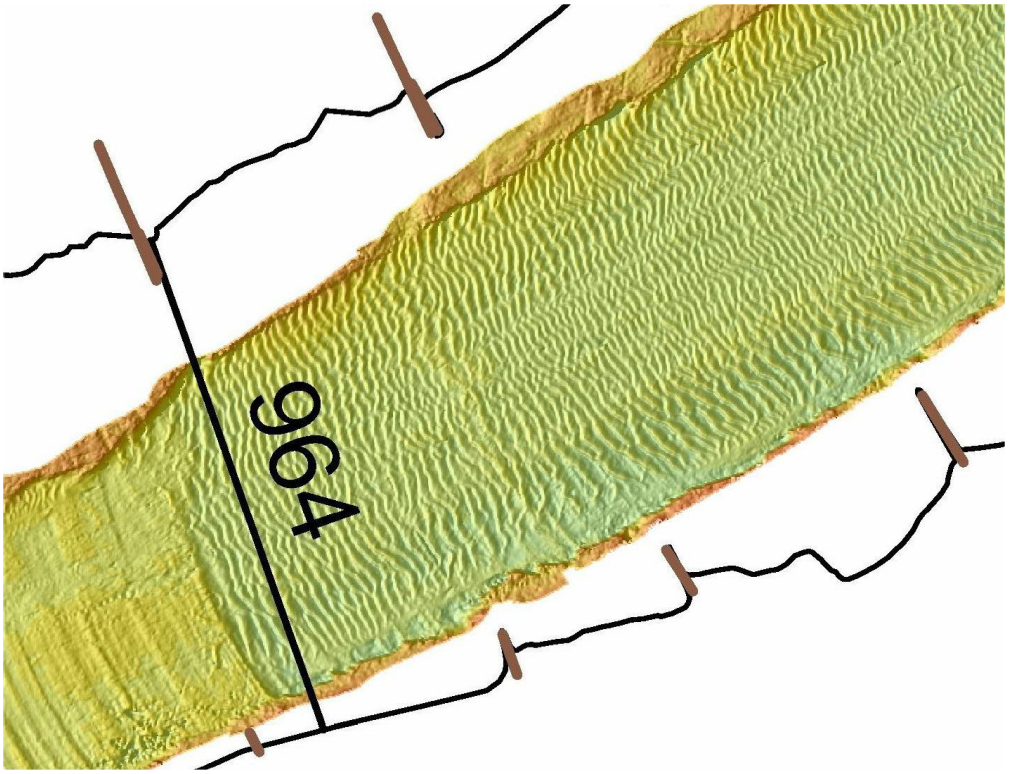
3.2 Activities and results achieved in December 2007 – June 2009-06-26

Activities by Deltares had to be scaled down drastically as a result of the severe budget cuts imposed on the project. Activities planned for 2008 and 2009 have been transferred to the strategic research programme of Deltares as much as possible. Nonetheless, PhD research at the universities of Delft, Utrecht and Twente as well as MSc research at UNESCO-IHE could be continued.

The operationalisation of 2D morphological models, partly developed under work package A2, has proven to be successful. Consultancies (DHV, HKV) now routinely apply these morphological models to PKB Room-for-the-River measures. Knowledge from work package A2 has been included in the PAO course on Room for the River.

The ***research for river bifurcations*** focused on sediment transport processes and bedform development in the case of sediment mixtures. PhD student Arjan Tuijnder studied the transport of widely graded sediment over coarse armour layers and supply-limited bedforms, i.e. at conditions in the Upper IJssel river at the IJsselkop bifurcation. He carried out laboratory experiments at the Leichtweiss Institute in Braunschweig and he tested new model concepts for supply-limited sediment dynamics and bed roughess in Delft3D at Deltares in Delft. His research revealed important feedbacks from supply-limited roughness to the modelling of sediment transport over armour layers.

