Proceedings NCR-days 2002
Current themes in Dutch river research

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NCR

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Preface

The Netherlands Centre for River Studies (NCR) aims to provide an open platform for all people interested in scientific research and communication on river issues. To that end NCR organises once a year the so-called NCR-days, where on two consecutive days scientists present their ongoing river studies, in order to maximise the exchange of ideas and experiences between the participants and to provide the researchers a sounding board for their study approach and preliminary results. Based on these contacts they can improve their approach and possibly establish additional co-operation.

The NCR-days 2000 and 2001 were held in Soesterberg (Kontakt der Kontinenten) and Wageningen (De Wageningse Berg), respectively. The proceedings of these conferences were published in the NCR publication series (NCR publication 03-2001 and 07-2001). The NCR-days 2002 were organised by the University of Nijmegen and Conference Agency Routine on November 7th and 8th, 2002 in Conference Centre Jonkerbosch (Nijmegen). Until the mid nineties the buildings of the Conference Centre Jonkerbosch accommodated a boarding school for children of bargemen. All lecture rooms were named after large European rivers and waterways or cabins of river barges. The corridors, landings and stairways were furnished and decorated with all kind of attributes from barges. In this 'riverine' atmosphere some 125 participants witnessed in total 60 oral and poster presentations on current themes in river research. In order to meet the results of evaluations of preceding NCR-days, the organising committee included keynotes of river managers and also programmed presentations of institutes that were not yet involved in the research programme of NCR. Lively discussions took place, not only following each plenary presentation, but also during the poster sessions, the intermissions and the field trip to Gelderse Poort. The Hyde Park Corner approach for plenary poster presentations, introduced at the 2001 NCR-days, was again very successful and highly appreciated. The 'two-minute-talks' about posters guided us through the essence of river research: i.e., scientific and societal relevance! The present book contains the papers of oral and poster presentations. 110 river scientists in total contributed to these proceedings of the NCR-days of 2002, yielding a rather impressive overview of Dutch river research.

We would like to thank G.W. Geerling, B.T. Nolte, R.J.W. de Nooij and S. Wijnhoven of the University of Nijmegen, and M. Koenen and T. Verheij-van der Linden of the Conference Agency Routine for their help in organising the NCR-days 2002. Gerard van der Velde, Lex Kempers, Gerard Bögemann 'connected' the Rhine with the Mississippi. With their Piggly Wiggly Washboard Stompers band they performed 'original' river blues and jazz during the evening programme and clearly demonstrated multidisciplinary expertise of river scientists at University of Nijmegen. B.G. de Bruijn of the water board 'Waterschap Rivierenland' and B. Peters of the consultancy firm 'Bureau Drift' contributed to the field trip and elucidated societal and ecological benefits of sustainable flood defence measures. Special thanks are due to E.C.L. Marteijn, former President of the NCR scientific Programme Committee. He excellently chaired these NCR-days. Last, but not least, we also wish to thank all authors for their presentations and contributions to the proceedings.

We are looking back at a very inspiring conference, an elucidating field trip and fruitful discussions. The UNESCO - IHE Institute for Water Education will organise the coming NCR-days from 6th - 8th November 2003 in Marina Ooldehuuske Resort, Roermond (see http://www.ncr-web.org/). We are looking forward to meet you all again there.

R.S.E.W. Leuven, A.G. van Os & P.H. Nienhuis

Abstract

The Netherlands Centre for River Studies (NCR) is a collaboration of the major developers and users of expertise on river science and management in the Netherlands, viz. the universities of Delft, Utrecht, Nijmegen, Twente and Wageningen, UNESCO-IHE Institute for Water Education, ALTERRA, TNO-NITG, RIZA and WL | Delft Hydraulics. NCR's goal is to build a joint body of knowledge on river systems and to promote co-operation between the most important scientific institutes in the field of river studies in the Netherlands. Key functions of NCR are:

1 The network or platform function that is reflected in the organisation of meetings at which expertise and experience are exchanged (other parties are very welcome to attend these meetings).
2 Research-orientated co-operation in which a real commitment of the partners is reflected.
3 Knowledge dissemination (e.g. by strengthening education-oriented cooperation).

This book presents the proceedings of the fourth annual NCR-meeting (7-8 November 2002 in Nijmegen, The Netherlands) or so-called NCR-days 2002. The oral and poster presentations are arranged according to the current themes of NCR's research programme:

1 Genesis of floods,
2 Multiple spatial planning: living in harmony with the river, and
3 Cyclic floodplain rejuvenation.

In addition, future educational and research activities of NCR are summarized. General conclusions of the NCR-days 2002 are:

- River management needs a shift from 'flood control' to 'flood risk management' and a much greater role for international cooperation, multiple spatial planning, dynamic management approaches and socio-economic impacts.
- Field observations are of utmost importance to verify the concepts of various processes as used in the numerous river models (e.g. hydrological, geomorphologic, biogeochemical and ecological models) and to calibrate and validate these models.
- Environmental risk analysis and impact assessments require attention to changing environmental conditions in river catchments (e.g. landscape dynamics and climate change).
- NCR aims at multi- and interdisciplinary studies but the input of various disciplines in its research programme is not yet well balanced (e.g. strong dominance of civil technology and hydrology, much geomorphology, little ecology and hardly any social and economic sciences).
- Future activities of NCR focus on strengthening the NCR network, cross education, building a common 'body of knowledge', facilitating the recruitment of trainees and new staff and last but not least initiating new joint research projects that focus on sustainable flood risk management (e.g. within the 6th Framework programme of the European Union).

Samenvatting

NCR staat voor Nederlands Centrum voor Rivierkunde. Het is een samenwerkingsverband van wetenschappelijke onderzoeksinstituten in Nederland dat op 8 oktober 1998 is opgericht. De partners zijn de universiteiten van Delft, Utrecht, Nijmegen, Twente en Wageningen, UNESCO-IHE Institute for Water Education, ALTERRA, TNO-NITG, RIZA and WL | Delft Hydraulics. Het doel van het NCR is het bevorderen van samenwerking tussen de belangrijkste wetenschappelijke instituten op het gebied van rivieronderzoek in Nederland door:

- het opbouwen van een kennisbasis van voldoende breedte en diepte in Nederland omtrent rivieren waardoor adequaat kan worden tegemoet gekomen aan de maatschappelijke behoefte, zowel nationaal als internationaal;
- het versterken van het wetenschappelijke onderwijs en onderzoek aan de Nederlandse universiteiten;
- het vaststellen van een gezamenlijk onderzoeksprogramma.

NCR wil dit doel bereiken via gecommitteerde samenwerking en het bieden van een platform. De platformfunctie komt onder andere tot uiting in het jaarlijks organiseren van de zogenaamde NCR-dagen, waarop kennis en ervaringen worden uitgewisseld (andere partijen zijn daarbij van harte welkom). De voorliggende publicatie bevat de “proceedings” van de NCR-dagen die op 7 en 8 november 2002 werden gehouden in Nijmegen. De lezingen en posterpresentaties zijn geordend aan de hand van drie actuele thema’s uit het NCR-onderzoeksprogramma, namelijk:

1 Genese van hoogwater,
2 Meervoudig ruimtegebruik, en
3 Cyclische verjonging van uiterwaarden.

Daarnaast wordt een doorkijk gegeven in de toekomstige onderwijs en onderzoeksactiviteiten van NCR. Algemene conclusies van de NCR-dagen 2002 zijn:

- Rivierbeheer vereist een transitie van hoogwaterbeheersing naar risicomanagement. Daarbij spelen internationale samenwerking, meervoudig ruimtegebruik, dynamische beheersstijlen en sociaal-economische effectanalyses een belangrijke rol.
- Veldwaarnemingen zijn van vitaal belang voor de verificatie van diverse concepten voor processen die worden beschreven in talrijke riviermodellen (zoals hydrologische, geomorfologische, bio-geochemische en ecologische modellen) en voor het kalibreren en valideren van die modellen.
- Bij de milieurisicoanalyse en milieueffectrapportage is aandacht vereist voor de veranderende milieuomstandigheden in rivierstroomgebieden (zoals landschapsdynamiek en klimaatverandering).
- NCR beoogt multi- and interdisciplinaire studies, maar de inbreng van verschillende disciplines in het onderzoeksprogramma is nog onevenwichtig (bijvoorbeeld sterke dominantie van civiele techniek en hydrologie, veel geomorfologie, weinig ecologie en bijna geen sociale en economische wetenschappen).
- Toekomstige NCR-activiteiten zijn gericht op het versterken van de netwerkfunctie, wederzijdse educatie, wetenschapsontwikkeling, faciliteren van de werving van stagiaires en personeel en initiëren van gezamenlijke onderzoeksprojecten gericht op duurzame risicobeheersing van hoogwater (onder andere in 6^e Kaderprogramma van de Europese Unie).

NCR-days 2002: Introduction

Current themes in Dutch river research: general introduction

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Abstract
This chapter coherently outlines the various contributions to the fourth annual meeting of the Netherlands Centre for River Studies (NCR) from 7-8 November 2002 in Nijmegen (The Netherlands). The presentations are arranged according to the current themes of NCR's research programme:
1 Genesis of floods,
2 Multiple spatial planning: living in harmony with the river, and
3 Cyclic floodplain rejuvenation.

In addition, future educational and research activities of NCR are summarized.

Introduction
The Netherlands Centre for River Studies (NCR) is a collaboration of the major developers and users of expertise on river science and management in the Netherlands, viz. the universities of Delft, Utrecht, Nijmegen, Twente and Wageningen, UNESCO-IHE Institute for Water Education, ALTERRA, TNO-NITG, RIZA and WL | Delft Hydraulics. NCR's goal is to build a joint body of knowledge on river systems and to promote co-operation between the most important scientific institutes in the field of river studies in the Netherlands (Figure 1). Three key functions are (Stouthamer & Van Os, 2002; De Nooij *et al.*, 2003):
1 The network or platform function that is reflected in the organisation of meetings at which expertise and experience are exchanged (other parties are very welcome to attend these meetings).
2 Research-orientated co-operation in which a real commitment of the partners is reflected.
3 Knowledge dissemination (e.g. by strengthening education-oriented cooperation).

This chapter describes the outline and topics of the proceedings fourth annual meeting of NCR (so-called NCR-days 2002).

Outline of the proceedings
The presentations are arranged according to three themes of NCR's research programme, adopted in 2002 (Stouthamer & Van Os, 2002): (1) Genesis of floods, (2) Multiple spatial planning: living in harmony with the river, and (3) Cyclic floodplain rejuvenation. The proceedings conclude with future educational and research activities of NCR. Although the themes of NCR's research programme facilitate a structured approach of the various contributions, it is almost impossible to avoid some overlap between themes and ambiguous classification of research projects. For instance, many contributions to the NCR-days 2002 focus on actual research issues related to flood (risk) management and ultimately are relevant for all themes. These presentations are assigned to the most relevant section of the proceedings (mostly genesis of floods), but the results may also be discussed in relation to other themes.
The proceedings give a rather impressive overview of ongoing river research in the Netherlands. However, the contents may be somewhat biased, because a two days conference can never cover all projects of NCR-institutes and other parties involved in river research and management. NCR's research programme particularly focuses on three major research themes and doesn't intend to include all river

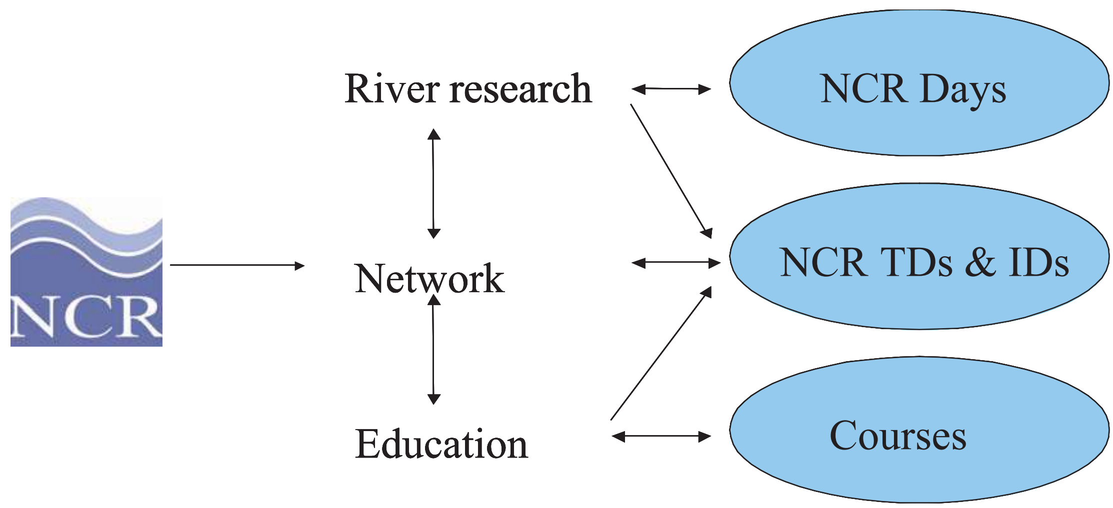

Figure 1. Coherence of NCR activities and the relations with various meetings and courses (NCR: Netherlands Centre for River Studies; TDs: Thematic Days; IDs: Institute Days; from De Nooij et al., 2003).

issues. The whole of the NCR-research programme is much more than the content of these proceedings. Moreover, we would like the reader to bear in mind the aim of the NCR-days: to give young scientists the opportunity to present their ongoing river studies, in order to maximise the exchange of ideas and experiences between the participants and to provide the researchers a sounding board for their study approach and preliminary results.

Genesis of floods

Modelling rainfall-runoff processes

A main topic is how the formation or genesis of (extreme) floods can be correctly described in terms of basic physics. NCR research related to this theme particularly links processes involved in the rainfall-runoff relation to models that describe these processes (Savenije & Luxemburg, 2003). Zhang *et al.* (2003) apply the representative elementary watershed (REW) approach to model the relation between rainfall and runoff. In this approach a watershed is divided into a number of sub-watersheds, called REWs, serving as computational units. The boundary of each REW coincides with the topographic boundary delineating an area of the land surface that captures precipitation and delivers it to the river channel. Duizendstra (2003) presents the development of a near real-time flood forecasting, warning and management system based on satellite radar images, hydrological, hydraulic and data-assimilation models and in-situ data. This so-called FloodMan project aims at an instrument for an improved monitoring and forecasting of discharges and corresponding water levels during floods for different types of drainage basins. This instrument will form the heart of a flood management information system.

Model calibration and validation

Field observations are of utmost importance to verify the concepts of processes as used in the numerous models that relate rainfall to runoff (Figure 2). Savenije *et al.* (2003a) describe the effects of unpaved roads on the runoff processes and their relation to up-scaling in hydrological models. Savenije *et al.* (2003b) analyse groundwater-induced floods of the river Somme (France) in 2001 and present a conceptual model that explains the processes observed. This model still has to be verified by further geo-physical research. Calibrating spatially distributed rainfall-runoff models is difficult, especially for models that are applied at a regional or local scale. At these levels of scale, the heterogeneity of soils, vegetation and topography cannot be ignored and methods that enable a regionalisation of the model calibration parameters are needed. Van der Knijff (2003) tests how a spatially distributed soil database can be used to improve the estimations in a catchment model. Kleinhans & Buskes (2003) argue that even explanations which use highly sophisticated physical computer models are not deductions but indications to the best

Figure 2. Monitoring rainfall runoff processes under hill-slope conditions in the Alzette catchment in Luxembourg (From Savenije et al., 2003a).

explanation (retroduction). The most important reason for using retroduction instead of the logically sounder deduction is the heavy underdetermination of earth-scientific theories by observations and because of the impossibility of observing past and long-term phenomena, the problem that many models give the same outcomes for various different parameter combinations, and the fact that some systems are chaotic. Consequently, the reduction of earth science to physics is hampered in practice by underdetermination problems (morphological convergence by different processes, eroded 'evidence', etc.).

Changing conditions

Flood extremes have also to be assessed under changing environmental conditions. For instance, climate change and riverine landscape dynamics (e.g. land use changes and vegetation succession) can have serious impacts on physical characteristics that determine the flood extremes. Over the past centuries, series of measurements on channel dimensions and flow characteristics were carried out in the Rhine branches. These data were used by Hesselink & Kleinhans (2003) to identify channel pattern and flow characteristics of the Rhine distributaries, and to quantify these changes in characteristics on a timescale of decades to a few centuries. Lammersen (2003) describes the influence of land use and river training measures in Germany on flood conditions in the Dutch Rhine river basin. The results show, that land use changes and currently planned retention measures cause minor effects upon the discharge at Lobith. It is obvious that with a better coordination of design and use of the retention measures the efficiency could be improved. Future research will also take into account extreme rainfall, the discharge capacity of the existing riverbed upstream of Lobith (Nordrhein-Westfalen), inundation of the hinterland and other flood reduction measures (Lammersen *et al.*, 2003). Van der Linden (2003) focuses on the impact of climate change on the water balance in (sub)arctic basins. Changes in the natural flow regime of a river may threaten the livelihood of people living along this river. Meijer (2003) discusses a conceptual model for environmental flow requirements. This model will be tested to study flow requirements for livelihood in developing countries (e.g. Bangladesh).

Jonkman (2003) discusses the FLORIS (flood risk) project of the Dutch water authorities. This project deals with the assessment of the probability of flooding of dikes, dunes and hydraulic structures, the determination of the impacts of floods and the development of methods to take into account uncertainties. Uncertainties in the calculation of flood risks, split up in inherent uncertainties connected to natural variation and future developments (e.g. climate change), and uncertainties due to lack of knowledge (model input data), will complicate causal relationships (Wehrung, 2003).

International river management

De Bruin (2003) defends the proposition "International river management is a precondition for adequate high-water protection". Recently, Dutch and German water authorities signed a declaration for co-operation in flood control (Lammersen *et al.*, 2003). A joint research project is expected to result in an effective transnational flood protection strategy for the river district of Nordrhein-Westfalen (Germany) and the Province of Gelderland (The

Netherlands). The policy interest is in full swing regarding the location and design of inland retention basins, calamity areas for the storage of superfluous river water and construction of compartmentalization dykes to prevent large areas of the Dutch-German river district being flooded without any retardation on both sides of the Rhine (De Bruin, 2003). Socio-economic and ecological consequences of these measures were extensively discussed during the field trip to the Ooijpolder; a proposed calamity polder along the river Waal near Nijmegen.

Multiple spatial planning: living in harmony with the river

Dynamic management approaches

River management is facing large developments (Van Alphen *et al.*, 2003). On the one hand, river restoration of the Maas and Rhine branches aimed at protection against floods, offers important opportunities for the return of natural processes and dynamics, like vegetation succession and morphological processes (Figure 3). On the other hand, our river systems are vital for e.g. national and international shipping, water transport, water supply, recreation and agriculture. These functions impose tight restrictions on natural processes. Therefore the expected transition towards a more dynamic way of river management requires new knowledge on temporal and spatial scales of these dynamics, critical thresholds and recovery intervals, corrective measures, monitoring strategies, management support systems and predictive models. Sustainable (ecological) river management means that user functions of the river basin (e.g. navigation, agriculture, urbanisation) should be accommodated to the dynamics of the natural river system (Van Alphen *et al.*, 2003), and not the other way around, as has been practised for about 1,000 years (technological river management).

Creating room for the river

Several contributions deal with the Dutch 'Room for the river' policy (Ministerie van Verkeer en Waterstaat, 1998), adopted after the high water threats of 1993 and 1995 in the river Rhine and Meuse. Following this policy, a number of measures have to be taken inside the riverbed and basin. De Wit *et al.* (2003) report results of the integrated outlook for the river Meuse and explore possibilities and impossibilities to reduce the flood volume in the Meuse at Borgharen by taking measures upstream of the Netherlands (e.g. effects of reforestation, re-meandering, increased inundation of floodplains, nature recovery in small streams, uncontrolled retention and controlled retention). Most measures proposed in this study are insufficient to substantially reduce the discharge volume at Borgharen during extreme flooding events. Controlled retention may be an exception, but only if large volumes are available and the management of the reservoirs are optimised for flood control. In spite of recent construction of embankments along the Meuse in the Netherlands, additional widening and deepening of the riverbed in the River Meuse and additional elevation of numerous embankments are required to achieve the statutory flood protection level (Meijer & Verkerk, 2003). In the Resilience Study for the Rhine Branches exploratory investigations

Figure 3. Current situation and artist visualisation of more room for natural processes in the river Nederrijn (From Van Alphen *et al.*, 2003).

have been carried out to define measures that combine the demands of safety for a discharge of 18,000 m³/s at Lobith with the development of nature. The results of the impact assessment for these measures form the basis for the development of the Planning Kit (Blokkendoos). With the Planning Kit it is possible to explore the possibilities of transporting 3,000 m³/s extra through the Rhine Branches without dike heightening and with a possibility to change the discharge distribution at the bifurcation points (Van Schijndel, 2003).

During preliminary design of plans for flood prevention, river rehabilitation and floodplain reconstruction, water authorities are often forced to apply rules of thumb and analytical calculations to derive parameters and boundary conditions. According to Kruyt and Bart (2003) it would be beneficial to fine-tune these rules: both to be able to base a design solely on rules of thumb and also to make an accurate preliminary design. With an accurate preliminary design the use of numerical models is far more effective than when the preliminary design is inadequate. Meanwhile, a series of decision support systems (DSSs), including various numerical models, have been developed for integrated impact assessment of management measures. Favier (2003) compares ecological modules of DSS for river basin management of the Rhine and Meuse branches in the Netherlands (e.g. DSS Large Rivers and INFORM). Aspects like variability in morpho-dynamics and ecological connectivity to nature in adjacent areas are not yet incorporated in the ecological modules.

The design of hydraulic engineering structures, e.g. groynes, is vitally important to guarantee the discharge of water and ice and keeping the main navigation at proper depth and location. Berg (2003) compares the behaviour of three new designs of groynes with the behaviour of the reference one. A groyne with a less steep slope of its head gives a smaller scour hole, a higher discharge of high waters and smaller velocity gradients. This partly is the case with a permeable groyne but these groynes will give some sedimentation in the main channel and less bank protection than the reference groyne. The hybrid groyne has no really negative points but gives no improvement in case of high water discharge. Prototype research is now necessary to measure the effects of ships on the flow and for a quantification of the effects of the new designs on the riverbed morphology.

Successful implementation of policy and science

A minor number of contributions were devoted to the societal values of river systems. The success of a river basin management plan will depend for an important part on the willingness of different parties to contribute to the plan and to the implementation of resulting water management measures. Dynamic actor network analysis, focusing on the different stakeholders and their views on river management, structures the management problems in the basin and provides focal points for further elaboration (Hermans & Muluk, 2003). Timely consultation of a wide range of actors reduces the risk of a biased problem formulation. Rovers (2003) focuses on the role of actors and the process of decision-making, the design of the decision process and the role of public interests. Knippenberg and De Groot (2003) postulate that the obstacle for successful implementation of management measures is not the recognition or acceptance of the problem as such, but the mode in which the problem is raised, formulated, communicated and acted upon by the dominant actors: the government agencies, scientists, planners and consultants. In other words: the problem is not the content of policy and science, but the style. The problem is not non-acceptance of the problem, but the resistance of the people at large and local administrators against the colonization of their visions by central government and central science. A plea is made for the 'bottom-up' approach, i.e. river management that contributes to the welfare of groups of people economically and socially connected to the river, such as fishermen, agriculturists, and people dedicated to wildlife preservation, rural housing and extensive recreation facilities (Knippenberg & De Groot, 2003). Ultimately these functions have to be decisive for the flow regime of the river. Most Dutch rivers, however, have a 'top-down' installed flow regime, accommodating navigation and the unimpeded discharge of water to the sea.

Cyclic rejuvenation of floodplains

Floodplain management concept

Smits & Middelkoop (2003) briefly introduce cyclic rejuvenation of floodplains (CRF), a novel floodplain management concept that is strongly related to 'Room for the river' policy. In pristine fluvial hydrosystems erosion and sedimentation periodically reset the morphological and

Figure 4. An example of a nature rehabilitation project in the floodplain Klompenwaard along the river Waal in the Netherlands (From Smits *et al.*, 2003). Excavation of the top clay layer of the floodplain and a secondary channel will create more room for hydro-morphodynamics and suitable conditions for riparian biodiversity.

vegetation succession. During the meandering of the river, erosion of the outer bend occurs, leading to the breakdown of floodplain forest and other riparian vegetation. In the inner bend of that meander, sedimentation occurs, and the natural succession starting with pioneer plants species begins all over again. This cyclic rejuvenation of floodplains is characteristic for natural rivers (Baptist *et al.*, 2003; Geerling & Smits, 2003, Schoor *et al.*, 2003), but it is completely absent in our regulated and armoured rivers where numerous man-made groynes prevent the stream from meandering. Therefore, cyclic rejuvenation of floodplain along the Rhine and Meuse means tailor-made and controlled management actions by man, mimicking the natural processes, by excavation of the topsoil and digging of secondary channels (Figure 4). The spatial and temporal dynamics of floodplain communities, however, are insufficiently known. It is an inherent characteristic of the lowland sections of our large rivers that there is a net sedimentation of silt and sand, finally becoming dry land that is incidentally flooded by the river. Cyclic rejuvenation of floodplains therefore primarily demands more knowledge of the ecology and succession of vulnerable and rare floodplain communities.