The ***research for morphological processes during floods*** focused on the growth and the deformation of subaqueous dunes. PhD student Mohamed Abdu Nabi developed an advanced three-dimensional model based on finite volumes, large-eddy simulation, an isotropic unstructured cartesian grid with adaptive local refining, a ghost-cell immersed-boundary technique for cells intersecting with the immersed boundaries and motion of spherical sediment particles. The final objective is to formulate simplified physics-based submodels for dune development for use in operational flood forecasting models as well as for use in the WAQUA models for periodic verification of the MHW design conditions along the Dutch Rhine and Meuse branches. Mohamed Abdu Nabi carried out part of his research at Hokkaido University in Sapporo.



The ***research for floodplain development in response to Room-for-the-River measures*** focused on the interactions between engineering, vegetation growth, water flow and sedimentation. PhD student Noortje Hobo applied the method of optically stimulated luminiscence to determine the time of deposition of floodplain sediments along the river Waal. This allowed a comparison between sedimentation rates before and after the construction of river dikes. MSc students at UNESCO-IHE carried out case studies of the rivers Waal and Grensmaas. They used Delft3D to analyse the complex interactions between vegetation growth, water flow and sedimentation. Samir Saleh's & Crosato's (2008) article on the effects of riparian and floodplain vegetation on river patterns and flow dynamics, presented at the Fourth ECRR International Conference on River Restoration, was selected for translation into Russian by RosNIIVKh (Russian Research Institute for Integrated Water Management and Protection).

4 Work package A3: Data-driven, statistical and hybrid modelling in flood forecasting and quantification of uncertainly

4.1 Objectives and content

Physics-based hydraulic and hydrological models traditionally play the main role in flood forecasting and assessments of flood-induced risks. Developments in recent years have shown, however, that data-driven models can complement and enhance the physics-based approaches. These data-driven models include various statistical approaches, neural networks, machine learning, fuzzy systems and chaos theory. Moreover, these models allow for quantification of the uncertainty of predictions. Work package A3 deals with further improvement and testing of a number of data-driven approaches. It consists of four subpackages:

- A3-1: Data-driven methods in river flood forecasting.
- A3-2: Predicting sea water levels and surges.
- A3-3: Methods of multi-variate statistics, extreme-values analysis and Bayesian statistics.
- A3-4: Improving probability analyses of 1:10,000-yr storm-surge levels and wave characteristics using novel methods of dating deposits.

The objectives of subpackage A3-1 on data-driven methods in river flood forecasting are:

- To develop hybrid hydrological and data-driven models that can be incorporated in the flood forecasting system used for the Meuse;
- To develop an hourly data-driven model that can improve the switch between the time scales of two IHMS-HBV models;
- To analyse the applicability and physical representation of hybrid and committee models in flow forecasting;
- To ensemble the information from different weather stations using recent data-driven techniques.

The objectives of subpackage A3-2 on predicting sea water levels and surges are:

- To develop the framework “voting model” or ensemble model for combining the surge forecasts of various European North Sea models from the Netherlands, Denmark, UK, Germany and possibly other countries. The approach to be developed will focus on using the best features of these forecasts coming at an almost-real-time rate. Expert judgements will be combined with the data-driven approach used in the committee learning machines (“boosting”, mixtures of specialized models), information theory, Bayesian-based model averaging, chaotic models and instance-based learning;
- To further develop the methods of nonlinear dynamics and chaos theory aimed at surge predictions. This development aims at improving the accuracy of short- and medium-term flood forecasting. The subpackage will focus on a number of open issues, allowing for the following:
    - including the forecasted series of the meteorological variables (along with the observed ones) into the non-linear models;

  - improving methods of multivariate chaos in case of highly variable data (especially important for flood and surge forecasts);
  - giving uncertainty estimates of the water level predictions;
  - linking chaos theory tools to the predictions of the Dutch Continental Shelf Model, which will lead to a hybrid model that could considerably improve surge and water level predictions;
- To develop the uncertainty prediction model with focus on the uncertainty of ensemble models. This model will predict the uncertainty (accuracy) of predictions made by various hydrodynamic models of the North Sea. Statistical, fuzzy and data-driven approaches will be combined. The focus will be on developing a data-driven model (neural network or other machine learning methods) that would be able to predict the upper and lower confidence intervals of the hydrodynamic model predictions. This part has close links with the EU FLOODsite project.

Subpackage A3-3 on methods of multi-variate statistics, extreme-values analysis and Bayesian statistics has the following objectives:

- To develop improved methods for quantile estimation when data availability is scarce;
- To investigate the propagation of uncertainties in estimations for the design of civil engineering structures (such as flood defences) when finite-element models (in particular for geotechnical modelling) are needed.

Subpackage A3-4 deals with improving probability analyses of 1:10,000-yr storm-surge levels and waves characteristics using novel methods of dating deposits. It aims at the reconstruction of storm-surge levels and wave-height – wave-period combinations that occurred during extreme storm events in the Holocene history of the Netherlands. The reconstructed data will significantly improve the historical record of extreme events which goes back about one century. In the dunes of North-Holland, extreme storm-surge deposits occur up to 7 m above mean sea level. These deposits can be dated (using optically-stimulated luminescence; OSL) and added to the existing data series used in extrapolation. A similar approach can be applied for reconstruction of wave-height – wave-period combinations during extreme storms. These data can be obtained from the Oyster Grounds, North of the Wadden Islands, at water depths of 35 m and more. The objectives of this subpackage are:

- To expand historical observations on storm-surge levels with information from deposits of extreme storms, which are more extreme but less frequent than historical observations;
- To improve spatial and temporal scales, in order to improve predictions of frequency and elevation of extreme storm surges;
- To calculate wave-height – wave-period combinations of extreme storm waves, in order to improve design criteria for sea defences.

4.2 Activities and results achieved in December 2007 – June 2009-06-26

Subpackage A3-1 deals with data-driven methods in river flood forecasting. Artificial neural networks and other methods of computational intelligence were optimally combined with the HBV hydrological model and a SOBEK hydrodnamical model to predict floods on the rivers Meuse and Rhine. This improved the accuracy of the predictions.

Subpackage A3-2 deals with the prediction of sea water levels and surges. The accuracy of model-based predictions of ocean surges was improved by a novel approach to forecasting based on (a) chaos theory and non-linear dynamics, (b) forecasts from various physics-based North Sea models, and (c) novel methods of uncertainty analysis of these model predictions (UNEEC approach).

Subpackage A3-3 deals with methods of multi-variate statistics, extreme-values analysis and Bayesian statistics. A probabilistic assessment of the 17th Street flood wall of New Orleans was performed, leading to a more accurate method for assessment of flood defense systems. Furthermore an overview was prepared of statistical methods to determine the extreme values of river and sea related variables. In-depth study was dedicated to methods to predict the occurrence probabilities of extreme waves, surges along coastlines, extreme river discharges and corresponding water levels as well as to carry out a correlation analysis of the related variables. The methods were critically reviewed, improved at some parts, applied to existing datasets and compared.

Subpackage A3-4 deals with improving probability analyses of 1:10,000-yr storm-surge levels and waves characteristics using novel methods of dating deposits. A storm-surge layer preserved about 7 m above NAP in the dunes near Bergen was analysed using optical dating on the basis of optically stimulated luminescence, a new dating method that allows geologists to determine the time of sand layer deposition. This allowed the determination of the age of storm deposits with an accuracy of, probably, better than 10%. The calculated age was coupled with the measured elevation of the storm layer, thus forming a vital data point in the existing, historically measured time-elevation series. This approach is seen as a breakthrough in storm-surge research, opening doors in the global analysis of ancient surge levels and thus providing excellent visibility of Delft Cluster in the international research community. A similar approach will be applied for reconstruction of wave height and wave period combinations during extreme storms.