Hydro- and geomorphologic dynamics

A number of contributions deals with the consequences of the removal of obstacles from the embanked floodplains and the removal of the summer dikes, connected to the lowering of floodplains by excavating the top layer of the silted up grounds. Creating room for the river is still mainly seen as a physical problem, leading to changes in the hydrological and geomorphologic dynamics, e.g. the sedimentation and erosion of sand and silt. These processes have been mimicked in flume experiments (Baptist & Thannbichler, 2003; Blom, 2003). Van Vuren (2003) investigates to what extent lowering of floodplains and removal of summer dikes along the river Waal may lead to more bed level variability. Teuling *et al.* (2003) show that complex patterns of a meandering river can be explained by applying general physical principles.

Several authors focus on (reconstruction of) sediment budgets of river catchments. Keesstra and Van Dam (2003) reconstruct the change in the sediment budget of the catchment of the river Dragonja (SW Slovenia) due to reforestation. Weerts and Cleveringa (2003) describe the sedimentation of the river Vecht under human influence. Maas & Makaske (2003) focus on sedimentation of embanked floodplains along the rivers Waal and IJssel. Gruijters *et al.* (2003) optimise geological modelling of the subsoil in riverbeds.

Ecological impacts

The ecological consequences of creating more room for the rivers, however, are largely unknown, and can hardly be simulated in model experiments. Consequences of floodplain lowering for rare and characteristic biotic communities are virtually unknown. It is argued that certain communities of plants, specific floodplain grasslands, are almost lost forever in case of floodplain excavation, owing to their specific habitat requirements. Our knowledge of the vulnerability and resilience of floodplain communities, plants and connected animals, is highly insufficient. Only a few studies are dealing with these problems (Nijhoff & Hommel, 2003).

The conversion of agricultural land into ‘new nature’ triggers a number of new problems. Former meadows and croplands in river floodplains have been fertilized for decades, and the soils of these grounds have been heavily enriched, which hampers the oligotrophication trend of getting fewer nutrients (Antheunisse *et al.*, 2003; Van der Perk *et al.*, 2003). Besides that, the input of pollutants, brought in during high water, may rise if flooding frequency changes owing to removal of embankments (Thonon, 2003). Nolte *et al.* (2003) try to link sedimentation and ecology in riverine landscapes. A better understanding of these processes is very relevant for modelling impacts of climate change and physical reconstruction measures related to creating more room for the river or ecological rehabilitation. Heterogeneous contamination of floodplain soils is still a problem, especially when measures, such as lowering of floodplains will be carried out, exposing contaminated sediments from the fifties and sixties of the last century (Kooistra *et al.*, 2003). Monitoring and modelling of pollutants in embanked floodplains of the Dutch river district are of the utmost importance for ecotoxicological risk assessments (Schröder & Vink, 2003). However, spatial and temporal distribution patterns of pollutants in the soil do not coincide with the heterogeneous distribution patterns of small mammals (e.g. mice) living in the floodplain (Wijnhoven *et al.*, 2003). This lack of correlation makes model predictions in ecotoxicological risk assessment very complicated. Van Griethuysen (2003) analyses spatial variability in environmental risk of trace metals in floodplain lake sediments. Sediment contamination affects production and diversity of benthic invertebrates in river floodplain systems. Due to the moderate levels of contamination the benthic macro-invertebrate community is low in species diversity but high in productivity. This moderate level of contaminants may therefore be problematic for nature rehabilitation projects along Dutch rivers (De Lange *et al.*, 2003). The organic matter content of the sediment is linked to high algal biomass in the surface water as result of eutrophication. Ecological rehabilitation projects in floodplain areas should also consider nutrients in surface waters.

Safety - nature dilemma

The 'safety - nature development' dilemma received ample attention. Optimum safety requires control of maximum discharge of river water in the lower parts of the rivers Rhine and Meuse. In contrast, nature development implies a natural floodplain succession, characteristic for large lowland rivers, i.e. net sediment deposition, and consequently an increase of the width/depth ratio of the river, succession of vegetation units via low herbs, brushwood and shrubs, and finally to soft- and hardwood floodplain forest.

Quite a number of contributions are devoted to vegetation friction, describing the retardation of the water flow by vegetation elements (Geerling & Smits, 2003; Hoffmann, 2003; Straatsma *et al.*, 2003). Vegetation roughness is, of course, seen as a negative factor in terms of safety and discharge of water. Most studies look at this dilemma from the physical-geomorphologic angle (Baptist et al., 2003; Schoor *et al.*, 2003). Studies in 'relatively undisturbed' rivers systems, e.g. the Allier in France (Baptist *et al.*, 2003) and the Lower Volga in Russia (Schoor *et al.*, 2003), yield useful information on vegetation succession in reference situations. Model calculations are developed based on algorithms for the relations between water depth, flow velocity friction by vegetation, height and density of the vegetation, and consequent flow velocity friction by vegetation (Hoffmann, 2003). Various types of remote sensing techniques, enabling the collection of data from large areas repeatedly, are very suitable to reveal the spatial distribution of vegetation and look promising for monitoring hydraulic roughness of vegetation (Geerling & Smits, 2003; Straatsma *et al.*, 2003).

A positive feedback between 'safety and nature development' is offered by the successful digging of secondary channels, as lateral branches of the main gully of the river, creating dynamic shallow water habitats favouring an array of rheophilic fish and macroinvertebrates (Buijse & Van der Molen, 2003).

Interdisciplinary research

CFR appears to be an appealing theme, as many contributions refer to or are relevant for further elaboration of the CFR-concept. Smits & Middelkoop (2003) classify scientific domains of these contributions and note that hydrology, geomorphology and eco(toxico)logy are well represented. However, socio-economics and management practice requires more attention in future research.

Future activities

Future activities of NCR particularly focus on establishing and reinforcing the position of Dutch scientific river research and enhancing education and scientific research at Dutch universities.

De Nooij *et al.* (2003) summarise new educational activities of NCR, such as Thematic Days and Institute Days for students and young researchers. The Thematic Days aim at cross education, strengthening the NCR network and building a common 'body of knowledge'. The goal of the Institute Days is to give undergraduates and PhD students an overview of (the contents of) the working field of the NCR-institutes, and to facilitate the recruitment of trainees and new staff. Both initiatives are highly appreciated by all parties concerned.

Finally, Van Os (2003) summarises the main results of the IRMA-SPONGE programme, i.e. a European research programme led by NCR aiming at development of methods and tools to assess the impact of flood risk reduction measures and of land-use and climate change scenarios, in order to support the spatial planning process for the Rhine and Meuse river basins. General conclusions from this research programme emphasise the need for a shift from 'flood control' to 'flood risk management', and advocate a much greater role for multiple spatial planning. However, flood risk management should not only aim at a reduction of flood risks but may also enhance the ecological quality of rivers and floodplains, and the quality of the living environment at large. There is a need for inclusion of social and economic sciences. NCR aims to address this need in the 6th Framework programme of the European Commission.

General conclusions

- Field observations are of utmost importance to verify the concepts of various processes as used in the numerous river models (e.g. hydrological, geomorphologic, biogeochemical and ecological models) and to calibrate and validate these models.
- River management needs a shift from 'flood control' to 'flood risk management' and a much greater role for international cooperation, multiple spatial planning, dynamic management approaches and socio-economic impacts.
- Environmental risk analysis and impact assessments require attention to changing environmental conditions in river catchments (e.g. landscape dynamics and climate change).
- NCR aims at multi- and interdisciplinary studies but the input of various disciplines in its research programme is not yet well balanced (e.g. strong dominance of civil technology and hydrology, much geomorphology, little ecology and hardly any social and economic sciences).
- Future activities of NCR focus on strengthening the NCR network, cross education, building a common 'body of knowledge', facilitating the recruitment of trainees and new staff and last but not least initiating new joint research projects that focus on sustainable flood risk management (e.g. within the 6th Framework programme of the European Union).

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NCR theme Genesis of floods

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Abstract

The extreme of floods in the rivers Rhine and Meuse is a phenomenon with strong societal interest. Genesis of Floods is a NCR theme that relates to the formation of floods. Through the theme in NCR context relevant partners learn about ongoing research and are in the opportunity to attune research programmes.
In a broader context, but with identical aims, the Hydrological "Triangle" has been constituted, focussing on issues in the field of hydrology of the rivers Rhine and Meuse. The Triangle is a collaboration of Dutch scientific institutes. Three main types of partners constitute the Triangle: institutes that develop fundamental scientific knowledge (universities), institutes that develop applied scientific knowledge (large technological institutes), and Dutch governmental institutes (RIZA, KNMI).
As genesis of floods is one of the items falling within the interest of the Hydrological "Triangle" a combination of efforts was established. The scope of the "Triangle" is somewhat wider, as not only the formation of floods is of interest, but also flood-attenuating measures, operational flood forecasting and low flow control. Both initiatives, "Genesis of floods" and the Hydrological "Triangle" have reached at the phase of defining relevant research activities, intended to conclude in mid 2003.

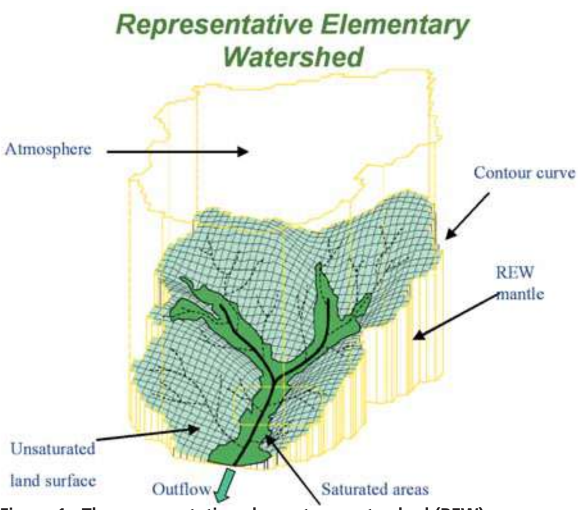

Figure 1. The representative elementary watershed (REW) schematization of a catchment.

Introduction

In flood management a main topic is how the formation of floods can be described in a physically correct manner. The formation, or genesis, deals with the processes involved in the rainfall-runoff relation. To this extent flood extremes have to be assessed under changing and non-changing conditions. Changing conditions of climate and physical characteristics as a result of land use changes can have serious impacts on the extremes. Also reliable predictions of runoff in real time are of outmost importance. When it comes to predictions some sort of models are required. The research related to genesis of floods links processes to models that describe the processes in a physically correct manner.
To improve predictability of models, numerous uncertainties have to be solved. Recently significant progress has been achieved through distributed models that describe physical processes at a pixel scale. This so-called physically based distributed modeling is data intensive, and the processes that are simulated at a pixel scale are not necessarily the relevant processes at larger scales. With the intention to handle the scale issues, models are preferred that operate at a large enough scale to represent the aggregated processes, but still represent the relevant processes properly.
Promising is the representative elementary watershed (REW) methodology based on a catchment approach to describe the aggregated physical processes (Figure 1). In general, physically

NCR is a co-operation of the universities of Delft, Utrecht, Nijmegen, Twente and Wageningen, UNESCO-IHE Institute for Water Education, RIZA, ALTERRA, TNO-NITG and WL | Delft Hydraulics

Figure 2. Typical hill slope landscape in the Rhine basin from where the genesis of floods starts.

based modeling provides the opportunity to compare model results with field observations. In this way equifinality in calibration of parameters can be dealt with. Equifinality means that parameters appear not to be unique so that different sets of parameters give similar results.

Research issues

There is no universal solution to improve the predictability of floods. Identifying the relevant blanks in this respect and defining lines of approach is exactly the objective of the theme. Research could focus on roughly three topics i.e. defining approaches, developing techniques or applying techniques to obtain answers. Not having the intention to be complete a few research topics will be mentioned:

Defining approaches

- It should be defined where the largest improvement in predictions can be expected. Options are to focus on improvements of the timing of high water peaks, or more accurate discharge volumes. Obviously this is related to the size of the catchment. In either case a proper description of catchment characteristics, weather predictions, and the actual state of the hydrologic parameters are of importance. Obviously the type of solution depends on the purpose of prediction i.e. for operational purpose of an occurring event, or for not yet occurred events, for example under climate change scenarios.

Developing techniques

- By tuning model results to observed processes in the field model concepts can be evaluated, improved, or related to specific conditions. This would need models that give state variables, which can be observed in the field. Several universities are involved in fieldwork abroad in catchments of the Rhine or Meuse, where the formation of runoff takes place (Figure 2). Ideally various model concepts are tested simultaneously in catchments of various sizes.
- A promising technique that needs to be developed for hydrologic applications is the remote sensing of earth gravitation. Measurable gravitation variation is caused by variation in total amount of stored water, a key parameter in hydrologic modelling.

Applications

- With available knowledge specific questions can be investigated. For example the effect on the runoff hydrograph of retention basins in the river system can be assessed. Other options are the effect of temporary storage of rain in capillaries, or storm direction over the catchments on the runoff generation.

With reference to other presentations related to the theme of genesis of floods, it is communicated that field observations are of outmost importance to verify the concepts of processes as used in the numerous models that relate rainfall to runoff.

Modelling rainfall-runoff relation by representative elementary watershed approach

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Introduction

The representative elementary watershed (REW) approach is a newly developed watershed modelling approach describing the relation between rainfall and runoff. In this approach a watershed is discretized into a number of sub-watersheds, called REWs, serving as computational units. The boundary of each REW coincides with the topographic divide delineating an area of the land surface that captures precipitation and delivers it to the river channel. Reggiani *et al.* (1998, 1999, 2000) describe watershed-scale balance equations for mass, momentum, energy and entropy that serve as a base for the mathematical model underlying our computer code. The governing equations constitute a system of coupled ordinary differential equations, leading to a drastic simplification of the mathematical model. Model equations are obtained by averaging the corresponding point-scale equations over the scale of a REW and as such, in the approach the model variables and parameters are spatially lumped over an REW. Therefore, compared to fully distributed, complex physically based modelling approaches (Rientjes, 1999), our approach has the advantage that much fewer parameters and thus less input data are required while yet, at the core of the mathematical model, the real world physics underlying watershed runoff dynamics is maintained.

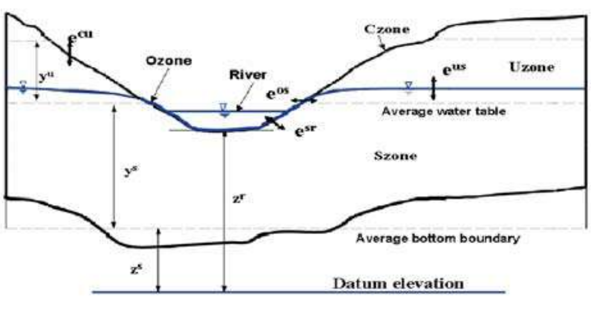

Figure 1. Cross-sectional vieuw of a REW with mass exchange terms and characteristic state variables added.

Model structure

REWs form the model building blocks and represent the spatial regions where water flows take place. REWs are organized around the tree-like structure of the channel network and are linked laterally through a subsurface flow model to allow for regional groundwater flow. Based on the characteristics of the runoff mechanisms as observed in the real world, a REW is sub-divided into 5 zones (Figure 1, Figure 2):

1 Unsaturated zone (Uzone);
2 Saturated zone (Szone);
3 Saturated overland flow zone (Ozone);
4 Concentrated overland flow zone (Czone); and
5 River channel.

Continuity equations of mass and momentum have been developed and govern the water movement and mass exchange across the zones and REWs. Mass balance equations for each zone are the core of the mathematical model and are listed here.

1 Unsaturated zone mass conservation:

$$\rho \frac{d}{dt}(\theta^u y^u \omega^u) = e^{us} + e^{uc} + e^u_{wg}$$

2 Saturated zone mass conservation:

$$\rho\varepsilon \frac{d}{dt}(y^s \omega^s) = e^{su} + e^{so} + e^{sr} + e^{s,bot} + e^{sA}$$

3 Saturated overland flow zone mass conservation:

$$\rho \frac{d}{dt}(y^o \omega^o) = e^{o,top} + e^{os} + e^{or}$$

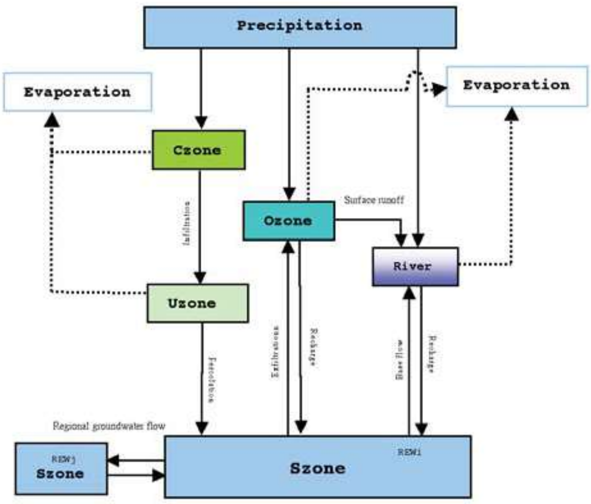

Figure 2. Flow chart of the REW model.

4 Concentrated overland flow zone mass conservation:

$$\rho \frac{d}{dt}(y^{c}\omega^{c}) = e^{c,top} + e^{cu}$$

5 River flow zone mass conservation:

$$\rho l \frac{dm}{dt} = e^{rA} + e^{r,top} + e^{rs} + e^{rs} + e^{ro}$$

where: ρ is water density, θ soil moisture content, y average depth of the zones (water depth for oveland flow zones), ω projected plannar area fraction covered by zones, *m* and *l* cross-section area and lenth of the river segement respectively. In the equations, superscripts are zone indices with exceptions that bot and A are for REW bottom and mantle boundaries respectively, *top* for either rainfall or evaporation. In the right hand side of the equations, *e* stands for flux exchange terms among zones. The momentum equations as well as model assumptions are described in Reggiani *et al.* (1998, 1999, 2000, 2001) and will not be repeated here.
Combined with momentum balance equations and constitutive geometric relationships, the final set of coupled non-linear odinary equations have been obtained through parameterization. In the numerical model, the computed hydrological variables are, e.g., a) soil moisture content, b) groundwater table, c) river discharge and d) overland flow zone area fractions. The dominant model parameters that need intensive calibration are saturated hydraulic conductivity, soil porosity and Manning roughness coefficient.

Application and results

We applied the REW approach to the Geer basin, located in Belgium to simulate the rainfall-runoff relation. The Geer basin, covering an area of 494 km2, is characterized as a "deep" groundwater system. The unsaturated zone is underlain by an aquifer that extends beyond the boundary of the catchment. Prior to a model simulation, TARDEM software (Tarboton, 1997) was applied to subdivide the watershed into a number of REWs (Figure 3) based on a specified Strahler order threshold value. By doing so the REW discretization and the extraction of geometric data were carried out. The numerical model was tested using a series of constant effective rainfall inputs and different parameter sets. The model testing results are presented in Figure 4 and show

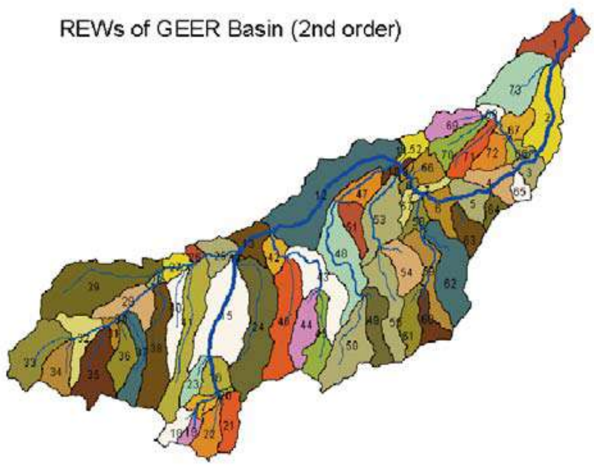

Figure 3. Identification of REWs for Geer basin.

catchment outlet hydrographs that indicate the model is sensitive to different inputs. In order to analyse whether the physics of the catchment hydrological runoff behaviour is represented in the model calculations, also the behaviour of hydrological state variables such as soil moisture content, groundwater table depth, the size of saturated-excess flow area fractions are calculated throughout the simulation. A second test dealt with the application of measured daily rainfall and evaporation data to the model. We present here the hydrograph at the outlet of the basin (Figure 5) for the period 17-05-1994 till 25-08-1994. In the graph it can be observed that the base flow discharge is simulated appropriately while some peak flow discharges are over-estimated and others under-estimated. The effect of the time-varying rainfall inputs, however, is clearly represented. The results indicate that the rainfall-runoff relation can be simulated accurately by the REW approach. In order to be more conclusive on the performance of our model approach, the approach must be applied to catchments in different physiographic and climatic settings.

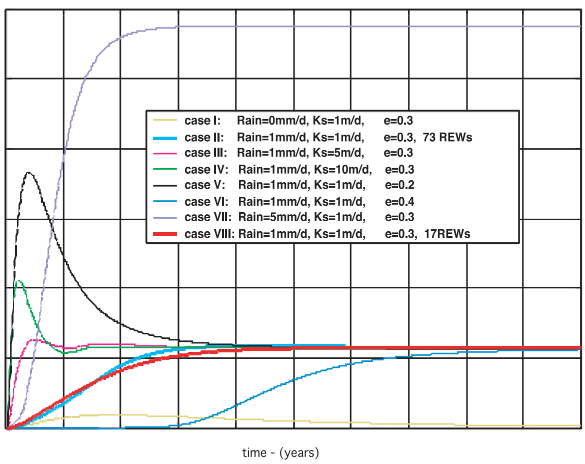

Figure 4. Hydrographs at the outlet of Geer basin with various rainfall rate and parameter sets.

Conclusions

REW approach is a semi-distributed and physically based approach. It forms an appropriate base for watershed hydrological modelling tool. REW approach also gives a prospective for runoff forecasting and prediction and possibly for analysis of effects of land use and climate changes.

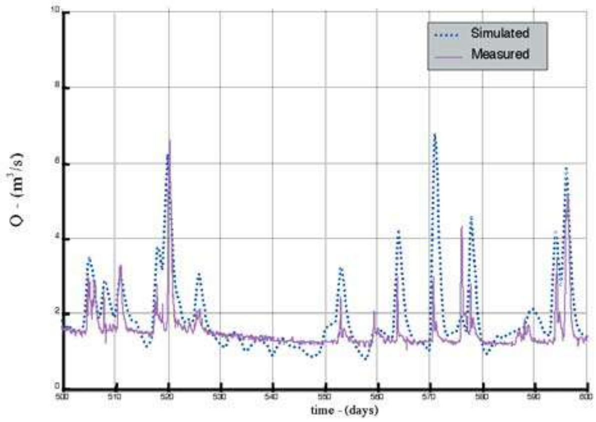

Figure 5. Discharge at the outlet of Geer river.

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FloodMan: A near real time flood forecasting, warning and management system based on satellite radar images, hydrological, hydraulic and data-assimilation models and in-situ data

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Abstract

The FloodMan project will develop an instrument for an improved monitoring and forecasting of discharges and corresponding water levels during floods for different types of drainage basins. This instrument will form the heart of a flood management information system that can be extended with several modules. Possible extensions are for instance 1) an information exchange model, 2) an evacuation model, 3) a model for the prediction of losses (lives, damages and costs) and 4) a model for redesigning the river geometry and possible other models.

Introduction

The FloodMan project will be carried out within the Fifth Framework Programme, Research Programme, Energy, Environment and Sustainable Development (Research Area Key Action 1.5.2 Improved Flood Forecasting). The project starts January 2003 and will be finished by January 2006. The project will be carried out by eight partners from five European countries (Table 1). The contribution of the European partners and countries to the project is shown in figure 1.

Table 1. European partners in the FloodMan project.

1 NORUT	**NORUT IT Ltd., Norway**
2 HUT	**Helsinki University of Technology, Finland**
3 CNR-IFAC	**Italian National Research Council (CNR), The Institute of Applied Physics (IFAC), Italy**
4 FEI	**The Finnish Environment Institute, Finland**
5 TSS	**TromsØ Satellite Station, Norway**
6 HKV	**HKV Consultants, The Netherlands**
7 BFG	**Federal Institute for Water Management and Science, Germany**
8 PDA-SIT	**Provincia di Alessandria Sistema Informativo Territoriale, Italy**

The volume of the project is estimated at 310 person months and will cost € 3.4 million of which € 1.9 million will be refunded by the European Commission. The project is divided in six work packages in which several partners work together. The lead contractors co-ordinate the several contributions within the work packages.
An essential part of the Flood Management Information System is the distributed database system shown in Figure 2. Through a common interface (ellipse) the data in different databases are made available for analysis and services. The databases are owned by the different institutions and housekeeping is done by the existing services. The interface is realized through servers and the information of the databases will be made available on demand.

Computation cycle of models with several input data

HKV Consultants will focus on the interfaces for the hydrological and the hydraulic model. By these interfaces the models will be fed with several EO, meteorological and in-situ data, discharges and water levels.
HKV will develop the data-assimilation routines and the controlling interface around these routines and the hydrological and hydraulic models (Figure 3). By the proposed modelling cycle the hydrological and hydraulic model will be re-calibrated almost continuously by which a high accuracy will be secured.
It is well known, that the accuracy of hydrological models and hydraulic models are quite different. At this moment not much is known about the accuracy of the SAR data used for the computation of the flood extent. There are still a lot of questions and problems that have to be answered in this project.

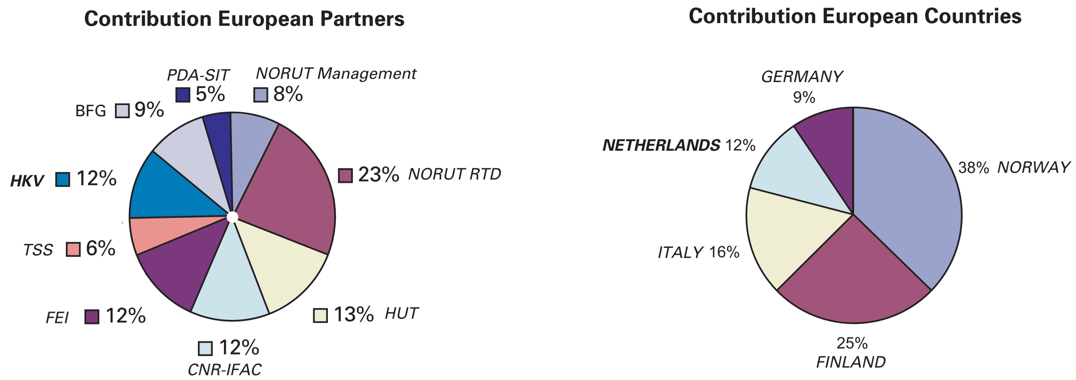

Figure 1. Contribution of the European partners and countries to FloodMan (Partners are listed in table 1).

Expected questions and problems

- Limited availability of SAR images of specific catchments (at the present once every two days);
- Accuracy of SAR data;
- Different accuracy of the several input data;
- Different accuracy of hydrological and hydraulic model;
- Selection of relevant input data for the models;
- (Inadmissible) computation time.

However, FloodMan will start by January 2003, the expectations are high and in the near future FloodMan may become the common used Flood Forecasting, Warning and Management system for Europe.

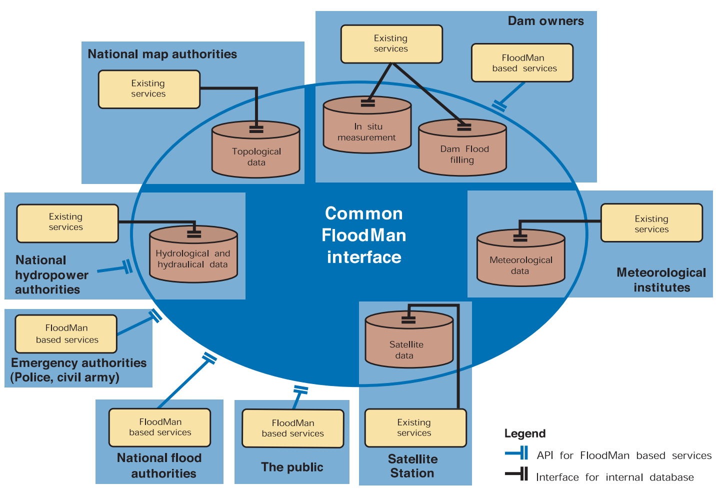

Figure 2. Model of the distributed database system.

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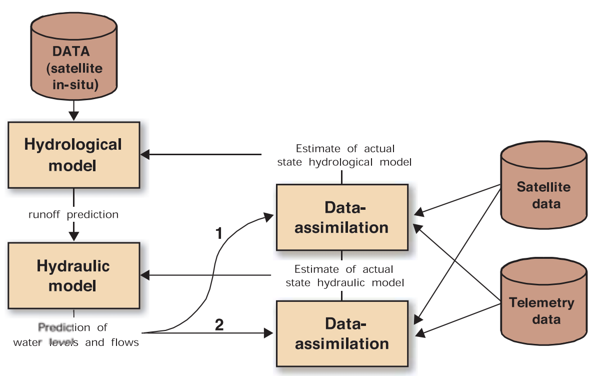

Figure 3. Proposed modelling cycle.

The Luxembourg experience, effects of unpaved roads on the runoff processes and its relation to up scaling

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Abstract

This field based research deals with the aspect of up scaling of rainfall runoff processes under hill slope conditions. In particular the effect of unpaved roads on the process is discussed as a result from recent observations. The ongoing research takes place in the Alzette catchment in the country of Luxembourg, as collaboration between Delft University of Technology (DUT) and the Gabriel Lippmann Institute.

Introduction

Many rivers in the Netherlands have their catchments abroad, where the rainfall runoff processes usually take place under different circumstances than we are used to. These circumstances are shortly characterized by saying that hill slope processes are more dominant in these catchments, in a different geological setting.
The reason for the Netherlands to be involved in the understanding of the processes that result in discharges in our rivers is to better predict extreme discharge events, under unchanged and changing conditions. DUT has started monitoring nested catchments within a small basin in Luxembourg. These are catchments ranging from 2 up to 66 ha. The specific goal is to study in a quantitative way the effects of unpaved roads on the runoff process in relation to spatial up scaling.

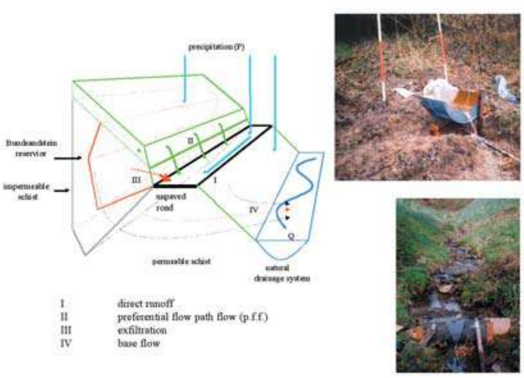

Figure 1. Up scaling of hill slope processes.

Observations Discharge on Unpaved Roads

Discharge measurement devices were installed next to the unpaved roads, catching the discharge of a 200 m stretch of unpaved road (Figure 1). The road runoff measurements were combined with visual observations of the runoff process. During the installation phase of the discharge devices in April 2002 visual inspection during a rain event indicated two runoff processes with distinct time scales. An immediate runoff occurred from the road itself, lasting for hours, and a runoff occurred from the uphill slope as exfiltration water, collected by a drain along the road, lasting for days.
Later in spring and summer the exfiltration was no longer observed, as it is seems to occur under conditions of a high level of saturation of the top layers. A recession analysis of the immediate reacting run-off showed two distinct processes. From four events, a fast process with an average recession constant of K=5 minutes and another process with a recession constant of K=45 minutes could be distinguished (Figure 2).
The fast event is attributed to the direct runoff from rain on the road itself. The slower component is attributed to direct runoff from the slopes, supposed to originate from root canals and referred to as preferential flow path flow. The uphill sloping area only discharged 1.0% of the gross rainfall. Volume wise the road and uphill slope discharged equal amounts. Related to the uphill surface area, this means that 1%

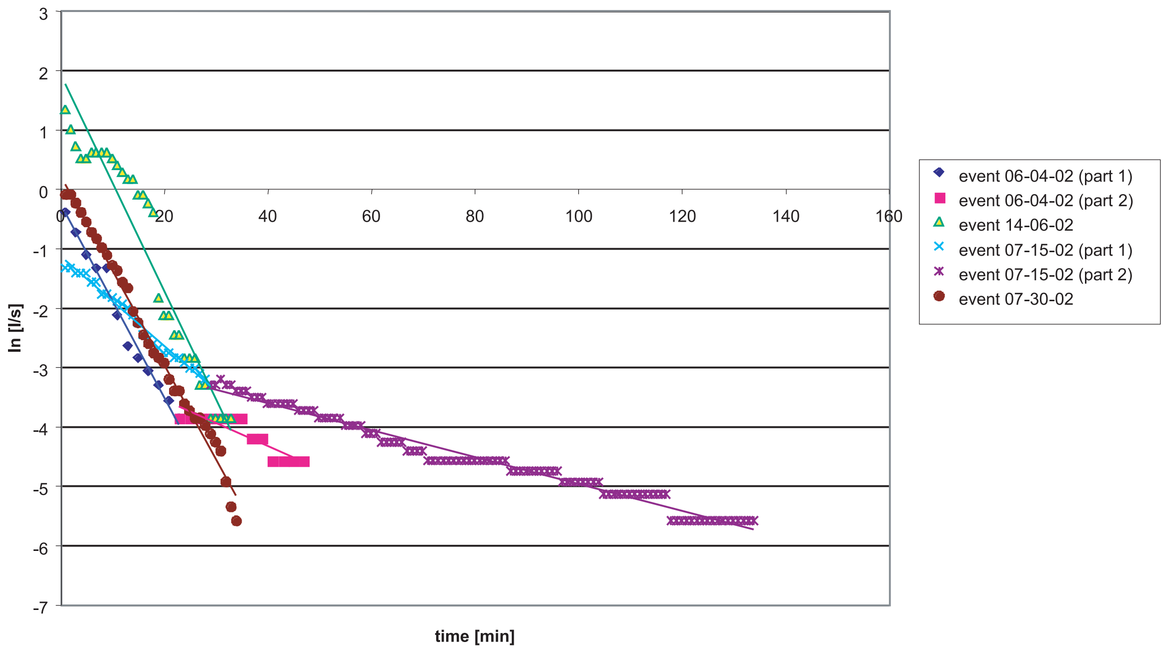

Figure 2. Observed recession curves on logarithmic scale.

additionally is discharged as a result of the presence of the road. However, it was observed that immediately downstream of the measuring device the flow infiltrated very localized on the down slope side of the road. Therefore it is expected that the discharge from the roads in late spring and summer has not much effect on the river discharge. This might be completely different in autumn, winter and early spring, when the subsurface is much more saturated and also exfiltration from the uphill slope from the road occurs.

Observations river discharge

Two automatic gauging stations with a V-notch were installed in the Maisbich: one station on top of the catchment, measuring 17 ha, and a lower one measuring almost the full catchment, i.e. 66 ha. The monitored unpaved roads are located within these catchments. The recession as a result of depleting base flow is noted. An analysis showed two distinct reservoir constants. In May the reservoir constant is somewhat higher K=6.5 day (1) than later in the year when K=9.5 days (2,3) (Figure 3). This is possibly related to the exfiltration process, occurring at the lower slopes near the riverbed. Due to higher levels of saturation of the subsurface this effect could still have occurred in May, whilst ceasing later in spring and summer.

The discharge from the 17 ha catchment in times of recession is extremely low, too low for a recession analysis. However, the hydrographs as a result from rain events could be analyzed and compared to the hydrographs of the same a rain events in the larger, 66 ha, catchment. As an example the hydrographs of the rain event on July 10, 2002 are compared (Figure 4).

Striking is that major undulating effects noted in hydrograph upstream have disappeared when moving downstream. Secondly, a recession analysis showed that not simply one or two reservoir constants could be established. This indicates that different processes simultaneously result in the direct runoff process. However, on average, the recession of the hydrograph from the downstream station starts with a reservoir constant of K=30 min and ends with a reservoir constant K=15 hours.

Conclusions

Comparing the found reservoir constants for recessions of discharge hydrographs of rain events, indicate a general increase in reservoir constant with increase in catchment size. This can be explained by an increase in average resident time or time of concentration in the larger catchments.

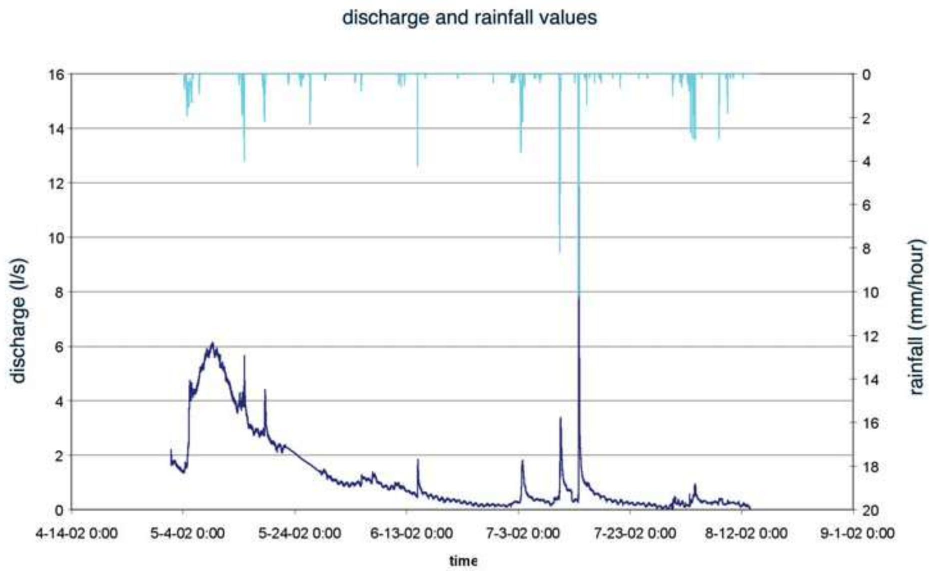

Figure 3. Discharge and rainfall data.

For the analysed events it was noted that an unpaved road results in double the discharge compared to a sloping hill without the unpaved road (from 1% to 2% of the gross rainfall). Relating the discharge volume from a rain event in the river with the gross rainfall indicated that the increased runoff from the path is not noticed in the river. For the 17 ha catchment it was found that actually less than 1% of the gross rainfall drained into the river. For the 66 ha catchment this was around 1%. Hence the runoff from the unpaved road did not result in additional runoff from the slope downhill of the road. This can be explained and confirmed by the observations in the field during rain events. It was noticed that the discharge coming from the road infiltrates immediately and very localized in the soil on the downhill side of the road and hence will no longer contribute to the process of direct runoff. In winter and early spring this might be completely different when, due to high levels of saturation of the subsurface, the flow from the road will not immediately infiltrate. The presence of gullies on these spots confirms the hypothesis.

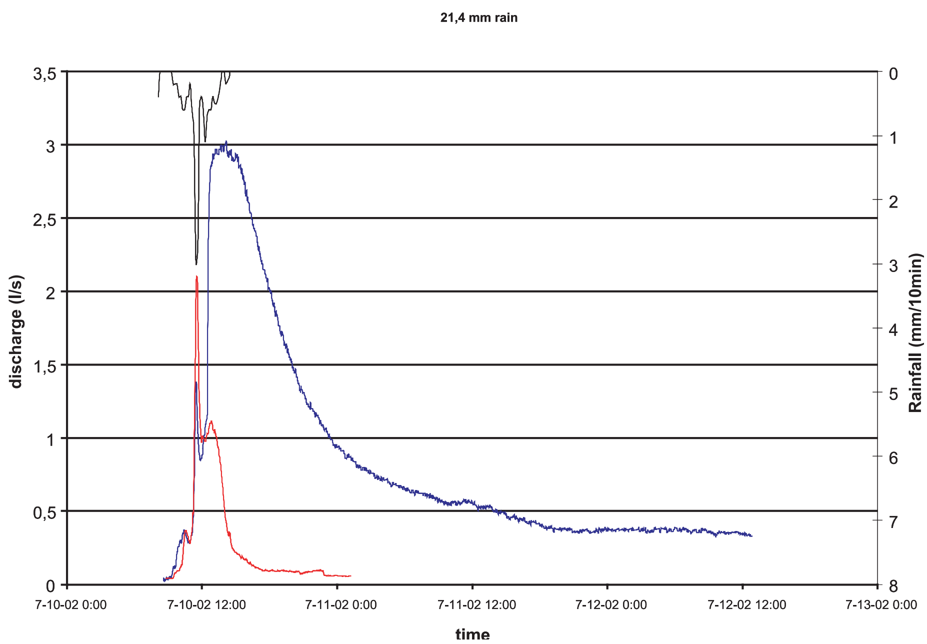

Figure 4. Hydrographs of a 21 mm rainfall event.

Groundwater induced floods of the Somme River in March 2001

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Introduction

In March 2001 large areas were flooded in the Somme river basin in northern France (Figure 1). Before 2001 there were no records on such high discharges. Not only the flood levels but also its duration and sudden rise of the water table in the area just before the flood gave rise to the impression that an unusual phenomenon was responsible for the flooding. During the course of the flood that lasted for several months, all sorts of explanations circulated. Allegedly water from the river Seine was discharged into the Somme through navigation canals. Another explanation mentioned the spring tide at sea, higher than normal, as a causing factor. This paper reports on a hydrological approach to the analysis of the phenomenon resulting in a conceptual model that explains the processes observed, but which still have to be verified by further geo-physical research.

Water balance

The interesting aspect of this flood is the water balance showing more water discharged through the river than the total volume of rainfall in the hydrological year from September 2000 until August 2001. After studying the available data from 1995 until 2001, the flood of 2001 appears to partly originate from water stored in the sub-

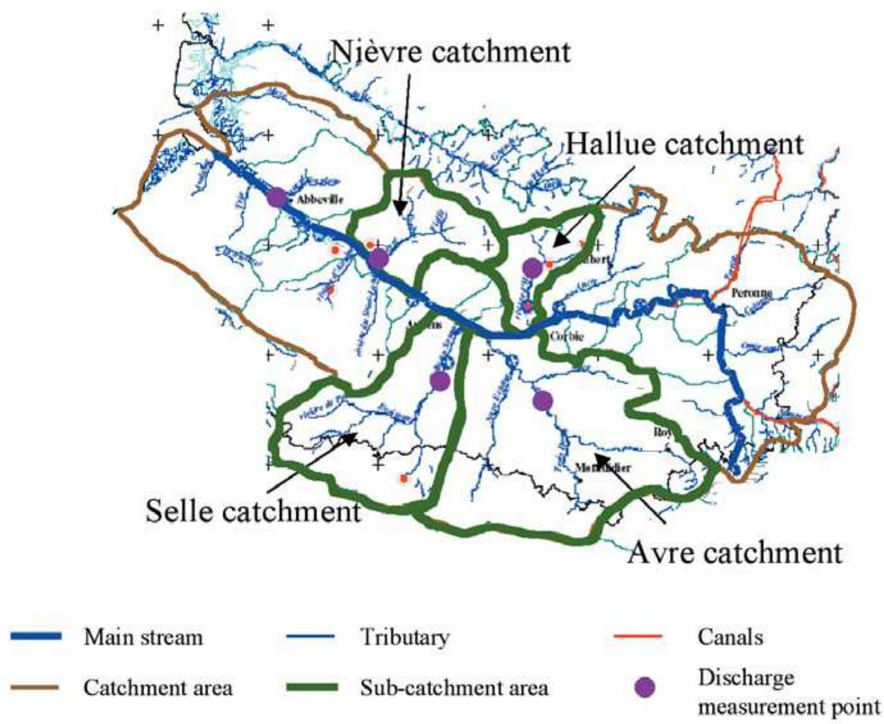

Figure 1. The Somme catchment and its tributaries.

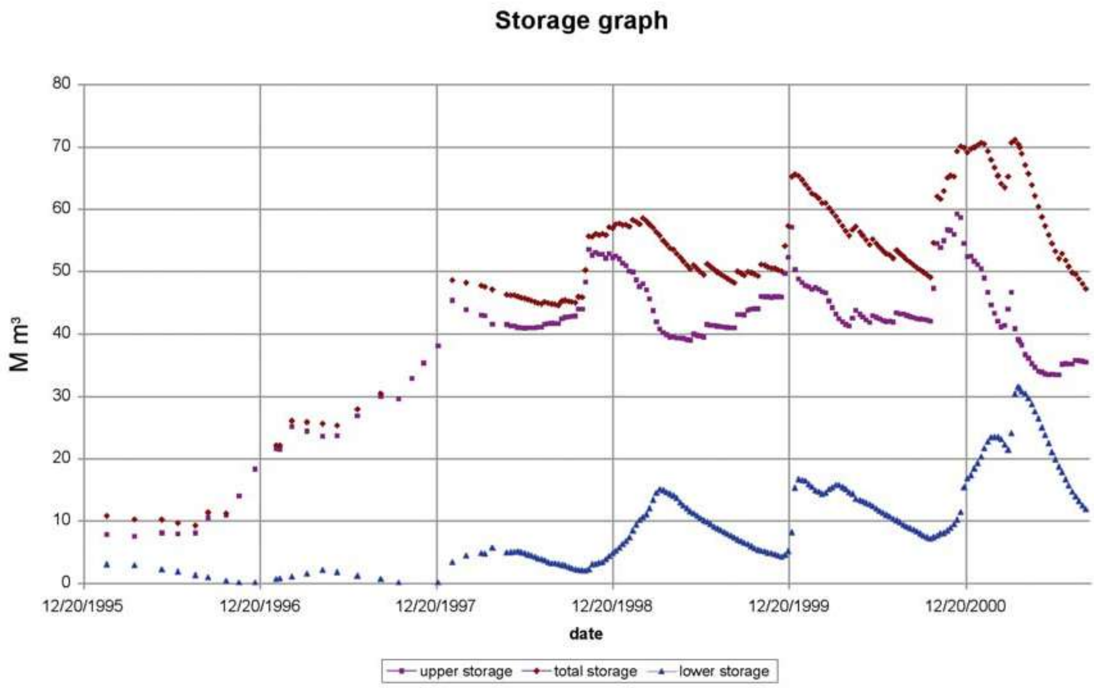

Figure 2. The Storage graph, Hallue river.

surface from 1995 to 1997 (Figure 2). Apparently the sub-surface stores water for several years, which does not drain out as part of the regular groundwater storage. The water hardly contributes to the discharge in normal years, but is somehow responsible for a large part of the flood of 2001 (Figure 3).

Storage and release capacity of chalk

The type of underground of the Somme department is chalk, covered by a layer of loess. The chalk, in this area varying from 100 m to 300 m thick, is responsible for the unusual processes. The chalk is suggested to have an unexpected storage capacity and exceptional release of the stored water. It has a high porosity matrix structure, with a large storage capacity, interconnected by fractures. The permeability of the subsurface is itself very small, except for the preferential flow paths through the fractures. These underground features have a dominant effect on the rainfall-runoff relation in this area. The hypothesis for the draining of the upper zone is that the upper zone above the current water table contains large quantities of water that under specific conditions quite suddenly connect with the groundwater storage (in this way expediting drainage). There are two possible explanations for the storage and release of water in the upper zone. The first option is that the high porosity of the matrix can be responsible for the storage of the water. The rise of the groundwater table is responsible for the increasing permeability of the soil due to saturation, resulting in a lower soil water content after saturation than before saturation. The second option is that a layer of air (or a semi-permeable layer) retains water in the subsurface, which is called a perched aquifer. This perched aquifer is connected to the water table when the water table reaches the air-layer. The perched aquifer joins the groundwater system and will drain as part of the regular groundwater storage, resulting in an increase of discharge. A flood is called "groundwater induced" when it is caused by a water table rise. The initial groundwater rise resulting in the upper zone storage draining to the groundwater storage is a result of the more than average rainfall in the end of 2000 and beginning of 2001.

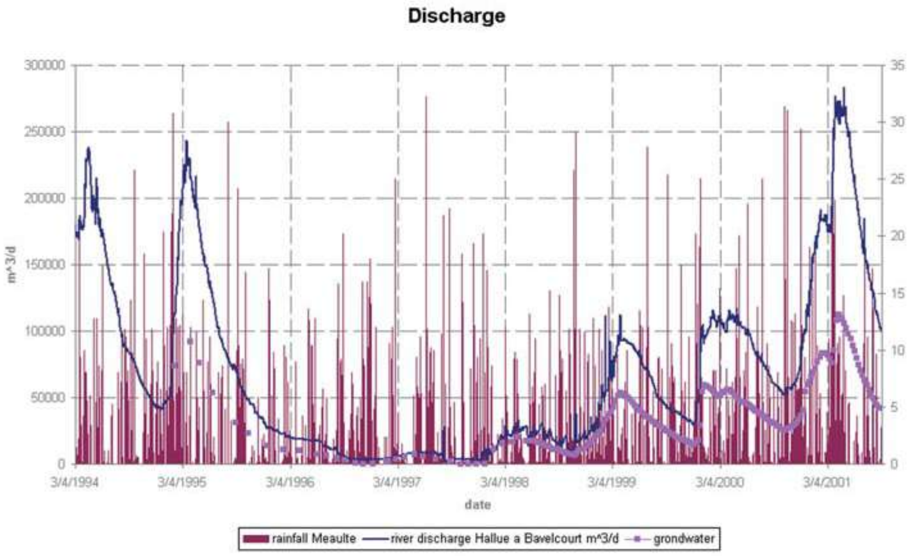

Figure 3. Rainfall, runoff and discharge graph.

Rainfall-runoff model

In this research data from one of the sub-catchments of the Somme River, the Hallue River is used for the development of a conceptual model. By using a sub-catchment the influence of the canals from the Seine can be neglected. Only the processes influenced by local circumstances will then be modelled. The hypothesis of "groundwater induced floods" is tested by the conceptual rainfall-runoff model. The model gives insight into the processes in the subsurface, and results in a possible explanation of the flood. The structure of the model is related to the possible mechanisms. Because the storage in the subsurface appears to be influencing the rainfall-runoff relation, a reservoir model is chosen. The storage in the subsurface is divided into two reservoirs (Figure 4), the upper and lower storage.