The successful reconstruction of storm-surge levels from the last 10,000 years received abundant media attention:

Newspapers:

- Een vergeten storm onder het duin. Volkskrant, Wetenschapsbijlage, 5 January 2008;
- Rode stenen herinnering kerstvloed. Noordhollands Dagblad, 10 January 2008;
- Duinenrij geeft superstorm prijs. All regional HDC Media and De Stentor newspapers, 10 January 2008;
- Oude vloedgolf geeft nieuwe informatie. Delta, 10 January 2008;
- De duinen geven een eeuwenoude superstorm prijs. BN De Stem, 21 January 2008;
- 'Heemskerkse superstorm' dateert uit 18de eeuw. Noordhollands Dagblad, 18 September 2008;

- Television:
  - Storm onthult superstorm. VARA Nieuwslicht, 2 January 2008;
  - Superstorm. Regio22 Televisie, 2 februari 2008;
  - Aflevering 1: Noord-Holland en Zuid-Holland. NCRV NL onder Water, 23 September 2008;
- Radio:
  - Various interviews with researchers broadcasted on regional and national radio.

Presentations were delivered at the following conferences and workshops:

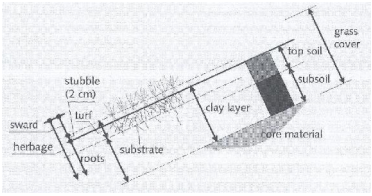
- 32nd Congress of the International Association of Hydraulic Engineering and Research in Venice, Italy;
- 8th Int. Conference on Hydroinformatics in Concepcion, Chile;
- 7th International Conference on Hydroinformatics in Nice, France;
- Coastal Structures 2007 International Conference in Venice, Italy;
- 5th International Probabilistic Workshop in Ghent, Belgium;
- 5th International Symposium on Environmental Hydraulics in Tempe, Arizona, USA;
- Joint ESREL 2008 and 17th SRA-Europe Conference at the Universidad Politécnica de Valencia, Spain;
- European Conference on Flood Risk Management, Research into Practice, FLOODrisk 2008, in Oxford, UK;
- 6th International Probabilistic Workshop in Darmstadt, Germany;
- Several European Geosciences Union (EGU) Assemblies in Vienna, Austria.

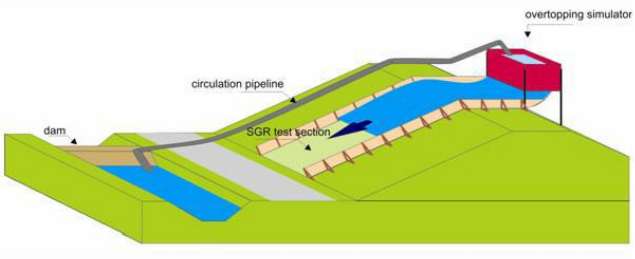
5 Work package B: Strength and loads of flood defences

5.1 Objectives and content

The objective of work package B is to obtain more insight in the actual probability of failure of defences and subsequent flooding. This insight requires knowledge on the development of loads and load effects, knowledge on the strength of defences and hydraulic structures, and knowledge on the reliability of procedures in alarm and emergency situations.

For practical reasons, the work package has been divided into subpackages on sea defences, river dikes and hydraulic structures.





5.2 Activities and results achieved in December 2007 – June 2009-06-26

The findings from work package B are to be incorporated in guidelines for flood defence design and evaluation, thus affecting the evaluations for the "*Hydraulische Randvoorwaarden*".

All results date from before December 2007. The work package has been terminated prematurely due to the severe cuts in the budget of the project. Activities planned for 2008 and 2009 have been transferred to the SBW programme as much as possible.