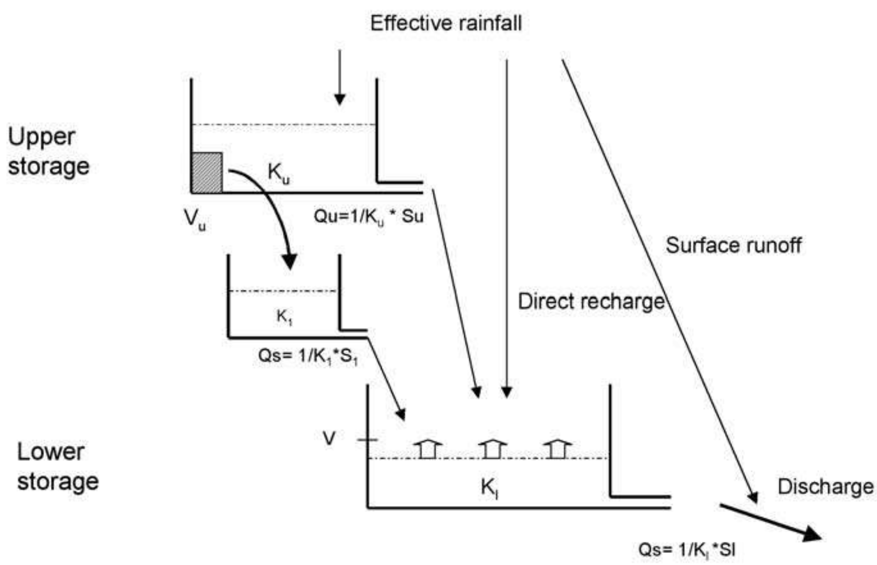

Figure 4. The rainfall-runoff model concept.

The outflow of these reservoirs is linear related to the storage in the reservoir. When the lower reservoir reaches a certain level a volume of water will be released from the upper storage into an intermediate reservoir, which releases its water quicker than the upper storage. At eight levels this mechanism is put into practise. This model was quite able to describe the measured discharge (Figure 5), which indicates that the assumptions made in the model concept are the likely mechanisms that have occurred in this system. Even before 2001 the triggered mechanism is apparent, although it did not reach the dramatic effect of the year 2001.

The physical mechanism of forced releases is yet unexplained and is subject to further research.

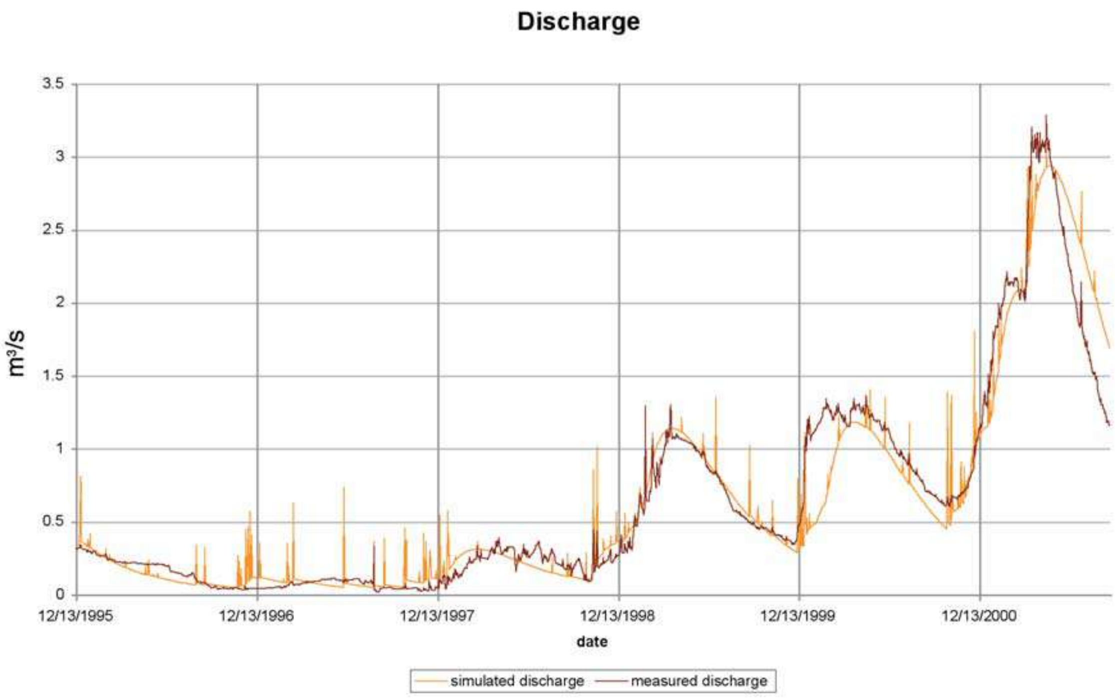

Figure 5. Simulated (orange) and measured (brown) discharge graph.

Comparison of calibrated soil depths with information from a spatially distributed soil database

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Abstract

Calibrating spatially distributed rainfall-runoff models can be a difficult task, especially for models that are applied at the regional scale (or smaller). At this scale, the heterogeneity of soils, vegetation and topography cannot be ignored, and methods that enable a regionalisation of the model's calibration parameters are needed. Recently, a spatially distributed soil database of Europe has become available, which provides soil information at a scale of about 1:1 million (King et al., 1994). The present study will test how this information can be used to improve the estimation of effective soil depth (and its spatial distribution) in the spatially distributed LF-Light catchment model.

Water balance model

The LF-Light model is a water-balance model that is capable of simulating daily stream flow in large catchments. It is a cross between the distributed LISFLOOD water balance model (De Roo *et al.*, 2000) and the conceptual HBV-model (e.g. Killingtveit & Sælthun, 1995). The model contains four parameters that are estimated by calibration on measured stream flow records. Its effective soil depth parameter (*SD*) is particularly important, as it defines -in combination with the moisture content at field capacity- the storage capacity of the soil. Theoretically, it is possible to infer soil depths directly using prior information from the soil database, which provides estimates of the depth at which impermeable layers (acronym: *IL*), solid rock (*DR*) and obstacles to plant roots (*Roo*) occur in the soil. However, even though *IL, DR* and Roo are obviously all related to soil depth, which one should we use? An inter-comparison shows that the spatial patterns as predicted by the three soil attributes are quite different. Finally, even though the soil database provides a relative ranking of depth classes, it is somewhat difficult to infer absolute soil depth values from these classes.

Model calibration

In an attempt to evaluate whether the soil database could be capable of improving the estimation of spatially distributed soil depths, calibrated values of effective soil depth were compared with estimates from the soil database. Records of measured stream flow were available for 12 gauges, and average values of IL, DR and Roo were computed for the contributing area of each gauge. Also, 9 different classifications of 'deep soils' were made, and the percentage of deep soils was calculated for each gauge's contributing area. The LF-Light model was calibrated using the generalised likelihood uncertainty estimation (GLUE) method (Beven, 2001), which provides a relatively simple way to incorporate parameter uncertainty in the analysis. Random sampling from a uniform distribution was used to generate over 4000 different parameter sets. For each parameter set, the model was run and the agreement between simulated and observed stream flow was characterised by a statistical performance measure. For each gauge location, acceptable - in terms of the performance measure - parameter sets were selected. Optimised soil depth was taken as a weighted average of soil depths from all acceptable parameter sets (likelihood-weighted approach). These values were then plotted against the soil depth estimates from the soil database, and a correlation analysis was performed.

The correlation analysis showed that the optimised soil depths are most strongly correlated with the percentage of soils in the deepest DR class. Scatter plots of the deepest *DR* and *Roo* classes (Figure 1) suggested that a better fit could

NCR is a co-operation of the universities of Delft, Utrecht, Nijmegen, Twente and Wageningen, UNESCO-IHE Institute for Water Education, RIZA, ALTERRA, TNO-NITG and WL | Delft Hydraulics

be obtained using a combination of both classifications. Therefore, a new 'deep soils' map was created which combines *DR* > 120 cm and *Roo* > 80 cm by taking their intersection (logical OR). The lower plot of Figure 1 shows that the combined classification results in an improved agreement with optimised soil depth. Besides, the combined approach yields a relation that is much more linear, which makes it more readily applicable over different spatial scales.

Application in Meuse basin

The agreement between optimised soil depth and the combined 'deep soils' classification demonstrates that the information in the soil database can be used to characterise the spatial distribution of effective soil depths throughout the Meuse basin. This information can be used to improve the parameterisation of rainfall-runoff models such as LF-Light. The simplest approach would be to define a linear distribution function that relates soil depth to the percentage of deep soils in each (sub)catchment, and to treat the coefficients of this distribution function as calibration parameters. Testing such a calibration scheme will be one of the next steps in this research.

Acknowledgements

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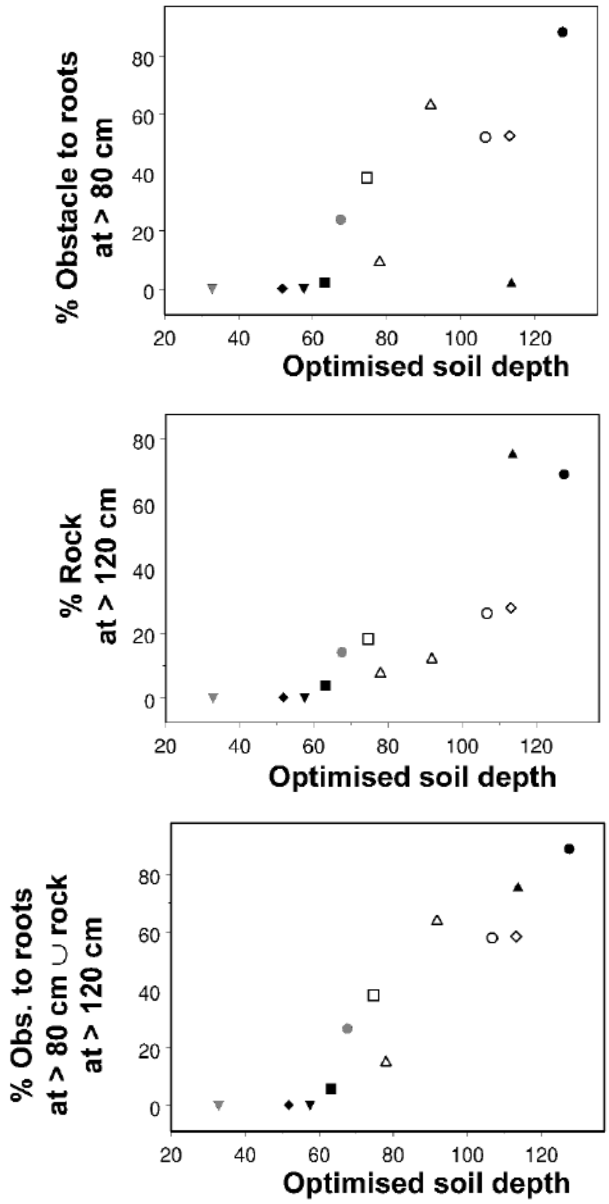

Figure 1. Scatter plots of optimised soil depth vs. percentage deepest soils as calculated from depth of obstacle to roots (upper left); depth to rock (upper right) and the intersection of both classifications (bottom). Each symbol represents one stream gauge.

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Philosophy of earth science; just sloppy physics?

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Introduction

When the philosophy of natural sciences is confronted with the practice of earth science, background insights can be gained why earth science must necessarily be interdisciplinary. The philosophy of science according to the influential Vienna Circle (1920s) can be caricatured as follows (e.g. Klee 1997): "All phenomena consist of physical entities; spirits, souls and essences are either redundant or in principle explainable in physical terms. Thus, all phenomena can in principle be explained with the laws of physics plus a description of initial conditions. Consequently all (real) sciences will eventually be reduced to physics." Despite the normative influence of the Vienna Circle on the practice of science, biology and psychology and others emancipated in the past decennia as their autonomy due to emergent properties (like organisms, evolution and consciousness) was recognised (e.g. Mayr 1985; Figure 1). Organisms and even conscious human beings consist solely of physical entities, but most of their aspects and behaviour cannot be explained by physics.
Earth science on the other hand has largely been neglected by philosophers of science, presumably because it is thought to be reducible in principle to physics and chemistry. Three arguments will be discussed why this view is wrong.

Principal argument

From a number of textbook definitions and from practice, it follows that earth science (environmental science, geology, engineering etc. all including) has biological and societal components. Many examples related to rivers and other systems in highly populated areas can be found. Physics (and chemistry) is a science that causally explains phenomena by physical (or chemical) laws and their boundary conditions. Biology and sociology employ functional (e.g. what is the function of a species in this ecosystem) and intentional (e.g. what were the motivations of a society for this action) explanation types. The latter two are not reducible to causal explanations without serious loss of explanatory power (e.g. Mayr, 1985). Therefore earth science is not reducible to physics and not just physics.

Practical argument

One specific issue caught much criticism from the physics-oriented: qualitative historical descriptions and 'explanations' of phenomena that have never been observed directly. It can be argued that historical explanation is more than just description, and that it follows the logical scheme of retroduction (inference to the best causal, potential, explanation) (Lipton, 1991), rather than the well known deduction (derivation of instantiations from laws) or induction (construction of generalisations from a limited number of observations). Moreover, it can be argued that even explanations which use highly sophisticated physical computer models, are not deductions but inferences to the best explanation in which deductions play an important but not principal role. In short, we argue that historical explanations are attempts at causal explanations, and the result is not a proof or a theory but a hypothesis of the most likely explanation (Lipton, 1991). This is not necessarily the true explanation, because the true explanation need not have been among the conceived hypotheses, but this most often cannot be verified because of the following point.

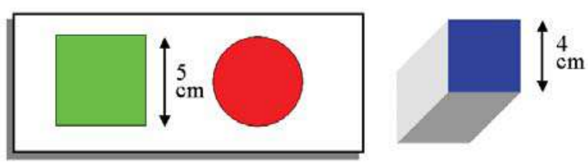

Figure 1. Putnam's Peg: the microscopic (physical and chemical) properties of the peg and plate cannot be used to predict through which hole the peg will fit, but the macroscopic (geometrical) properties can be used, while they cannot be reduced to the microscopic. This is probably true for barchan sand dunes and many other landforms, and is an anti-reductionistic argument.

Fundamental underdetermination problems

The most important reason for using retroduction is the heavy underdetermination of earth-scientific theories by observations. Consequently, the reduction of earth science to physics is hampered in practice by the underdetermination problems. Examples of underdetermination are: a) the evidence of a certain process may have been eroded, or b) various different explanations are possible for a single phenomenon, or c) there are not enough clues or different types of evidence to decide between competing theories or various different models with different concepts converge to the same end result (e.g. Oreskes *et al.*, 1994), or d) a sensitive model needs detailed and highly accurate initial and boundary condition data which cannot be collected in that detail or for the required long period (e.g. Holocene), therefore the model 'runs into a frenzy and crashes', or e) a system is chaotic and the necessary precision of initial conditions for prediction into the future cannot be obtained (Werner, 1999). These are all fundamental underdetermination problems. So earth science is not sloppy physics.

Theory of alternate glaciation as example

An example corroborating the three anti-reductionist arguments is found in the development of the theory of alternate glaciation and deglaciation of the Earth in the past million years. Many hypotheses have been conjectured to explain various phenomena such as relic glacial landforms in a temperate climate, the changed course of the Rhine valley, fluctuations in the oxygen isotope ratios in continental ice cores and deep ocean cores, severe changes of vegetation and so on. A combination of at least two physico-mathematical models provide a hypothetical explanation: a climate model that explains climatic change with irradiation change at high latitudes, and an orbital model that explains irradiation change with orbital fluctuations of the Earth. An alternative model explains global irradiation change with stellar energy fluctuations. However, all the mentioned phenomena cannot directly be deduced from either of these physical theories and much more steps are needed. Unfortunately most steps cannot be done due to the underdetermination problems. Moreover, vegetation response cannot be modelled physically. Nevertheless, given the evidence and the available hypotheses, it is inferred that the orbital theory is the best explanation of the 'ice ages' of the given hypotheses. This is a retroduction and, as said, a complete reduction to physics is impossible and the ultimate verification of this explanation is not feasible.

Implications for earth science

An important consequence for the practice of earth science is that it is necessary to have different stances at the same time: in (attempts at) causal explanations, deductive and inductive approaches can be combined in an inferred (but ultimately not verifiable) best explanation. To work only deductively means to run the risk of missing the complexity of the real world and excluding seemingly outrageous hypotheses (e.g. such once outrageous hypotheses of glacials and of plate tectonics), and to work only inductively means to run the risk of having hypotheses that conflict with the laws of, e.g., mass conservation. Models may serve heuristically to test for such conflicts, but cannot be used to prove the validity of (physical) theories beyond absolute doubt (Oreskes *et al.*, 1994). Moreover, functional and intentional explanations address very relevant but unphysical aspects of reality (Mayr, 1985). In practice, the researchers in the NCR already cooperate to some extent to join the stances, which is in happy agreement with our philosophical position.

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Flow characteristics of the Rhine distributaries, The Netherlands, calculated from historic flow measurements

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Introduction

In the past decades Dutch water management adopted a new approach to enlarge the discharge capacity of the rivers if safety standards have to be maintained. A political decision was made not to build higher dikes, because of increasing chances for a catastrophic dike breach, but e.g. to remove obstacles in the embanked floodplains, to reopen abandoned (secondary) channels, and to excavate the top layer of the embanked floodplains. Efforts to establish sustainable flood protection, and simultaneously encourage nature rehabilitation and maintain shipping routes are most likely to be successful if they are linked as much as possible to natural processes. It is therefore important to study the morphodynamics of the rivers Rhine and Meuse during the period before they were completely harnessed, on a time scale of decades to centuries, using the wealth of historic data present in The Netherlands. Over the past centuries, series of measurements on channel dimensions and flow characteristics were carried out in the Rhine distributaries. These data was used to:

1 Identify channel pattern and flow characteristics of the Rhine distributaries;
2 Quantify these changes in characteristics on a timescale of decades to a few centuries.

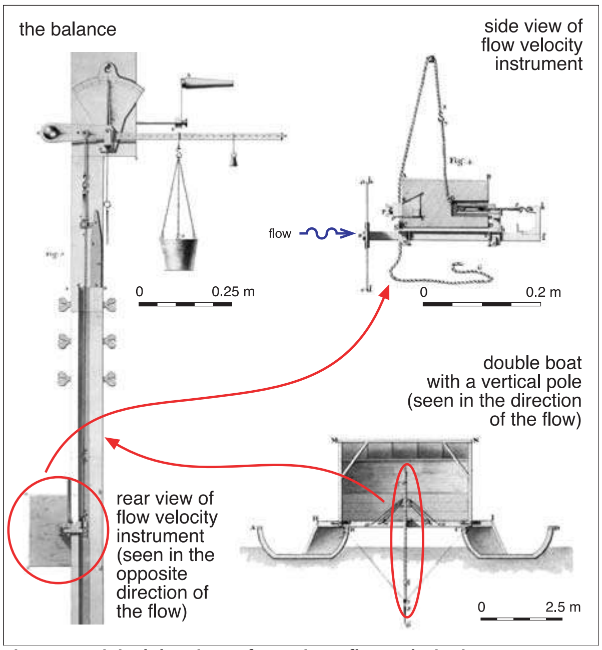

Figure 1. Original drawings of Brunings' flow velocity instrument (Conrads, 1798). The operation is based on a dynamic balance between the drag force (FD) exerted by the flow on a submerged vertical plate and the gravitational force (FG) on a weight above the water surface.

Brunings' historic flow velocity instrument

Two flow velocity measurements of the Rhine distributaries were carried out in 1790 and 1792 AD to determine the new discharge distribution over the Rhine distributaries after digging the Pannerdensch Canal in 1707 AD. For this purpose, Brunings developed a flow velocity instrument in 1786 AD (Figure 1), which he used to measure flow velocities at different height intervals (Figure 2). Brunings' thorough description of his flow velocity instrument, measurement techniques he used (Brunings, 1798), and flow velocities (Brunings *et al.*, 1790, 1792) enabled to assess the accuracy of the instrument and data to calculate flow velocities and discharge near the bifurcations of the river Rhine in 1790 and 1792 AD. Based on this assessment it was concluded that Brunings' flow velocity measurements are realistic, and have no significant systematic error (Hesselink, 2002).

Discharge distribution in 1790 and 1792

The measurements of 1790 and 1792 showed that the discharge distribution of the Rhine discharge

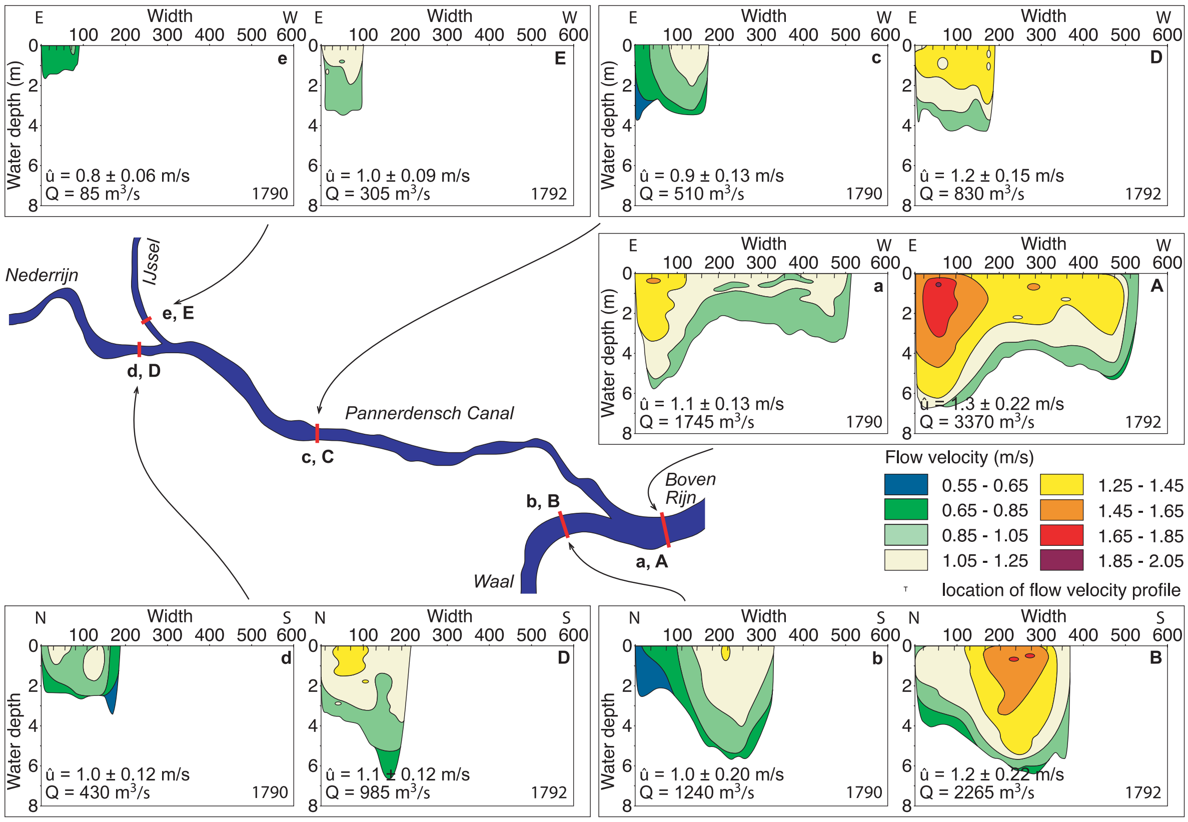

Figure 2. Flow velocities in the the Rhine distributaries in 1790 and 1792, based on the flow velocity measures by Brunings *et al.* (1790, 1792).

over the Rhine distributaries had improved after digging the Pannerdensch Canal (Table 1). The discharge at the end of the 18th century was even almost the same as the desired discharge distribution determined in the 18th century.

Discussion

Changes in channel width and depth, discharge, and valley gradient were quantified using old maps, depth measurements and the flow velocity measurements of Brunings for three periods with specific channel and flow characteristics of the Rhine distributaries (Figure 3):

1 1350-1707 AD. The period between embankment and modification of the Rhine bifurcations is characterized by wide and shallow channel. The specific stream power of the rivers Boven Rijn and Waal is three to four times as high as the stream power of the smaller branches Nederrijn and IJssel.

2 1707-1850 AD. The period from the modification of the bifurcations of the Rhine distributaries to the river normalization is characterized by an increase of discharge of the rivers Nederrijn, and IJssel. Sediment-mobility in the Pannerdensch Canal and the river IJssel was lower than that in the river Waal. This probably caused a tendency of silting of the rivers Nederrijn and IJssel in the long term.

Table 1. Discharge distribution of the Rhine distributaries in 1790 and 1792.

Distribution	Boven Rijn (%)	Waal (%)	Pannerdensch Canal (%)	Nederrijn (%)	IJssel (%)
Desired	100	67	33	22	11
1790	100	69	28	23	5
1792	100	70	31	26	8

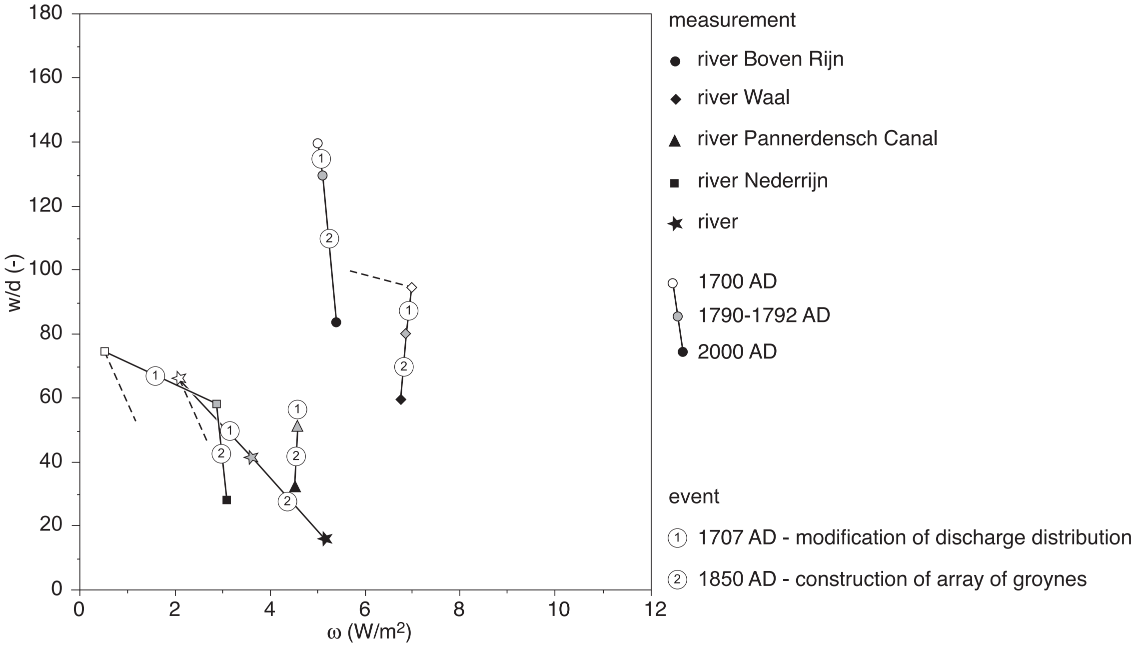

Figure 3. Changes in width/depth-ratio and specific stream power of the Rhine distributaries.

3 1850 AD- present. The period after the river normalisation works to the present is characterized by vertical erosion of the channel, and sediment deposition between the groynes. This had little effect on the specific stream power.

Conclusions

Reliable historical sources are a valuable source of information for the reconstruction of fluvial morpho- and hydrodynamics over the past changes. From these past changes, a few inferences can be made with regard to changes induced by future river management. If the river would be allowed to return to a (semi-) natural condition without groynes and other structures, this would in the long run result in wider and shallower channels with higher width/depth-ratios and smaller specific stream power. Removal of the structures at the bifurcations that ensure sufficient discharge through the Pannerdensch Canal would potentially lead to a renewed tendency of silting-up of the Pannerdensch Canal and the river IJssel, and eventually abandonment of the rivers IJssel and Nederrijn.

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Genesis of floods

How much water can reach the Netherlands through the river Rhine; IRMA-Project LAHoR and future investigations

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Abstract
In the frame of the IRMA-Project LAHoR investigations were carried out to quantify the influence of land use and river training measures on flood conditions in the Rhine river basin. The results show, that land use changes and currently planned retention measures cause minor effects upon the discharge at Lobith. It is obvious that with a better coordination of design and use of the retention measures the efficiency could be improved.
Based on these results further investigations are now done by Rijkswaterstaat, Province Gelderland and Nordrhein-Westfalen (NRW). Extreme rainfall, discharge capacity of the existing riverbed in NRW, inundation behind the dike and flood reduction measures are taken into account.

Introduction
Presently in the Netherlands there are several activities going on, which are important for coping with the problem of flooding along the Rhine branches:

- "Ruimte voor rivieren/Rijntakken: (Room for the rivers/Rhine branches);
- "spankrachtstudie" (Resilience study);
- "Noodoverloopgebieden" (Detention areas);
- "Randvoorwaardenboek" (Design flood).

All studies are dependent on boundary conditions and therefore assume discharge values for the Rhine at Lobith. Main questions are: "How much water can reach The Netherlands through the Rhine" and "What are the factors which influence the discharge in/from the catchment"? Therefore RIZA has carried out several studies to get an answer to these questions. One of these projects was the project LAHoR (Quantification of the influence of the land surface and river training on flood conditions in the Rhine catchment), which took place in cooperation with the Potsdam Institute for climate impact research (PIK), the Institute of Hydraulic engineering, University Stuttgart (IWS) and the Bundesanstalt für Gewässerkunde (BfG). Main goal of the project was to find out the influence of land cover, climatic boundary conditions and river training measures upon flood discharge.

Methods
For the investigation the rainfall-runoff model HBV was modified and used by IWS. Thus in addition to snow accumulation and melt, soil moisture, runoff generation and a simple flood routing interception storage, different land use classes and special effects of sealed areas could be simulated. HBV was coupled with the 1-D flood routing models SYNHP (for the upper Mosel) and SOBEK (for the rivers Main, Neckar and the Rhine between Maxau and Lobith), which made a combined modelling of land-use changes and retention measures along the main rivers possible. Five land-use scenarios were calculated: IST92 (present state of land cover year 1992), LN1 (scenario IST92 with an urbanized area enlarged for 2%-points), LN2 (LN1 with reduced sealed area), LN100 (IST92 with doubling of urbanized areas) and LNW (Rhine catchment entirely wooded). There were two retention scenarios taken into account: with retention measures (65 Mio m^3/s along the Niederrhein and 97.2 m^3/s along the Oberrhein) and without measures. Based on the historical precipitation data from the floods 1983, 1988, 1993, 1995 the model events (M83, M88, M93, M95) were generated using this precipitation data. In addition for the flood 1995 the model events M95+ and M95++ were created by increasing the rainfall for 20% only and increasing the rainfall for 20% plus adding a snow cover of 20 mm, respectively. Since

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the rainfall runoff model HBV only covered the catchment area downstream Maxau (Rhine) and Perl (Mosel), the measured discharges were used for the upper boundary conditions at Perl and Maxau. Thus upstream effects enlarging precipitation (M95+ and M95++), land-use change and retention measures could not be taken into account.

Results

Table 1 gives an overview over the resulting discharges of peak flow with corresponding return periods at Rees.

Table 1. Discharge Q and return periods (RP; flood series 1901 - 2000) of peak flow at Rees (Lobith) for land use scenario IST 92 (land cover year 1992) without retention measures.

	Q [m³/s]	RP [year]
M83	10350	25
M88	10955	40
M93/94	12089	70
M95	12509	80
$M95^{+}$	14948	600
$M95^{++}$	15328	800

Even the effects are different from place to place along the Rhine and different model events, the effects of the land-use scenarios LN1 and LN2 are rather small with an increasing flood peak of up to 1 cm / 40 m³/s at Lobith and greater effects for LN100 with up to 8 cm / 250 m³/s. In all cases maximum effect (i.e. increase of discharge and water level) could be observed at the rising limb of the flood wave (Figure 1). Greater effects could be observed for LNW (up to 80 cm / 2300 m³/s peak water level/discharge reduction at Lobith), with an over all decreasing discharge and water level over the whole flood wave. In all cases the size of the impervious areas loses significance when rainfall increases.
The reduction effect of forest cover decreases in case of extreme rainfall.
For Lobith also the effect of the retention measures is rather small with 3 cm / 95 - 101 m³/s reduction of peak water level / peak flow independent from the model flood (Figure 2). One reason for the small influence of the retention measures upon the flood peak is the fact, that the retention measures are already full when the flood reaches its highest level. It is expected, that the retention measures can be used more effective.
The combined effect of land use scenarios and retention measures is the sum of the single effects.

Conclusions

Even the land use changes are rather small for Lobith it could be shown by other subprojects of LAHoR (Bardossy *et al.*, 2002), that the effects for

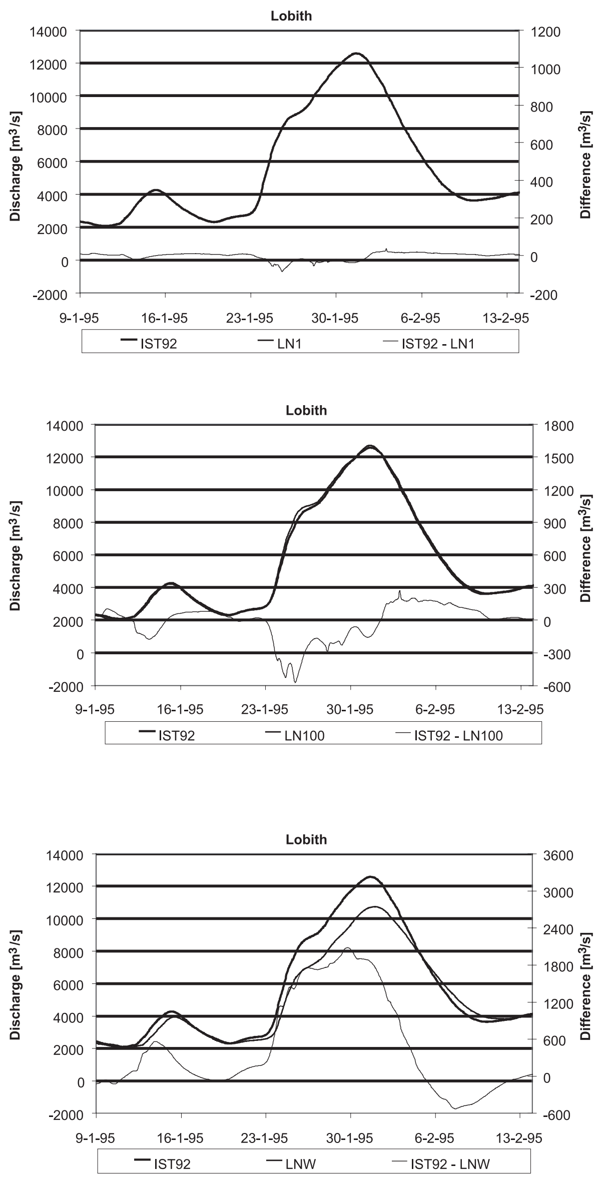

Figure 1. Impact of land use changes on flood waves at Andernach and Lobith (Model flood M95).

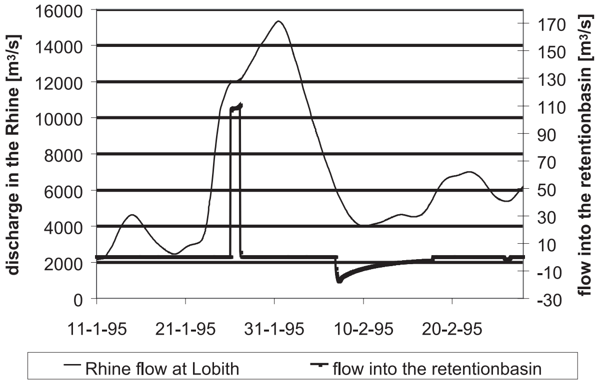

Figure 2. Discharge in the Rhine at Lobith and filling/emptying of retention polder Bylerward (Model flood M95++; Land use scenario IST92).

small catchments are remarkable, thus making land use changes an important tool to reduce flooding.

Also the effects of the planned retention measures are rather small, since the retention measures are already full when the flood reaches its highest level. Therefore more effective use of retention must be found.

There are other aspects, which could not be taken into account by the LAHoR-project:

- More sophistic way of generating extreme model floods;
- Rainfall-runoff procedure in the catchment upstream Maxau (thus covering the whole catchment);
- Retention measures along the Oberrhein between Basel and Maxau;
- More effective use of retention measures along the Niederrhein;
- Overflowing of dikes along the Ober- and Niederrhein;
- Inundation behind the dikes of the Niederrhein.

Therefore further investigations are carried out in the project "Extreme floods and flood protection along the Rhine in Nordrhein-Westfalen (Germany) and Gelderland (The Netherlands)" (Lammersen *et al.*, 2002).

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Extreme floods and flood protection along the Rhine in Nordrhein-Westfalen (Germany) and Gelderland (The Netherlands): A transnational floodprotection strategy

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Abstract

After the floods along the Rhine in 1993 and 1995 the Province of Gelderland, Rijkswaterstaat and the Ministry of Environment, Nature Conservation, Agriculture and Consumer Protection in Nordrhein-Westfalen signed a declaration of cooperation in flood protection. As part of this cooperation a project is carried out to investigate the effects of extreme floods along the Rhine in Gelderland and Nordrhein-Westfalen. Main questions of the project are:

- What are the extreme floods that can occur in Nordrhein-Westfalen and Gelderland?
- What is the discharge capacity of the existing riverbed between the dikes in Nordrhein-Westfalen and Gelderland?
- What happens, when design flood level is exceeded and which areas are flooded?
- What is the effectiveness of new flood protection measures such as retention basins and the enlargement of the riverbed between the dikes?

Introduction

In 1988, 1993 and 1995 high discharges in the Rhine catchment caused severe flooding in areas along those parts of the Mosel and Rhine, which were not protected by dikes. In the province of Gelderland 200.000 people were evacuated in 1995 because of fear that the dikes might burst and large low-lying areas (polders) would be inundated. These events made clear that floods in the Rhine are a problem of the whole catchment area and that transnational co-operation is vital for a proper flood protection system.

As result in November 1997 the Province of Gelderland, Rijkswaterstaat and the Ministry of Environment, Nature Conservation, Agriculture and Consumer Protection in Nordrhein-Westfalen signed a declaration for co-operation in flood control.

As part of this cooperation the project "Extreme floods and flood protection along the Rhine in NRW and Gelderland" is carried out to investigate the effects of extreme floods along the Rhine in Nordrhein-Westfalen and Gelderland.

The project is carried out by the Province of Gelderland, Rijkwaterstaat-East-Netherland, Rijkswaterstaat-RIZA, The Federal Institute of Hydrology (BfG) and the Landesumweltamt Nordrhein-Westfalen. An application has been submitted to receive funding from The European Regional Development Fund, INTERREG IIIB.

Methods

The project is divided into four parts (Figure 1). Part 1 investigates which extreme floods can be generated in the river catchment of the Rhine upstream of Andernach and of the tributaries along the Niederrhein in Nordrhein-Westfalen. A rainfall-runoff model covering the whole catchment area of the Rhine until Lobith is used in combination with an one dimensional flood routing model. To generate hydrographs of extreme floods the rainfall-runoff-model is fed with 1000-year rainfall data generated by a rainfall generator. As a result hydrographs of extreme floods in the Rhine at Andernach and at the tributaries of the Rhine downstream Andernach are calculated for the present situation in the catchment and the future situation with planned retention measures along

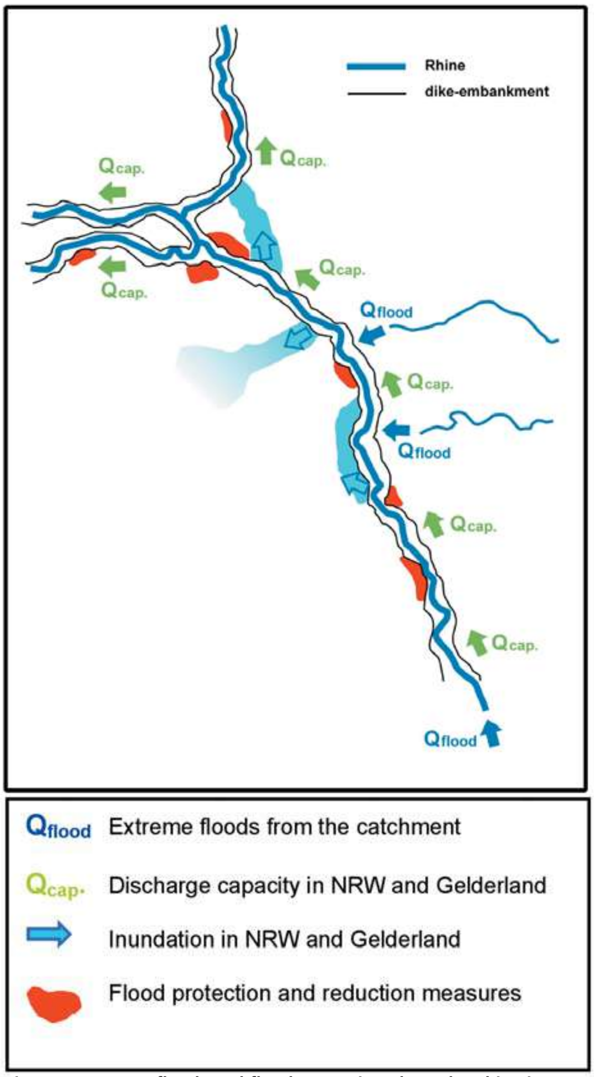

Figure 1. Extreme floods and flood protection along the Rhine in Nordrhein-Westfalen and Gelderland, a transnational floodprotection strategy.

the Oberrhein as well as future climatic changes. Possible dike overflow along the Oberrhein is also taken into account.

Using these hydrographs a two dimensional inundation model, which covers the whole area of the river between the dikes and behind the dikes in Nordrhein-Westfalen and Gelderland is used to determine the discharge capacity of the Rhine (part 2). It also describes the inundation behind the dikes after dike overflow (part 3).

The extreme flood waves from part 1 of the project are also used to calculate the flood routing in the German Rhine downstream Andernach and the Rhine branches in The Netherlands (part 4). A decision support system (DSS) is used. It is based on a one-dimensional hydraulic model. Flood protection measures, such as retention basins and enlargement of the floodplains are introduced into the DSS to investigate the effectiveness of the measures.

By coupling this model with the 2D-inundation model the effects of the flow of water from the river into the polder behind the dike and flowing from the polder back into the river can be taken into account when using the DSS.

Expected results and conclusions

The project is expected:

- To raise knowledge on the occurrence and behaviour of extreme floods in the Rhine catchment;
- To indicate flood prone areas in Nordrhein-Westfalen and Gelderland;
- To develop techniques and tools for evaluating flood protection measures;
- To develop an effective transnational flood protection strategy.

This project also will lead to a strengthening of the co-operation between regional and national authorities in Germany and The Netherlands in the field of flood protection.

The impact of climate change on the water balance in (sub)arctic basins

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Introduction

The Arctic is considered to be particularly sensitive to climate change and global warming can have immediate as well as long-term effects on the river systems. The impact of climate change on the hydrological system in the (sub)arctic Usa basin, East-European Russia was studied on time scales from months to years. The study shows that annual discharge increases as a result of global warming and the (sub)arctic regime may give way to a pluvial discharge regime. The effects of climate change may be non-linear and snowmelt runoff either increases or decreases depending on the amount of snowfall. Changes in climate and consequently in discharge in the Usa basin can have major implications for human society and the environment.

Hydrological modelling

A monthly hydrological model (USAFLOW-2) was applied in a simulation of the water balance components in the Usa basin for different climate conditions (Figure 1 and 2). The USAFLOW-2 model operates with monthly time steps. The model uses monthly temperature, precipitation and radiation, a digital elevation map (DEM), a vegetation map, and a permafrost map as input. The climate scenarios considered in this study were obtained from the HadCM3 Climate Change Experiments. Four integrations of HADCM3 were used, forced using the SRES A1, A2, B1 or B2 emission scenarios. The impacts were evaluated for the projections, 2010-2039 (2020's), 2040-2069 (2050's), and 2070-2099 (2080's).

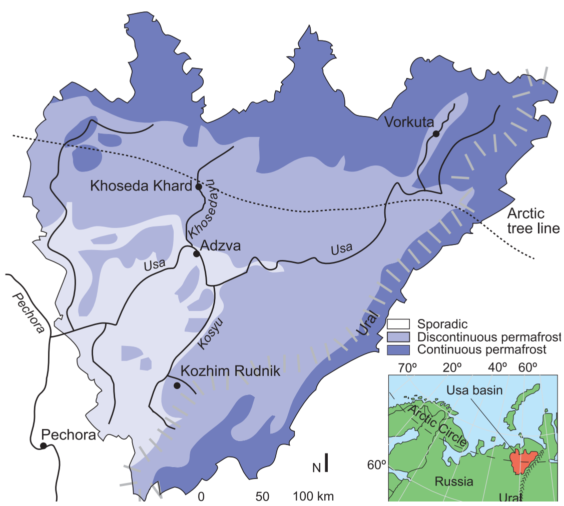

Figure 1. The Usa basin with the hydrometeorological stations in the East-European Russian Arctic.

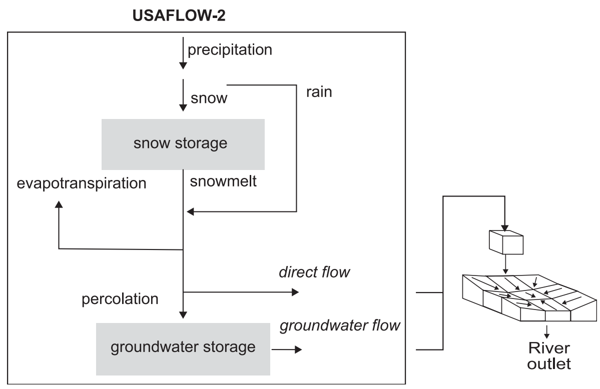

Figure 2. Flow diagram of the USAFLOW-2 hydrological model.

Changes in annual water balance

Changes in rainfall and snowfall, evapotranspiration, and discharge simulated by USAFLOW-2 were examined for the entire Usa basin. The rainfall-snowfall ratio increases as well as annual evapotranspiration amounts (Figure 3). Discharge is also simulated to increase for all four scenarios and is caused by the progressive increase of precipitation from present-day to the 2080's. The proportion of direct runoff versus groundwater runoff increases for the 2020's projection, because water availability increases, while percolation is hampered by the occurrence of permafrost. For the 2050's however, the thawed permafrost results in an increasing amount of percolation and a larger groundwater flow is sustained. Consequently, the ratio of direct versus groundwater flow decreases.

Seasonal changes in discharge

In figure 4, the range of the monthly changes of all four scenarios for each projection is shown. Spring runoff increases except for the HADCM3A1 scenario where discharge decreases for the 2080's. For the 2050's and 2080's projections, the peak shifts to May instead of June. Changes in summer flow are either positive or negative and are smaller than 5% for all scenario simulations. The amount of discharge in autumn and winter increases for all scenario integrations. The simulation with the HADCM3A1 scenario for the

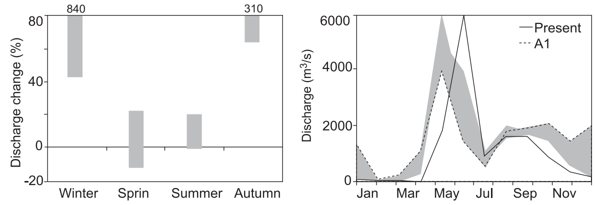

Figure 4. Mean seasonal discharge change (left) and monthly discharge regime (right) at the outlet of the Usa river for 2010-2039, 2040-2069, and 2070-2099. For each projection, an envelope is given that represents the range of the discharge changes as well as discharge for all four scenarios.

2080's shows the effect of a large temperature increase on the discharge regime. Autumn flow and especially winter flow become much more important at the expense of spring flow. As a consequence, the discharge regime changes from a (sub)arctic nival regime to a pluvial regime.

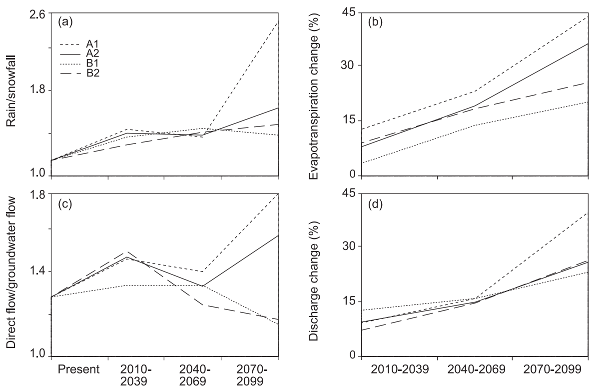

Figure 3. 30-Year mean changes in the ratio rain/snowfall (a), evapotranspiration (b), discharge (c), and the ratio direct flow/groundwater flow (d) for the 2020's, 2050's, and 2080's simulated by HADCM3A1, A2, B1, and B2.

Discussion and conclusions

Changes in climate and consequently in discharge in the Usa basin are expected to have the following implications for human society and the environment:

- Increased availability of water for industrial and domestic purposes in seasons that have limited water available at present (for example the winter season);
- A more even distribution of discharge throughout the year and the earlier break-up will be beneficial for inland navigation;
- Peak flow could increase and consequently floods will be more abundant;
- A discharge increase of all northern rivers can seriously affect the thermohaline circulation of the North Atlantic and consequently global climate.

Environmental flow requirements for livelihood - the development of a conceptual model

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Introduction

River water flowing into the sea has for a long time been regarded a waste of water. By constructing dams and weirs and abstracting water, man tried to exploit the river mainly for economical purposes. During the middle of the last century people became aware of the fact that these interventions in the river flow regime have important negative ecological and social effects in the downstream riverine and coastal areas.

This forms a challenge for integrated river management: besides the various demands that water resources managers already had to deal with when allocating the scarce water resource, the river itself has come up as an extra demand. To determine what characteristics of the original flow regime should be maintained so-called environmental flow assessment (EFA) methods have been developed.

For people living along rivers, the river ecosystem is important for many aspects of their life. It forms a direct source of water for drinking or washing, but is also a prerequisite for fish populations and other animal and plant species, which are used by people, and provides conditions for activities like navigation. Changes in the flow regime of a river may therefore threaten the livelihood of people living along this river.

Environmental flow assessment methods offer an opportunity to protect the interest of these people. However, current methods often focus on ecosystem characteristics, which do not necessarily relate to the livelihood of people. To consider livelihood in the assessment of environmental flow requirements, insight is required in what functions the river ecosystem has for the lives of people. This can be different for different groups of people; fish, for example, may form the main income to fishermen, but may also form the main source of protein in the daily diet of an entire village.