6 Work package C: Consequences of flooding

6.1 Objectives and content

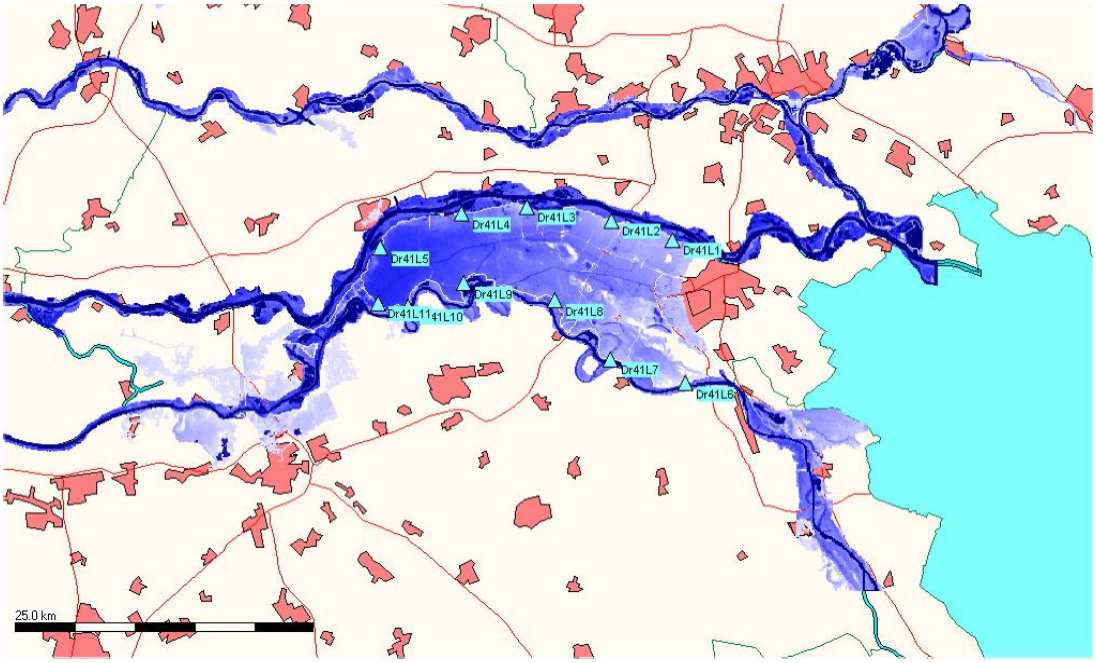
The objective of work package C is to contribute to the development of an integrated and transparent framework for multi risk-based decision-supporting for the control and mitigation of flood risks in the coastal zone and along estuaries and rivers in the Netherlands.

More in particular, the objective is to gain knowledge and insight in the following subjects:

1. **System behaviour of dike rings**, i.e. the response of a complete system of dike rings to an imminent flood (taking mutual dependence between the protection levels of dike rings into account);
2. **Consequences of floods**, in order to evaluate measures which might make areas less vulnerable to floods on their economical effectiveness. Information on the effects of the Katrina hurricane in New Orleans plays an important role in this subject.

6.2 Activities and results achieved in December 2007 – June 2009-06-26

The work on the system behaviour of dike rings has been completed and turned out to be so important for the overall safety of dike rings, that it will inevitably lead to the need of adopting a new safety philosophy on a short term. The work on the consequences of floods, however, had to be terminated due to the severe budget cuts imposed on the project. As a result, the component of consequences of floods produced only the preparatory outputs from the period before December 2007.



The last activities on the system behaviour of dike rings concerned the calculation scheme and the application to a realistic case study. The existing calculation scheme for estimating flood risk for a set of dike rings was elaborated further. The scheme co-ordinates the inundation probability calculations in PC-Ring (as used in the VNK project) and the calculations of hydrodynamic responses to dike breaches in Sobek. The dike breach locations were drawn randomly in monte carlo simulations. The required computation power was obtained by organising a computer network and by making the calculation scheme suitable for parallel computing. This allowed execution of the time-consuming monte carlo simulations within an acceptable time frame. The network was tested satisfactorily. The application to a realistic case concerned rivers and dike rings in the eastern part of The Netherlands, comprising dike ring 41 and surrounding dike rings. The hydraulic properties of this area were implemented in Sobek. Appropriate descriptions of different geo-technical failure mechanisms were developed, taking time dependence into account. This time dependence was found to play an important role in system behaviour.

7 Publications

7.1 Internationalisation beyong scientific community

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7.2 Work package A1: Genesis of floods

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