Few EFA methods consider livelihood, and the ones that do, neglect the importance of explicitly distinguishing the different functions for different groups of people and do not provide quantitative and transparent relationships between livelihood and river flows. Therefore, research is undertaken aimed at developing a method to determine environmental flow requirements for livelihood in a transparent, differentiated and quantitative way. This PhD research is defined within the framework of the Delft Cluster project Environmental Flow Requirement and Aid for Integrated Management (ENFRAIM). The objective of ENFRAIM is to develop the concept of environmental flow requirements (EFR) into an adequate planning tool for integrated river and coastal management. Enfraim is linked to a capacity building programme between Delft Cluster and the Bangladesh University of Engineering and Technology (BUET). As a first step a conceptual model for relating livelihood to river flows is being developed, based on literature research. This conceptual model will be tested in a case study in Bangladesh, after which it will be adjusted and again tested in another case study. The final model, translated in terms of quantified relationships will be incorporated in a river basin simulation model as well as in an existing environmental flow assessment method. This paper describes the preliminary conceptual model.

Preliminary conceptual model

A general environmental science model for the relationship between functions of the environment, the environment and human activities (Klijn, 1994) forms the basis for the conceptual model (Figure 1a). From left to right this model shows a standard setting chain, whereas from right to left it shows a chain of effects. In this research we are interested in the standard-setting chain. Starting at the socio-economic river-ecosystem functions (functions/values), then to

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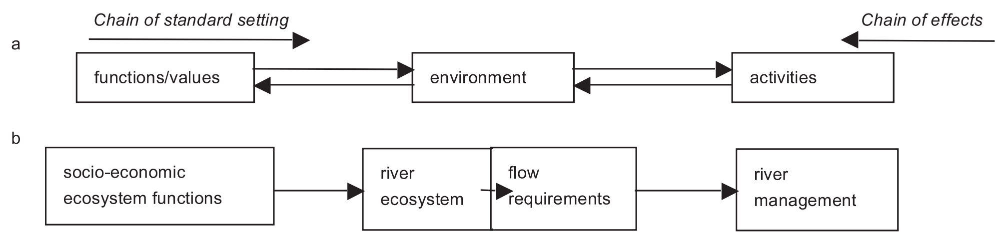

Figure 1. Relation between human use, environment and activities in environmental science (a) and with respect to river flows (b).

the river-ecosystem itself (the environment), which provides the functions, and more specifically to the river flows required for maintaining certain functions. Finally the required river flows need to be translated in activities of the river management, such as dam operation or reduction of water abstractions.

Starting from the socio-economic functions of the river-ecosystem we can identify relationships in two directions:

1 Between the river-ecosystem functions and the lives of (groups of) people living along the river;

2 Between the river-ecosystem functions and the river flow regime.

Relationship between the river-ecosystem functions and the lives of people living along the rivers

The socio-economic value of a good or service depends on the way it contributes to human welfare (De Groot, 1992). Different groups of people may have different understandings about what they consider human welfare, and may also use different functions to contribute to their own welfare.

Consequently, the first step must be to identify different groups of people living along a river. Groups of people can be distinguished by, for example, main income source, geographical location, or gender. Subsequently, indicators need to be defined for the concept of "human welfare" or "livelihood", which can e.g. be related to health, income, or food. In relating these livelihood indicators to groups of people, different priorities of different groups have to be considered. Moreover, the link between the defined indicators and the functions of the river ecosystem can vary for each group as well.

Relationship between the river-ecosystem functions and the river flow regime

Most of the functions are related to the river flow regime. However, this relationship can take on many different forms. The river can function as a condition or as a resource. The use of the river ecosystem by humans can be direct: for drinking, cooking, or washing, or by navigating the river; but can also be indirect: by the use of river-dependent plants and animals. The direct use can be split in use of the river channel and of related water bodies. Each of these types of use has its own requirements in terms of water discharge, depth, or velocity. Therefore, to understand what process and parameter of the river flow regime is important to maintain a certain use of river ecosystem functions, insight is required in the type of use of the river ecosystem.

Taking these relationships into account, we end up with the following extended model (Figure 2) for the first two blocks of figure 1b.

This preliminary conceptual model will be elaborated. The elaborated version will be tested in a case study in Bangladesh in the course of 2003.

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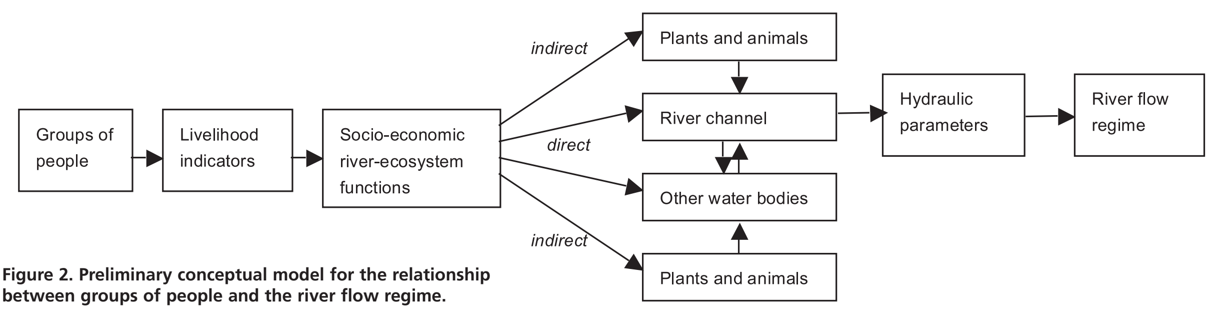

Figure 2. Preliminary conceptual model for the relationship between groups of people and the river flow regime.

The impacts of floods: considering the estimation of direct economic damage and loss of life

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Introduction

Large parts of the Netherlands lie below sea level and are threatened by river floods. Without the protection of dunes, dikes and hydraulic structures more than half of the country would be almost permanently flooded, as is shown in figure 1.
The last disastrous flood occurred in 1953. A storm surge from the North Sea inundated large parts of the Southwest of the country. Apart from immense economic damage, about 1800 persons drowned during this disaster. After the 1953 flood the Delta Committee was installed to investigate the possibilities for a new safety approach. In an econometric analysis (Van Danzig, 1956) the optimal safety level was determined for the largest flood prone area, Central Holland. This work laid the foundations for the new safety approach, in which dikes are dimensioned based on a design water level with a certain probability of occurrence.

Figure 1. The Netherlands without flood protection (the dark area would be flooded due to sea and river floods and the city Amersfoort would be localised on sea).

Since the work of the Delta Committee, carried out in the late 1950's the economic value situated in the flood prone areas has grown rapidly. It can be questioned if the protection standards as derived by the Delta Committee still provide enough protection when the current economic value is considered. In 1993 and 1995 extremely high river discharges occurred in the river system, which made large scale evacuations necessary. Also other recent disasters, such as the crash of the El Al Boeing in Amsterdam in 1993 and the explosion of the fire works storage in Enschede in 2000, have lead to increasing awareness of risks that face society and it's citizens. In the future climate change, the accompanying sea level rise and higher river discharges will lead to an increase of flooding probabilities for the Netherlands.

Background of the project

In the last decade of the 20th century methods have been developed to determine the probability of flooding and the consequences of a flood. These methods form the basis for the risk-based approach of flood protection. In this approach the probabilities and consequences of flooding have to be considered together and in coherence. The developed methods have been applied in a case study (TAW, 2000), in which the flood risks were determined for four areas in the Netherlands. Based on the outcomes of these case studies a project has been initiated to assess the safety of all flood prone areas in the Netherlands. The FLORIS (flood risk) project is carried out by the

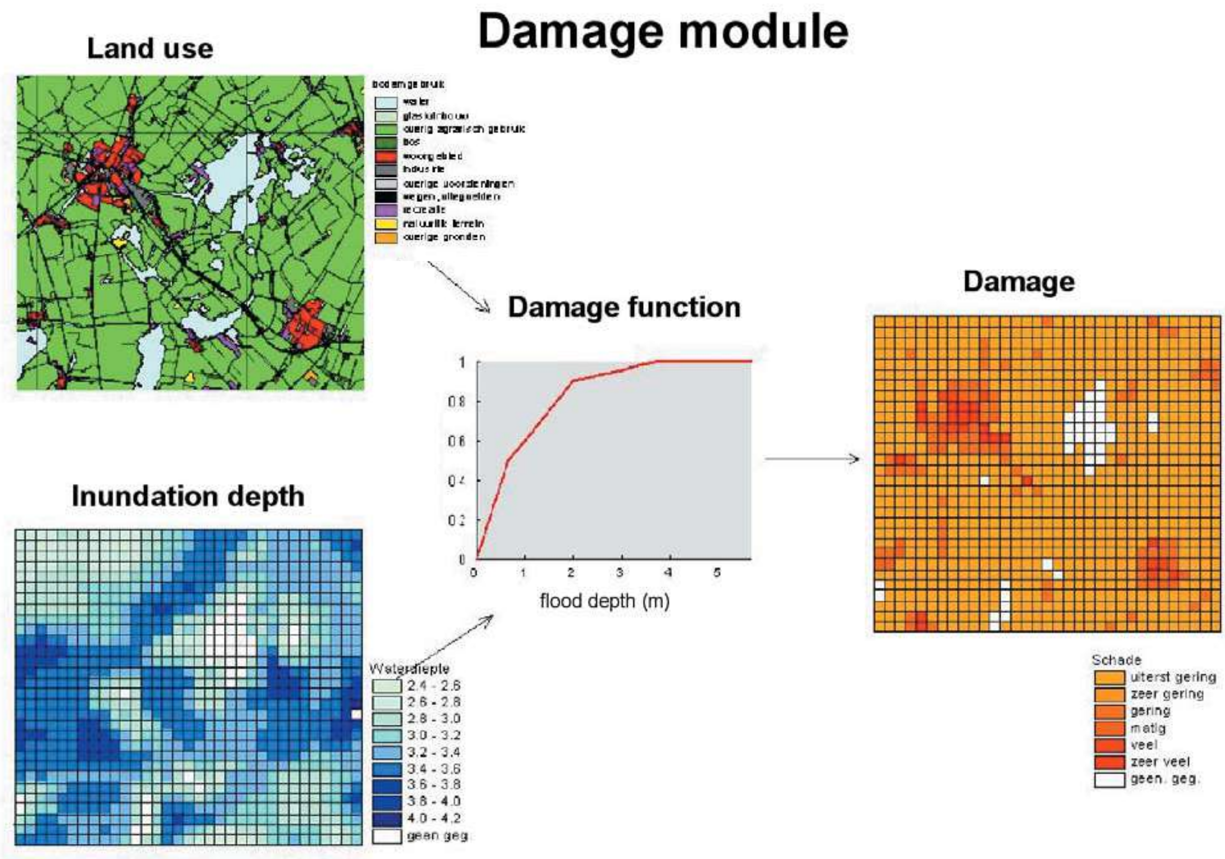

Figure 2. Principle of the method for assessment of economic damage.

Road and Hydraulic Engineering Division of the Directorate General of Public Works and Water Management (Ministry of Transport, Public Works and Water Management) together with the responsible provinces and water boards. FLORIS is divided into the following four subprojects:

1 Assessment of the probability of flooding of dikes and dunes;
2 Assessment of the probability of flooding of hydraulic structures;
3 Determination of the impacts of floods;
4 Development of methods to take into account uncertainties in subprojects one to three (Wehrung, 2003).

The project is scheduled to be finished in 2004 and it's outcomes will give insight in the current flood risks in the Netherlands and provide the basis for an informed discussion on the desired level of flood protection. This paper focuses further on the activities within the third subproject of FLORIS, namely the assessment of the impacts of floods.

Flood risks and the impacts of floods

Insight in the impacts of floods is an essential element in the approach mentioned above. The new insights will make it possible to develop a better view of the costs and benefits of high-water protection measures. These measures might be in the field of reinforcement and elevation of water defences, the lowering of water levels as well as the restriction of the consequences of floods due to technical and governmental measures. Examples of the latter type are measures in the field of spatial planning, which reduce flood damage (potential).

The consequences of floods can be of various nature: loss of life can occur, as well as economic damage, social disruption and damage to landscape, environment and cultural values. Within the flood impacts subproject several studies have been initiated which focus on the various types of consequences. Knowledge from disciplines such as economics, environmental planning, agricultural sciences, psychology, cultural history and nature conservation is hereby used. The remainder of this paper will focus on methods developed for estimation of economic damage, loss of life and the effect of evacuation.

Estimation of economic damage

Statistics on natural disasters show the immense economic damage caused by floods all over the world (see for example Münich Re Group, 2000). Moreover, the statistics indicate a growing amount of floods as well as an increase of the damages per event. An inundation of one of the densely populated, highly economically developed areas in the Netherlands will undoubtedly cause enormous economic damage. The extent of this damage depends on the nature of the flood, for example from sea or river, and the properties of the area, for example terrain height and land use. A method has been developed for estimation of the economic damage due to flooding (Vrisou van Eck *et al.*, 2001). The procedure for damage estimation is schematically shown in figure 2.

Information on land use is combined with flood data (water depth). Damage relations have been developed for different types of land use, which estimate (part of maximum) damage as a function of water depth. The result of the damage assessment is the total economic damage that can be expected, given that particular scenario.

The method as outlined above provides insight for decision makers in the effects of several measures, for example the damage prevention obtained by spatial planning. The method has proven a useful tool in some major projects in river engineering in the Netherlands, including the room for rivers study and the study on the use of emergency retention areas. While the described method focuses mainly on estimation of the direct economic damage, ongoing research (van der Veen *et al.*, 2001) is carried out to gain more insight in the indirect effects of floods on the national economy.

Estimation of loss of life and the effect of evacuation

Floods cause harm all over the world and are the leading cause of death for natural disasters as can be concluded from worldwide statistics (www.cred.be). Although most major floods of the last decades have occurred in Asia, Africa and South America, recent floods in Central Europe and "near floods" in 1993 and 1995 in the Netherlands have raised the awareness on this matter.

Although loss of life is seen as one of the major impacts of floods relatively little research has been done on prediction of the numbers of fatalities for floods. In the Netherlands a method for estimation of life loss has been developed, which is based on data from the 1953 flood disaster, which inundated large parts of the Southwest of the Netherlands and caused 1800 fatalities. In this method the probability of drowning is a function of the local water depth and the rate of rising of the water. It can be questioned whether the circumstances during the 1953 flood and the characteristics of the area during that time still represent the current situation in the Netherlands. For example building strength and warning systems may have undergone many changes since 1953. Furthermore, the function does not take into account the effect of an evacuation. It can thus be expected that the current "standard method" does not give a reliable estimation of loss of life caused by floods. Therefore a special project on loss of life modelling and evacuation simulation has been set up as part of the "impacts of floods" research. Within the suggested framework loss of life should be predicted as a function of flood characteristics and the effect of an evacuation should be taken into account. The following research activities are carried out.

General data from about 1300 worldwide floods, as is included in the international disaster database for floods that occurred between 1975 and 2002, has been analysed (The database is maintained by the Centre for the Research on the Epidemiology of Disasters: www.cred.be). It is investigated whether differences in mortality (fraction of the inhabitants that does not survive a flood) for different types of floods (for example flash flood or coastal flood) and different regions can be found. The outcomes of this study show that flood mortality is mainly determined by the type of flood (flash, river or coastal flood or drainage problems). Striking is the fact that the mortality rates are relatively constant for river floods, regardless the location of the flood. However, the results of the database analysis provide a general impression of flood losses and are not suitable for a more detailed estimation of loss of life for certain flood scenarios.

Therefore data from specific floods is analysed

more in detail to gain insight in the relation between drownings and the hydraulic circumstances of the flood. As a special case study a project is carried out together with the local authorities to analyse loss of life caused by the floods of the Odra in Poland in 1997. This study is at the moment in the data collection phase. Results will be reported in a future paper.
For evacuation a conceptual method has been developed to simulate an evacuation of a flood prone area (Barendregt *et al.*, 2002). The model takes into account various factors, such as the time needed for decision making, predictability of the flood, the required reaction time, infrastructure capacity, traffic management, etc. A typical outcome of the method is shown in figure 3.
The figure shows the percentage of the inhabitants evacuated as a function of time. At a certain point in time the dike breaches and the flood occurs (in the figure after available time). A certain fraction of the inhabitants (f_e) will still be present in the area and these persons will be exposed to the flooding conditions.
The methods developed within the loss of life and evacuation research can provide information on the reduction of impacts and the effectiveness of various measures. Decision makers can benefit from the evacuation model as a tool in their disaster management planning. Moreover, knowledge and methods developed will be important instruments in the risk-based approach of flood protection. The knowledge obtained offers the possibility to quantify flood risks with risk measures such as FN curves and individual risk contours, which are used in other sectors such as chemical engineering and airport safety to assess and limit risks (Jonkman *et al.*, 2003).

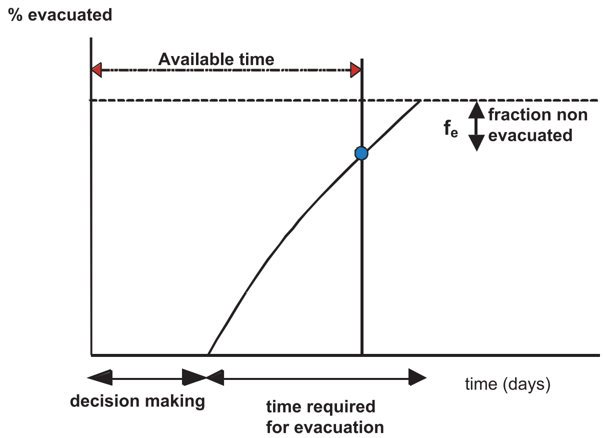

Figure 3. Development of evacuation as a function of time (Barendregt *et al.*, 2002).

Concluding remarks

A risk-based approach of flood protection requires insight in the probabilities and consequences of floods and the accompanying uncertainties. The results of the FLORIS (flood risk) project will provide more insight in the current levels of flood protection in the Netherlands. In this paper an overview has been given of the research within FLORIS on the impacts of floods, specifically considering the estimation of direct economic damage and loss of life. Since this article describes ongoing research activities, no final conclusions can be given yet. However, some concluding remarks are made here. International cooperation is necessary for the improvement of insight in flood impacts. "Learning from each other's mistakes" should be the basis for an improvement of the current methodology. Finally, the discussion on the desired level of flood protection should be based on open and objective information, in which the costs and benefits of various alternatives should be clearly put into perspective, without the exclusion of any type of measure. The methods outlined in this paper can provide a valuable contribution to this discussion.

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Uncertainties in the calculation of flood risks

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Background

Large parts of the Netherlands lie below sea level and are threatened by floods. For many foreigners this idea is hard to understand and even frightening. Dutch people themselves hardly even think about it. On the other hand everyone knows the great significance of '1953' in the country's history. In this year a storm surge from the North Sea inundated large parts of the Southwest of the country. The near-disaster of February 1995 is even fresher in people's memories. That year the Rhine and the Meuse drained large volumes of rainwater and thereby threatened the stability of embankments that had not been reinforced.
The requirement for protection against floods is laid down in the Flood Protection Act. Purpose of this Act is to provide long-term safety. For this reason the Act also outlines future developments in ideas concerning safety and flood defences.

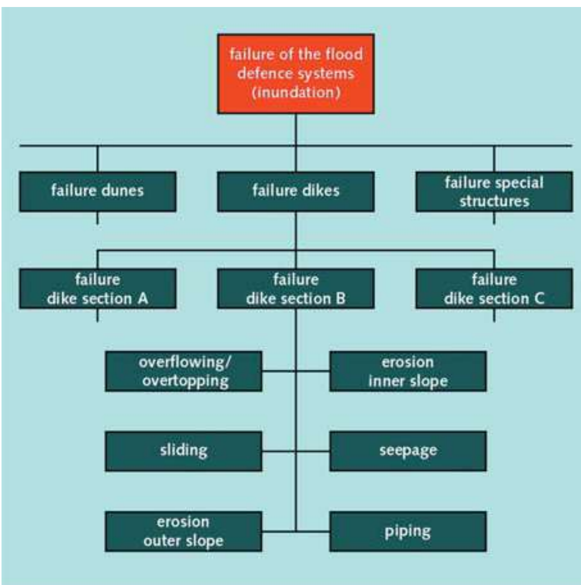

Figure 1. Causes of failure of flood defence structures.

Basis for the Act was the report of the Delta Committee, which was published in 1960. In this report the Delta Committee suggested the Delta Plan in which it was proposed to shorten the coastline of the South-West of the Netherlands considerably. The committee also argued for a more scientific approach by suggesting the determination of a desired level of safety per dyke area based on one hand on the costs of construction of flood defences and on the other hand on the damage caused by a flood. Due to technical limitations at the time this proposal was translated to a safety level based on design loads (design water levels) per dyke section.
In 1992 under supervision of the Technical Advisory Committee on Flood Defence (TAW) a research programme to investigate the safety of the water retaining structures in the Netherlands has started. Aim of this programme is to develop and apply methods to calculate the flood risk. In the end this will provide the elements to start the discussion whether the desired level of safety should be based on the risk of flooding per dyke area (Figure 1).

FLORIS

The main focus at the start of the programme was to development a method to calculate the probability of flood of a dike area. This method has been applied to four pilot dyke areas. This research (called Sprint) resulted in a report called "Van overschrijdingskans naar overstromingskans" (TAW, 2000). In this report the TAW has recommended to apply this method to all 53 dyke areas in the Netherlands in order to get a first impression of the weak links in the flood defence systems and the gaps of knowledge. Special attention should be given to the strength and dependability of special structures. Further research to gain insight in the size of uncertainties will have to be carried out. This has lead to a new

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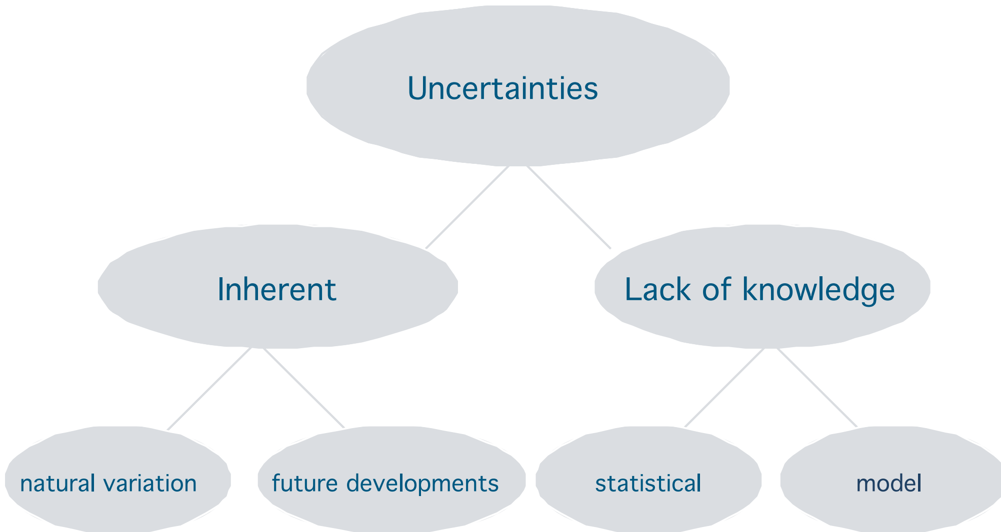

Figure 2. Various types of uncertainties.

project named FLORIS (Flood Risk; In Dutch this project is called: "Veiligheid van Nederland in Kaart"). This project is carried out by the Road and Hydraulic Engineering Division of the Directorate General of Public Works and Water Management of the Ministry of Transport, Public Works and Water Management together with the responsible provinces and water boards. FLORIS is divided into the following four subprojects (Jonkman, 2003):

1 Assessment of the probability of flooding of dikes and dunes
2 Assessment of the probability of flooding of special structures
3 Determination of the impacts of floods3
4 Dealing with uncertainties

The project is scheduled to be finished in 2004 and it's outcomes will give insight in the current flood risks in the Netherlands and provide the basis for an informed discussion on the desired level of flood protection. This paper focuses further on the activities within the fourth subproject of FLORIS, namely the dealing with uncertainties in the calculation of the flood risk.

Flood risks and uncertainties

Insight in uncertainties is an essential element to validate the results of a flood risk calculation. Based on the results of the FLORIS project the question has to be answered whether the safety of a dike area is reasonable in respect to the safety of other dike areas. In other to judge this it is of great importance that the calculated risks are comparable. The flood risks of the different dyke areas are only comparable when they are calculated in a clear and consistent way. Therefore it is very important that known uncertainties are systematically taken into account.

How to deal with uncertainties

First of all uncertainties can be qualified in two types, inherent uncertainties and uncertainties due to lack of knowledge (Figure 2). Inherent uncertainties -different than uncertainties due to lack of knowledge- cannot be reduced by further research.
It is not always possible to group various uncertainties according to the proposed grouping underneath. Model uncertainties for instance can be reduced by more advanced models, but these models often need more statistical data. What happens in this case is that uncertainties are not reduced; only that model uncertainty is replaced by statistical uncertainty.
Also in the way we deal with uncertainties different approaches are used for different types. In dealing with natural variation it is common practise to think in terms of probability (for instance probability of exceeding of extreme

water levels or river discharges).

For dealing with lack of knowledge different approaches are used ranging from 1) simply denying, 2) using safe assumptions, 3) calculating ranges to 4) an integral analysis of all known uncertainties. Probabilistic methods are developed to describe all known uncertainties with a probability density function. This leads to a description of the behaviour of the system that is also described with a probability density function. These methods make it possible that all known uncertainties can be integrated in the calculation. In this way uncertainties will be taken into account in the FLORIS project.

Uncertainties in future developments are mostly described in terms of scenarios. It is very hard and not very significant to take into account probability of occurrence of these scenarios.

Concluding remarks

The results of the FLORIS project will provide more insight in the current levels of flood protection in the Netherlands. Uncertainties play an important role within this research project. Insight in uncertainties is essential to value the outcomes of the project. Therefore a special subproject will be dedicated to develop a method how to deal with uncertainties in the calculation of flood risk. It is very important to realise that further research will never take all uncertainties away. Therefore one should not focus on all the things that are not known yet but on what is known sufficiently sure to draw conclusions or make decisions. The art of engineering is to draw sufficient conclusions from insufficient data.

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International rivers require cross-border river management

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Introduction

The Rhine flows through and along the borders of various countries and manifests in various forms (Figure 1). About 80% of the river is in Germany. Increasing discharges present a danger of flooding. Should Germany also have to solve 80% of the problems, if we consider the increasing indicative discharges?
It is important to look at why discharges have increased and will increase even further. This presentation focuses on the cross-border management of the river Rhine. The proposition being defended is: "International river management is a precondition for adequate high-water protection". This applies to the design and construction of measures as well as, when appropriate, to their deployment.

Increase in discharge

Until a few years ago, it was generally believed that higher discharges were the result of the layout and use of the catchments area. Much of the river's area has been reduced over the past 150 years. There was, and still is, also a tendency to discharge water into the river system as quickly as possible. This makes the job of high-water protection more difficult. Nevertheless, climate change is an even greater threat to the future. Experts tell us that the temperature increase in northwest Europe will give us dryer summers, wetter winters and, especially, greater extremes. A forecasted 20% increase in indicative discharges over the next hundred years is based on the so-called middle scenario. The percentage could be lower, but it could also be a lot higher.
Another aspect for which we suffer from a lack of knowledge is whether climate change will result in a greater coincidence of the tributaries' and principal river's top discharges. This has not been observed up to now, but what developments can we expect in that area? Indicative conditions only occur if everything is adverse:

- Some snow is still on the ground.
- The soil is frozen.
- The soil is saturated owing to a long period of rain.
- The river system is already subject to a considerable load.
- An extremely high level of precipitation falls over a large part of the catchments area.

There is hardly any retention or infiltration of water into the soil under these conditions. All the precipitation travels fairly close to the surface until it reaches the river system. There is no longer any (more) buffer space near the "capillaries".
In the meantime, a report was published on the extreme conditions in the Elbe River. After making a few (necessary) adjustments and projecting this precipitation pattern on the catchments area of the Rhine, computer calculations indicated that summer conditions would not have resulted in any major problems for the Rhine. However, there is some doubt about whether this conclusion would be justified in the case of winter conditions. Does that mean there would then be no major problems occurring?
The water's throughflow time in the river system is so long that upstream retention space can only be used for each river course. The throughflow time

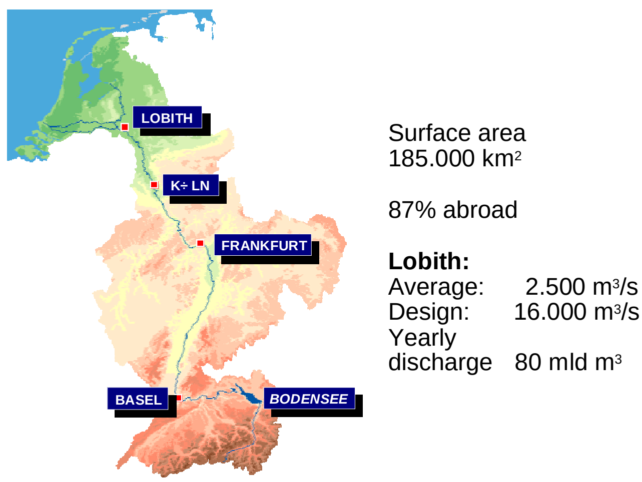

Figure 1. Catchment of the river Rhine.

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Figure 2. A failure in a German dyke may lead to large sections of Nordrhein-Westfalen and the Netherlands being flooded without any retardation.

of precipitation in the river flowing from Basel to Karlsruhe means that it takes 4 to 5 days for the water to reach Lobith. Our prediction method is currently reliable for 3 days. This means that precipitation in the Oberrhein cannot be retained before the Niederrhein and "our" Rhine because the prediction period also does not match.
There are variations in the flooding frequencies of the Rhine. The likelihood of the Oberrhein overflowing is currently 1/50 to 1/200 time per year, depending on the location.
The Mittelrhein largely runs in an eroded valley and has hardly any flooding frequencies. The city of Cologne, for example, still has no protection against high water that occurs 1/100 times per year.
In the Niederrhein, the aim for the southern section is 1/200 and, for the northern section, 1/500 times per year. The aim is to achieve the level of protection by 2015.
In the Netherlands, the standard for the longest section of the river has been set at 1/1250 times per year. The standard becomes even higher closer to the coast. This means that they can take river widening and/or containment measures in the Rhine in southern Germany and France that are very effective for the region, but which offer little comfort for the Netherlands' extremes.

International cooperation

Cooperation with Nordrhein-Westfalen may well lead to results. It must be remembered that our German colleagues make stronger and higher dykes than those in the Netherlands. This largely cancels the differences in safety levels.
Besides river widening measures, retention measures are also either being planned or are already underway in Nordrhein-Westfalen. Their deployment is (currently still) much to early for the Netherlands. They are using those works now, and for the near future, for a discharge rate of up to 14,600 m3/sec at Emmerich, whereas we currently aim for a discharge rate of 16,000 m3/sec at Lobith. If a discharge rate of that level were to occur, the retention provisions in Germany would long have been fully utilized.
In the High-water Action Plan for the Rhine, the countries along the banks of the Rhine agreed, among other things, to reduce extremely high waters by 0.70 m by the year 2020. Partly on the grounds of the conditions explained above, experts assume that the countries will fall far short of achieving this aim. We should be more than satisfied if it proves possible to make up for discharge increases caused by climate change.
It is extremely important that the High-water Action Plan means it is possible to take it for granted that there will be no structural increase in the height of the dykes in Germany, especially in the northern section of the Oberrhein. If the remaining risks in the German-Dutch border area have to be limited, a lot more retention space will have to be provided. As in the Netherlands, this meets with a great deal of (local) opposition. However, a good start might be to construct compartmentalization dykes on both sides of the Rhine, especially in Germany, from Duisburg. This would prevent a failure in a German dyke from leading to large sections of Nordrhein-Westfalen and the Netherlands being flooded without any retardation (Figure 2). Germany has submitted an initial proposal to actually restore a former compartmentalization dyke on the border of the Ooij polder. However, the provisions, which still partly exist, would have to be increased in height and sluice gates would have to be fitted again.
More retention of higher discharges in Germany would also have a considerable effect on the high-water wave. This levelled-off wave could only be further levelled off in the Netherlands if water could be stored in a retention area for a long period.

Conclusion

The above justifies the proposition "International river management is a precondition for adequate high-water protection" and therefore demands that the Netherlands, and particularly Nordrhein-Westfalen, should make a focused and decisive start on the work.

Dynamic river management requires new knowledge

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Introduction

River management is on the threshold of large developments. On the one hand, river restoration of the Maas and Rhine branches, mainly aimed at protection against floods, offers important opportunities for the return of natural habitats, processes and dynamics, like secondary channels, vegetation succession, bank erosion and tidal dynamics. The return of natural processes offers important opportunities for restoration of the environmental quality of our characteristic river landscapes (Figure 1). On the other hand, these river systems are vital for e.g. (inter)national water transport, water supply, recreation and agriculture. These functions impose tight restrictions on natural processes. For example, navigation requires a stable fairway with a guaranteed water depth. Therefore the reintroduction and implementation of natural dynamics has to be planned carefully, in order to avoid detriment or hindrance of the user functions.

The Department of Public Works and Water Management (Rijkswaterstaat) regional directorates involved in river management have made an inventory to gain insight in the expected effects of this more dynamic way of river management on the necessary organisation and knowledge (Douben *et al.*, 2002). The inventory also offers a overview of questions and research demands related to this new way of river management. Based on this inventory further actions will be initiated, e.g. the start of a pilot project to obtain practical experience with dynamic river management.

Research demands

The inventory was directed to people and organizations involved in present day river management. About 50 persons were interviewed. In addition, two workshops were held to discuss the results of the interviews. The first workshop dealt with the relationship

Figure 1. More room for natural processes implies more opportunities for sedimentation and erosion and natural vegetation succession. However, safety against flooding and safe navigation have to be guaranteed. This resulting more dynamic way of river management is aimed at reaching different objectives (e.g. safety, navigation, nature values and recreation) on the long term, but day to day decisions are made depending on day to day situations, expected trends and forecasts regarding exceedance of critical levels.

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between river management and policy goals, the second one was about the practical problems people in the field encounter and foresee with respect to the management of a more dynamic river system.
It was concluded that a dynamic river management requires clear standards for intervention, defining the "boundaries and margins", and monitoring strategies dedicated to more dynamic and variable river systems. Remote sensing techniques, able to collect data from large areas repeatedly, look promising for monitoring the resistance of vegetation to currents. Regarding new knowledge, we need to know more about the following issues.

Hydraulics
- Spatial and temporal scales of natural hydrological processes and hydraulics, especially to improve the quality (or give an indication of the reliability) of the prediction of floods, inundations, droughts, water depth, sedimentation patterns and time scales.
- Possibilities to decrease flood quantities by upstream retainment measures.
- Possibilities to regulate the distribution of discharges over the Rhine branches.

Sediment and morphodynamics
- Interaction between dredging operations and natural sedimentation processes in the fairway and groyne fields.
- Effects of natural hydraulics on bank erosion, secondary channels (design of maintenance free channels), graded sediments, behaviour of bifurcations, floodplain deposits (as natural habitats) and sites for dredged spoil.

Ecodynamics
- Natural development and succession stages of ecotopes, the requirements of different species with respect to hydro- and morphodynamics and, vice versa, the response of species to different management strategies, e.g. to natural or man induced fluctuations of discharge or inundation.
- The potential of "wood debris" to increase the diversity of ecotopes and to improve the water quality.
- The occurrence of algae blooms in relation to increased residence times of water in the floodplains.
- The requirements of resilient ecosystems and the response of these ecosystems to management actions like for instance large scale or repeated lowering of floodplains to increase the discharge capacity (cf. cyclic floodplain rejuvenation).

Specific measures, not included in the inventory
- The planning and possible execution of future flood protection works, like retention basins and diversion channels, generates new questions related to the constructions needed, the inundation process, avoidance of damage to inland areas, and possibilities to combine functions.
- To decide upon deepening of channels in downstream river sections knowledge is needed on the effects on retrograde riverbed erosion, salt intrusion and embankment stability.
- The increase of salt-fresh water transition areas raises questions on the increased influence of tidal dynamics on the downstream river sections (salt content, hydrodynamics, development of habitats, the need to dredge, bank protection, fresh water supply).

Supplementary to these questions, it is also necessary to develop management support systems and the related database and (shared) knowledge management. Models should be able to simulate more accurately the interactions between hydraulics, morphology and ecology on smaller scales, or, if this is impossible, give an explicit indication of the margin of error.

Conclusions
The expected transition towards a more dynamic way of river management requires new knowledge on a wide variety of topics and related phenomena (monitoring strategies, management support systems, predictive models). The Rijkswaterstaat regional directorates involved in river management are willing to stimulate and participate in the execution of necessary research programmes.

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The application of scientific knowledge in river engineering projects

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Introduction

Increasingly, central and local governments, water boards, provinces and municipalities develop plans for flood prevention, river rehabilitation, floodplain reconstruction and reconstruction of polders ("ontpolderen"). These projects have to deal with restricted budgets. Enormous amounts of money are needed for acquiring land, compensation for inhabitants and for construction of works. The budget for the design phase is limited and mostly insufficient for a complete cyclic design process.

As a consequence the design of flood prevention and physical reconstruction plans has to be made with limited tools. Extended modelling is not possible because it is too expensive. What remain are rules of thumb and analytical calculations to derive parameters and boundary conditions. As a result the description of the environmental and hydraulic effects of a design is mostly a qualitative one.

The design process is a cyclic process in the sense that the different stages of the design process have repeatedly to be followed. During the first stage an estimate of relevant ecological, hydraulic and morphological parameters is made. With these parameters a preliminary design is made. Ideally, this preliminary design and its effects on the environment can be quantified with a numerical model such as WAQUA. The results from the numerical model can be used for optimising and adjusting the design. The output of the model can be used as input for rules of thumb and analytical calculations (e.g. to determine the dimension of a stone armoured bed protection). This adjusted design can once more evaluated with a numerical model from which new adjustments can be derived. This can go on and on, until the desired design is obtained.

Rules of thumb approach

Current rules of thumb are often based on expert judgement, experience, hydraulic rules and experimental research. A disadvantage of rules of thumb is the restricted applicability, because they are derived for location specific conditions and can only be used under similar conditions. This

Figure 1. The construction of a meandering side channel along the river Bergsche Maas at Dombosch, near Geertruidenberg (The Netherlands).

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limits the use and for different conditions they have to be adjusted or validated again. Another disadvantage is the large number of rules of thumb for the same problem, and each of them usually gives a different result.

Case studies

The disadvantages of rule of thumb approaches will be illustrated for two projects. An example of the wide range of results produced by different rules of thumb for a similar problem is the construction of a meandering side channel along the river Bergsche Maas at Dombosch, near Geertruidenberg (Figure 1). There are several rules of thumb to predict the meander belt width and de meander wavelength. Application of these rules gave results varying from 300 to 700 m.

Another example is the Zuiderklip project, where it was necessary to predict the development of different types of vegetation in a fresh water tidal environment (Figure 2). There was no general applicable set of rules of thumb available to predict which types of vegetation will develop. From location specific literature and from a neighbouring project it was possible to make an assumption about the development of the vegetation. But at another location it would be hard to make an accurate prediction of the development of the vegetation unless, again, location specific literature is available.

The availability of a set of rules of thumb was desirable for both cases. Other areas of interest for the use of rules of thumb are predicting sedimentation and erosion, the construction of dyke inlets, etc.

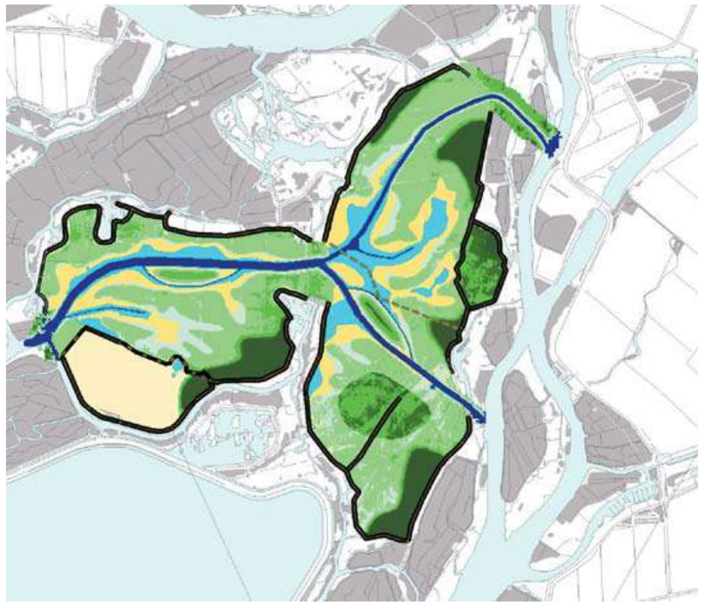

Figure 2. Predicted development of different types of vegetation in Zuiderklip (a fresh water tidal system in the Netherlands).

Conclusions

It can be concluded that the use of rules of thumb has several drawbacks. Their use is restricted to similar conditions as for which they were derived. Often these condition restrictions are not well documented. Another drawback is that different rules of thumb for the same problem often give a whole range of results and sometimes rules of thumb do not exist for a specific problem.

With the implementation of the 'Room for the river' policy in mind it would be beneficial to fine-tune the rules of thumb: both to be able to base a design solely on these rules and also to make an accurate preliminary design. With an accurate preliminary design the use of numerical models is far more effective than when the preliminary design is inadequate.

Communication between river scientist and engineers also needs to be enhanced and some sort of platform is needed to co-ordinate this communication. A good co-operation is needed to quickly pinpoint problem areas. Feedback from practical situations should stimulate pragmatic research.

Finally, during modelling there are still some uncertainties, which cannot be solved because it is impossible to predict all the processes involved completely. Knowledge management will help to minimise these uncertainties. In practical situations some uncertainties are accepted. It is, however, desirable to develop some sort of a "agreed applicability" for the most frequently needed rules of thumb. This "agreed applicability" should include a description for which situations and which constraints the rule of thumb can be used and a general acceptation to use that rule under the described conditions. In this way it is possible to speed up the design process.

Multiple spatial planning: living in harmony with the river

The Planning Kit for the Resilience Study for the Rhine branches

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Abstract

In the last decennium policy regarding river management has changed. Instead of applying ongoing dike reinforcements to protect the population against increasing river discharges the river has to be given more room. In the Resilience Study exploratory investigations have been carried out to define measures that combine the demands of safety for a discharge of 18,000 m^3/s at Lobith with the development of nature. The results of the impact assessment for these measures form the basis for the Planning Kit (in Dutch: Blokkendoos). With the Planning Kit it is possible to explore the possibilities of transporting 3,000 m^3/s extra through the Rhine branches without dike heightening and with a possibility to change the discharge distribution at the bifurcation points (Figure 1).

Introduction

The Resilience Study analyses the possibilities to transport large quantities of water through the Rhine branches without dike heightening (WL | Delft Hydraulics & RIZA, 2002a). It is assumed that in the year 2100 the design discharge at respectively Lobith (river Rhine) and Borgharen (river Maas) will be 18.000 m3/s and 4.600 m3/s, respectively. Furthermore the rising of the sea level is estimated to be 60 cm and the general assumption is that sedimentation in the lower rivers region will increase. The Resilience Study tries to define measures to reduce the peak water levels in the long term. Safety is an important aspect but quality of the environment also plays a significant part in the definition of measures. They should be durable and designed for the future. A new element in the Resilience Study is the fact that the discharge distributions on the bifurcations at the Pannerdensche Kop and the IJsselkop are subject to discussion.

Measures in the framework of the Resilience Study are defined in association with all the involved parties. The character of the measures varies from removing a flood free area from the floodplains, to creating a so-called green river through areas within the dike-protected area or the creation of a detention basin. For all these measures, approximately 400, WL | Delft Hydraulics has carried out an impact assessment that include the hydraulic effects, costs and development of nature. The results of all these effects are integrated in the Planning Kit, developed by WL | Delft Hydraulics and RWS-RIZA. All the hydraulic effects of the measures have been determined with the two-dimensional hydraulic model WAQUA.

Figure 1. Overview of the schematic implementation of the Rhine Branches in the Planning Kit.

The Planning Kit

The objective of the Planning Kit is to give users (policy makers) the possibility to easily define a combination of measures to safely transport 18,000 m^3/s from Lobith to the sea without raising the dikes (WL | Delft Hydraulics & RIZA, 2002b). In the Planning Kit the user can choose how to divide the extra discharge at Lobith over the Rhine branches Waal, Nederrijn en IJssel (Figure 1).

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Dependent on this choice the Planning Kit shows the rise of the water levels. After that, the user can start to play with the available measures to reduce the water levels on all the Rhine branches. The user is directly confronted with the possibilities or impossibilities of his choice. Transporting, for example, 2.000 m^3/s extra over the Nederrijn is not possible because there are simply not enough measures available in the Planning Kit to realise this. Apart from the hydraulic effects the Planning Kit contains a lot of other effects and costs of all measures, as well as a selection of aerial pictures and ground pictures of most of the measures. When the user has defined his total set of measures the Planning Kit gives a summarised report on all these effects.
To be able to use the Planning Kit the assumption is made that the water level effect of a measure does not depend on the discharge and that all the separate hydraulic effects can be added up to find the combined effect. For large sets of measures this assumption is justified. The difference between a 2D numerical simulation of all measures with WAQUA and the result of the Planning Kit for the same set of measures is limited to 0.05 à 0.10 m (Figure 2).

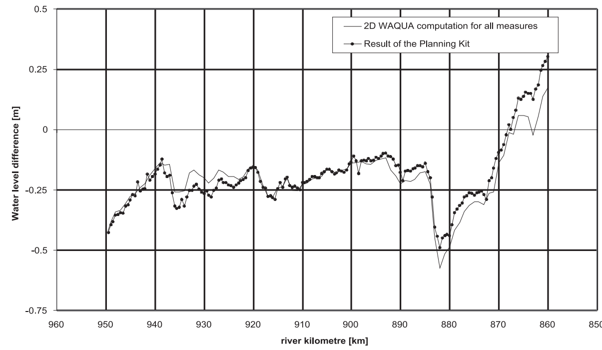

Figure 2. Water level effect of approximately 25 measures along the river Waal as calculated with WAQUA and as determined with the Planning Kit. The water levels by existing dike heights and without additional flood management measures form the reference situation for calculation of water level differences.

Conclusions

In the last year the Planning Kit proved to be a helpful instrument in the development of alternative strategies for flood management along the Rhine branches. It allowed both experts and laymen to learn about the river system. Furthermore it gave people in various organisations the opportunity to evaluate their vision on the design of the Rhine delta: which measures would they like to use and are they sufficient to transport the extra water?

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Multiple spatial planning: living in harmony with the river

Integrated outlook for the river Meuse (IVM); a look upstream of Borgharen

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Introduction

The project *Integrale Verkenning Maas* (IVM) explores the measures that are needed to reduce the flooding risk along the river Meuse on the long term. Reason for this exploration is the expected increase of flood risk due to climate change. IVM has started in December 2000 and will end in spring 2003 with an advice to the Dutch minister of water management. IVM focuses on the Dutch part of the river Meuse, but to evaluate the need for measures in the Netherlands one also has to consider possible measures and developments in the part upstream of the Netherlands. This study explores the possibilities and impossibilities to reduce the flood volume in the Meuse at Borgharen by taking measures upstream of the Netherlands (IVM, 2003).

Method

For this analysis the rainfall-runoff model Lisflood (De Roo, 2000) has been used to simulate four type of floods; the 1993 and 1995 floods, simulated with observed precipitation input, and the 1:250 year and 1:1250 year design discharge at Borgharen, simulated with imaginary rainfall volumes. Next, the effects of reforestation, re-meandering, increased inundation of floodplains, nature recovery in small streams, uncontrolled retention and controlled retention have been simulated by changing the settings of the Lisflood model. The effects of these measures have been simulated for all four types of floods. The difference in model simulation with and without measures gives an indication of the possible effect of above-mentioned measures on the (peak) discharge at Borgharen.

Figure 1. Retention in the Meuse basin. This photo of the Bar, a tributary of the Meuse in France, is taken during an average flood. It shows that also under the present conditions large volumes of water are retained in the Meuse basin.

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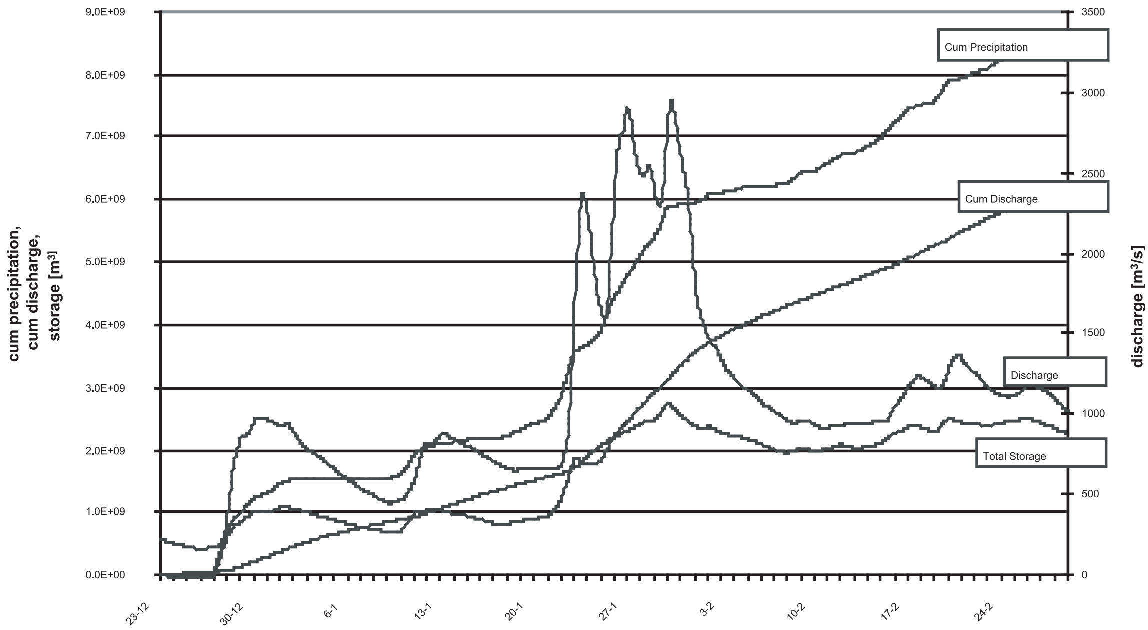

Figure 2. Precipitation, discharge and storage volumes during the flood of 1995. At the moment the 1995 flood at Borgharen reached its peak (end of January), about half of the precipitation volume of the foregoing month had been discharged at Borgharen. This implies that a volume of almost three billion cubic meters was (temporally) retained in the upstream basin. Note that this event took place during winter when evapotranspiration losses are small.

Results

From the model simulations it appeared that reforestation, re-meandering, increased inundation of floodplains, nature recovery in small streams and uncontrolled retention have a limited effect on the peak discharge at Borgharen during extreme events. Only controlled retention resulted in a substantial reduction of the peak discharge at Borgharen. However, in practice it will be difficult to optimise the management of the retention reservoirs, because the efficacy depends on the evolution of the flooding event, which is not known beforehand. The analysis also shows that the present storage volume of the Meuse basin is of a much larger magnitude than the increase of storage volume that may result from the implementation of the simulated measures (Figure 1 and 2). This illustrates the limited capacity to substantially effect the discharge volume of the Meuse during extreme flooding events.

Discussion

The study is meant to get a first impression of the possibilities and impossibilities to reduce the magnitude of the flood volume in the Meuse at Borgharen. The study has its restrictions: The quantification of the measures has been performed with a readily available model, and additional research to quantify the effects of local measures on the discharge at the basin outlet is advisable. To do so, data are needed that are not yet available. Moreover, the study does not judge about the feasibility of the proposed measures. For a more solid analysis international tuning is required.

Conclusion

A quick scan upstream of Borgharen suggests that most measures proposed in this study are insufficient to substantially reduce the discharge volume at Borgharen during extreme flooding events. Controlled retention may be an exception, but only if large volumes are available and the management of the reservoirs are optimised for flood control. These are serious constraints that have to be weighted in an international and integrated way.

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Multiple spatial planning: living in harmony with the river

Assessment studies for the Meuse Programme

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Background

After the floods of the river Meuse in 1993, the “Boertien Committee” made recommendations regarding the increase of protection measures against flooding of the villages and towns in the Meuse valley. The 1995 flood accelerated the construction of embankments, which offer a protection level of occurrence once in 50 years. Additional widening and deepening of the riverbed in the river Meuse and additional elevation of the embankments must increase the achieved protection level to 250 years.

General information

Since 1997, the project bureau “De Maaswerken” has been actively involved with the river-research projects, which bring together the preparation and execution of interventions in the Common Meuse (Grensmaas), Sandy Meuse (Zandmaas) and Maasroute (Navigation route). The project bureau is a joint venture of the Dutch Ministry of Transport, Public Works and Water Management, Ministry of Agriculture and Province of Limburg.
In 1999, “De Maaswerken” published the Environmental Impact Assessment Report (MER) regarding the Sandy Meuse and Maasroute. The project bureau is and will be dealing with the preparations for the purchase of land, the guiding of the execution of the experimental projects as well as the compilation of monitoring plans. For the entire duration of the project execution, the project bureau will co-ordinate and monitor the activities. The ‘Hydraulics and Morphology Team’ has been dealing with river engineering studies, described in this publication.

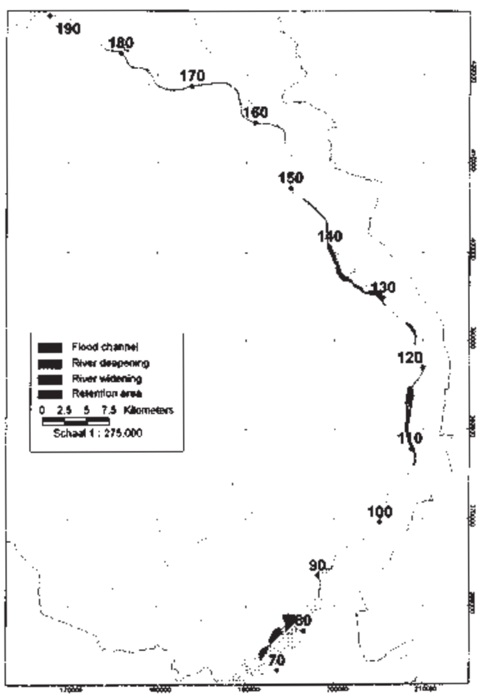

Figure 1. Overview of the river Meuse (river measures Sandy Meuse).

Additional simulations for the Environmental Impact Assessment

After the conclusions of the Environmental Impact Assessment Report (January 1999) the need was felt to verify the conclusions presented in this document, due to the modified insights about boundary conditions (design discharge waves, input from tributaries, downstream water levels) and the possibility to carry out flood simulations of the Meuse with the 2D modelling system WAQUA within acceptable processing times. In particular, this last factor offered the possibility of a high-quality verification of the conclusion as presented in the Environmental Impact Assessment Report report. These calculations showed that the desired protection level, both in the situation after the construction of the embankments and after execution of Maaswerken interventions, would not be achieved. Hence, new and additional river measures were proposed. An additional Assessment Document was published with new conclusions.

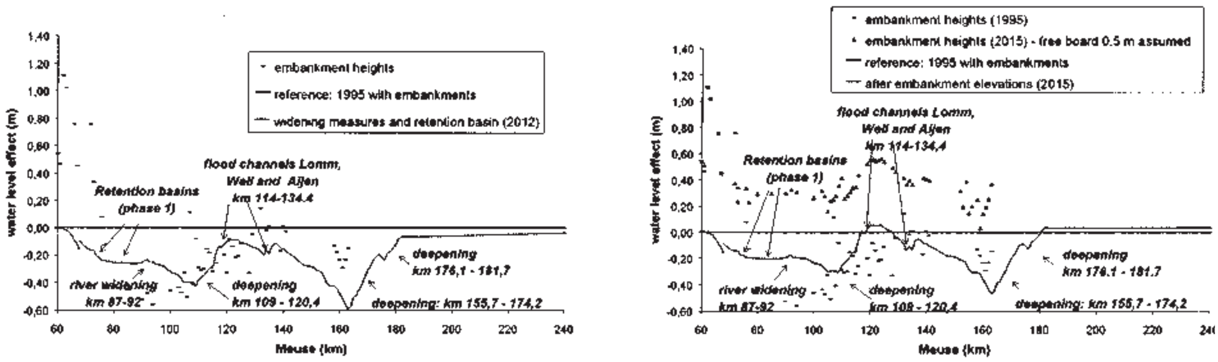

Figure 2. Water level effects computed by WAQUA flow simulations; left: design conditions 1/250 years after Groundplan (2012); right: after final embankment elevations (2015); both with respect to the reference situation (1995).

Groundplan Sandy Meuse

After the realisation of the supplement of the Environmental Assessment Report the Sandy Meuse project underwent a radical change on the basis of research results, with among others the supplemental embankment elevations. The decision for the Groundplan (Tracébesluit) was taken at the beginning of 2002. Figure 1 shows the river measures (river deepening, river widening, flood channels and retention areas).
The aim of the Groundplan Sandy Meuse is a 1/250 years' security level for the villages and towns behind the embankments. This aim will be reached by two means: lowering the design water levels by river widening measures (covered by the Groundplan Sandy Meuse), and increasing the heights of the embankments (covered by the Embankment Elevation Plan, to be determined in the future). At the same time, an important condition set to the project is that these measures may not cause an increase of water levels downstream of the project area for extreme flood conditions (1/1250 years' frequency).

Simulation results: design conditions

The 2D modelling system WAQUA enables detailed flood simulations in which the aim of the project and conditions set to the project can be adequately verified. Figure 2 (left) shows the water level effects of the Groundplan Sandy Meuse for the design conditions (1/250 years' flood). The right plot shows the effect of the final embankment elevations. The river-widening measures (left) cause a general drop of maximum water levels. The embankment elevations, however, cause water-level increases due to cutting off of flow and storage capacity on the floodplains. The resulting effect (right) is generally a decrease of water levels, with the exception of a local hydraulic bottleneck (Broekhuizenvorst-Wanssum) and downstream of the project area.

Simulation results: extreme conditions

Under extreme flood conditions (1/1250 years' flood) there is a downstream water-level increase

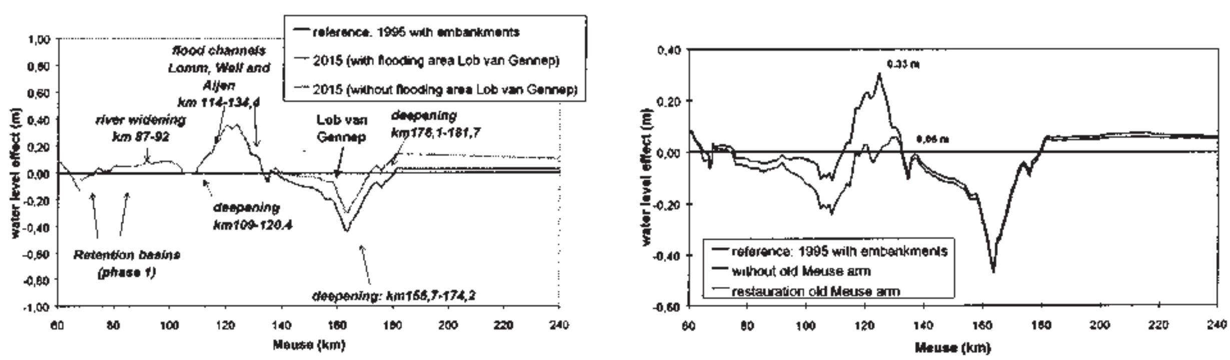

Figure 3. Water level effects computed by WAQUA flow simulations for extreme flood conditions (1250 years), left: the effect of the flood area 'Lob van Gennep'; right: relieve of the hydraulic bottleneck; both with respect to the reference situation (1995).

Figure 4. Results of WAQUA flow simulations: the village Borgharen is safe.

(Figure 3: left, grey line) which can be neutralised by an additional flood area (Lob van Gennep), to be used only for extreme conditions (1000 years' floods and higher). This flood area (10 km2) is situated in an ideal position for its aim: downstream of the project area, upstream of the river stretch to be relieved (Figure 3: left, blue line). The hydraulic bottleneck causes a water-level rise of almost 0,40 m (Figure 3: left), due to increased embankment heights, which cut off an old inundation and flow-conveying branch. This simulation assumes the villages not to be inundated. In reality the embankment heights, sufficient for design conditions, will not withstand extreme floods. Therefore the local water-level rise is expected to be less: 0,33 m (Figure 3 right: blue line). In two additional studies, alternative solutions for this embankment elevation were investigated, with successful results. The restoration of the flow-conveying branch almost compensates the local water-level rise (Figure 3 right: red line).
By combining the numerical results with geographical backgrounds in GIS, inundated and non-inundated villages can be distinguished, and bank elevation heights can be evaluated (Figure 4). In additional studies several project phases (1995, 2001, 2005, 2012 and 2015) were evaluated, in order to ensure that no temporary drop in security against floods would take place.

Additional activities

In addition to the above-mentioned tasks, the 'Hydraulics and Morphology Team' deals with local studies concerning optimisation of river measures (flood channels, retention areas (Figure 5), the hydraulic bottleneck Broekhuizenvorst-Wanssum). Beside, the team is represented in various project teams and advisory teams which deal with navigation, morphology and hydraulic structures, as well as in the project team COBEMA (Compensation Downstream Effects Meuse Programme). In COBEMA several stakeholders, in addition to "De Maaswerken", are represented: Ministry of Water Management Regional Directorate North Brabant, the City of Den Bosch as well as various water boards. COBEMA deals

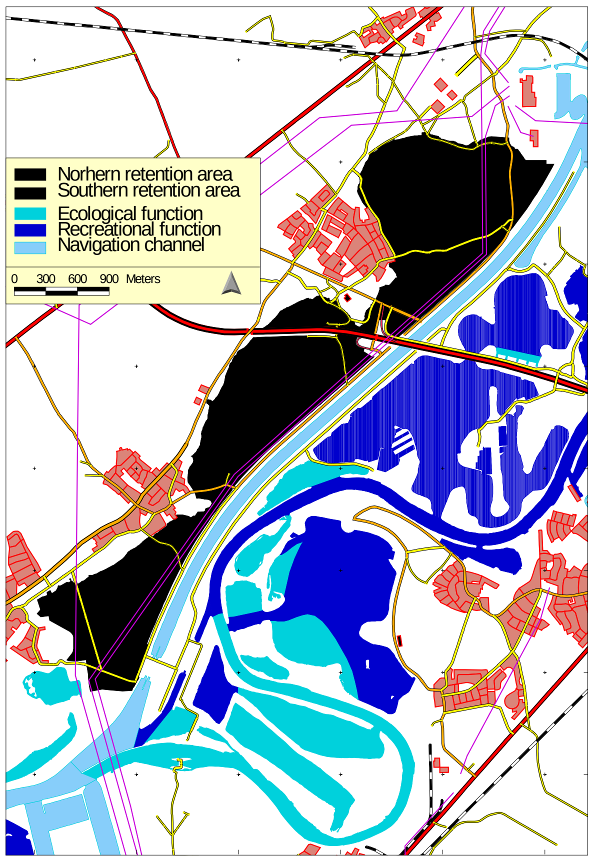

Figure 5. The Meuse near Roermond (with a flood channel, a navigation channel and two retention areas).

with the safety aspects near Den Bosch, which are determined not directly by the Meuse but by its tributary "Dieze". As the works in the Meuse River accelerate the peak of the Meuse flood, the flood level at the mouth of the Dieze River is affected by the Meuse Programme.

Conclusions

The evaluation of the Ground Plan (Tracébesluit Zandmaas) leads to the following conclusions:

- The intended safety level (1/250 years) requires, beside the river-widening measures, the elevation of numerous embankments in the project area. These elevations cause a rise of design water levels, due to a decrease of flow and storage capacity on the floodplains.
- No temporary drop in security against floods will take place during the project phases (1995-2015).
- The flood area 'Lob van Gennep' is essential for relieve of the river stretch downstream of the project area under extreme flood conditions.
- The hydraulic bottleneck (Broekhuizenvorst-Wanssum) can be solved by restoring the flow and storage capacity of the left floodplain. In this case, the villages need to be embanked separately.

Actor analysis for the implementation of the European Water Framework Directive in Turkey

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Introduction

In the coming years, water management in the European Union (EU) will be strongly influenced by the implementation of the European Water Framework Directive (WFD). Not only the current EU member states will have to comply with this Directive, also candidate member states must meet its requirements in order to be eligible for EU membership. Therefore, a Dutch-Turkish consortium is currently working on a project to prepare the implementation of the Water Framework Directive in Turkey.

The WFD requires changes at both the national and the regional level in Turkey, and likewise, the WFD Implementation Project executes activities on both levels. On the regional level, river basin management plans have to be formulated and implemented. These river basin management plans should be developed using a participatory approach, involving all relevant stakeholders. The WFD Implementation Project runs a pilot project for the Büyük Menderes river basin to gain experiences with integrated river basin management in Turkey that can be used on a wider scale in the country.

Actor analysis to support the regional pilot planning project

As part of the river basin management plan development, several parties need to be involved, because the government organisations that are responsible for water management will not be able to realise a sustainable situation without the co-operation of the other parties. The success of a river basin management plan will depend for an important part on the willingness of different parties to contribute to the plan and to the implementation of resulting water management measures. Therefore, an actor analysis has been executed, focusing on the different actors and their views on water management in the Büyük Menderes river basin.

The actor analysis has been done using dynamic actor network analysis (DANA), an approach that is based on the notion that actions and decisions of actors are influenced by their views of the problem situation (Bots *et al.*, 2000). Therefore, understanding these views is important to understand the dynamics of actor networks. DANA represents the views of the actor in cognitive maps, showing the relevant problem factors, important objectives, and their causal relations. An example of such a cognitive map is shown in figure 1. For each individual actor, one cognitive map is made, and the set of maps forms the basis for analysis, which is supported by DANA software (Bots *et al.*, 2000).

The input data for the analysis were obtained through interviews with selected actors in the river basin, allowing them to express their view of water management in the Büyük Menderes river basin. These interviews were conducted using a short list of open questions, covering the formal responsibilities and tasks of the actors, their objectives, their ideas about what the important problems were, causes and solutions for these problems, their opinion on the establishment of a river basin management organization, and their main relations with other actors. Two provinces that are located (almost) entirely within the river basin were selected to conduct interviews, one located downstream (the province of Aydin) and one located more upstream (the province of Denizli).

Summary of main conclusions

The actor analysis provides insight into the views on water management of the different actors in the Büyük Menderes river basin. It shows that there is a general agreement among the upstream and downstream actors in the basin on

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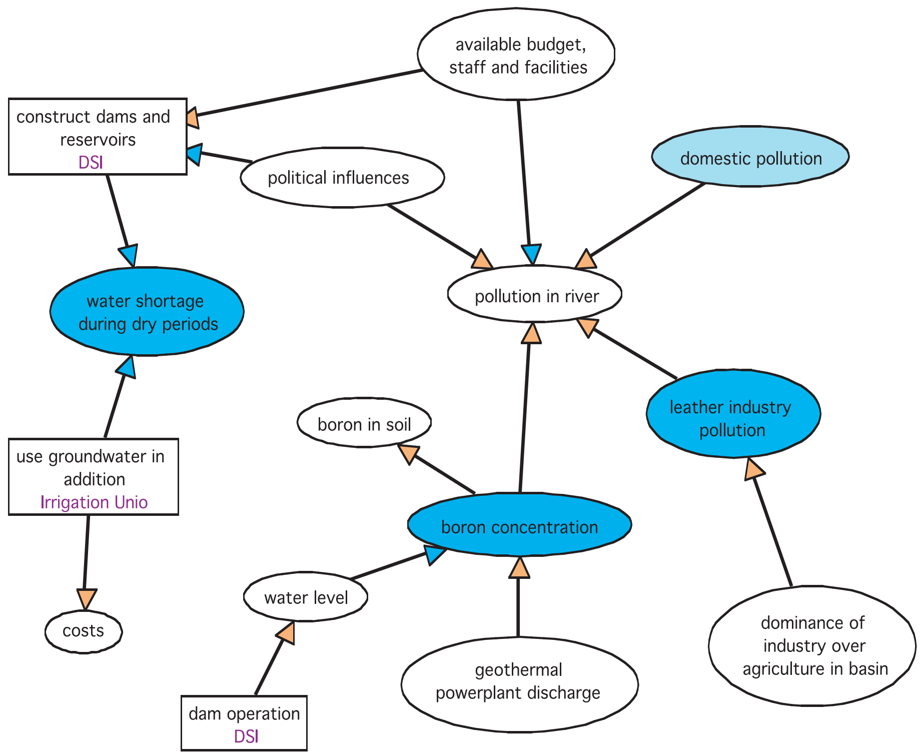

Figure 1. Example of a dynamic actor network analysis map.

the most important problems, which provides a good basis for co-operation on a joint river basin management plan. Problems related to pollution together with institutional problems are highest on the agenda of the actors, followed by problems related to agriculture and irrigation. The limited resources, financial as well as personnel and equipment, pose important limitations to the problem solving capacity in the basin, which clearly indicates the need to set priorities; it will not be possible to address all issues with the same intensity at the same time. Several instruments have been identified to solve some of the problems. Technically, most of these solutions will not be difficult to implement, but finding the necessary funds, people and equipment is likely to be the bottleneck.

Evaluation of use of DANA to support the regional pilot project

The actor analysis is believed to have some positive effects for the regional pilot project. The actor analysis structures the water management problems in the basin and provides focal points for further elaboration. Also, the consultation of a wide range of actors reduces the risk of a biased problem formulation by the project team. Finally, the actor analysis results helped to prepare the first stakeholder workshops in the basin, starting the actual process of plan development by the actors themselves. Nevertheless, the exact contribution of DANA cannot yet be evaluated, as the regional working group is currently working on its own problem formulation, and it remains to be seen to what extent they find the DANA input useful for their work. The analysis contains a first overview and analysis of the opinions of a wide range of relevant actors, and therefore it hopefully can serve as a good source of inspiration and as a help to focus the activities in the coming months.

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Policy crashes, styles of regulation and styles of science in river management

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Introduction

Dutch river management policy has changed dramatically in the last decade. This was partly caused by several near flooding disasters. However, perhaps even more important was a radical - if not paradigmatical - change in the perception of river management and flood prevention, by the responsible actors.

The idea was abandoned that the only or best way to prevent a river from flooding was to contain the river inside a rather narrow but well embanked high-water bed. It no longer seemed to be an appropriate or even realizable solution. In its place a new and far more dynamic vision on water management was developed. It turned out to be an almost complete U-turn: instead of the static and almost exclusive emphasis on containment, the accent was placed upon the enlargement of the absorptive capacity of the river basin, on giving the river more space to (over)flow. But that was not all. An integral part of this new approach was the 'prescription' that it should not hamper the other functions of the river, such as navigation, or fundamentally disrupt the possibilities for people to live, work and recreate alongside the river. In fact, the essence of the idea was the wish to develop a management approach that would benefit simultaneously as much actors and functions as possible.

The core of the policy crash problem and its 'social nature'

Since this almost revolutionary shift in the thoughts about river management, a lot of new approaches have been thought over, tested and sometimes applied. The result was a number of significant policy successes but also a number of rather spectacular policy crashes.

The daring novelty of the policy and the great discrepancy of the outcomes have encouraged an intensive discussion and raised a lot of questions. Often these questions have a social undertone. No wonder that planners and policy makers frequently look at the social sciences for assistance to find the answers. From time to time they got answers. However, these answers often are not as convenient as hoped. This is especially true when proposed or applied solutions meet resistance of the local population or other stakeholders who do not directly profit, get harmed or think they will get injured. The so-called 'not in my backyard' or NIMBY deadlock is well known and fiercely feared by all policy makers and planners. It is even considered to be so insurmountable, that there is a strong call for stringent laws to override this kind of 'irrational, egoistic, fuddled and emotional blockades'. Apart from the fact that laws are not the best way to get new ideas or policies wholeheartedly accepted, the more urgent question is whether the social sciences are not able to offer more suitable ways to tackle this kind of problems.

Mainstream social theory (the actor oriented rational choice theory) claims that these successes and failures must be ascribed to features of policy content and societal, largely economic, interests. This, however, may be a much too narrow view. There are other theories and ethics than 'rational choice' and the ethics of the *Homo economicus*.

Perhaps, and even probably, the obstacle is not the recognition or acceptance of the problem as such, but the mode in which the problem is raised, formulated, communicated and acted upon by the dominant actors: the government agencies, scientists, planners and consultants. In other words: the problem is not the content of policy and science, but the style. The problem is not non-acceptance of the problem, but the revolt of the common people and local administrators against the colonization of their visions by central government and central science.

'Stylish' way out

If this is true, a new style of policy and science should be developed, a style which couples respect for the ethics of *Homo honoris* with efficiency, in stead of the predominant policy style which focuses almost exclusively on content and interest-based social interaction. In fact there are promising ways to do this. Some of social sciences, especially those 'framed' to investigate policy conflicts outside the so called western world, have built up a lot of knowledge and experience, very well suited for the kind of problems the new waterpolicy makers are confronted with.

They offer ways to look into, describe and tackle problems raised by the clash of different policy styles and the collision of government or other 'institutional' actors with the local population. These confrontations often emanate from the effort to construct new institutions and arrangements in order to deal with new problems or old but very tough ones. The core of the problem mostly is a clash between a more or less technocratic style of problem-definition and approach - often the style of the planners, policy-makers and scientists - and a more diffuse, but strongly contextual style of perception and approach, the common style of a local population. A lot of these conflicts occur in situations where an approach is become operative to protect or enlarge an isolated 'common good' at the expense of a 'private or local good', or the other way around. The word isolated is deliberately underlined. The main trouble of non-policy makers (local shareholders) with the policy they are confronted with is not so much that they are not involved in the process of problem-definition and problem solving. Their main trouble is that the problem is treated as a case on its own, as something that it is detached from the broader social and physical context they live in. That is the main difficulty; this style of problem definition and approach, so typical for a technocratic or instrumental rational worldview. In the perception of local people you cannot isolate problems and approaches in the way that policy makers are inclined or think they are obliged to do.

Table 1. Case Grensmaas: research questions, method and approach.

Research-method
- Mitigation and de-assemblage: opening up of existing policy styles and knowledge packets;
- Re-assemblage of policy-style and knowledge that reproduces the style of common people involved.

Approach
- Theory-driven case studies; Open interviews.

Research-questions:
- What are the causes and background of renowned policy crashes: style or content?
- How do common people perceive the regulation and communication styles they are confronted with and are supposed to respond to?
- Which possible alternatives do common people, local administrators, policy makers, scientists and engineers see?

Method for case Grensmaas

One of the more promising methods to deal with this kind of problems is developed by Ostrom (1990). Her method comes down to a manner of simultaneously contextualizing the problem, approach and solution; to locally embed a supra-local problem, as well social, political as physical. The proposed trajectory, from problem definition towards solution, contains three steps:

1 Build the moral community around the problem situation;
2 Tell the story of the problem situation in its context;
3 Until the solution arises out of the compelling representation of the problem situation.

The basic idea is that the only way to solve this kind of problems is to mutual embed content and style: to get the supra-local content accepted you have to accept and respect the local style.

This approach also is promising for more familiar circumstances, such as conflicts arising out of the new river policy in The Netherlands, for instance the problems around the Grensmaas project. Precisely this last case, where an in principal good plan was crippled because of bad policy, is a good example to apply and test the above-mentioned theory and method. The outcome of this research could contribute greatly to further the maturity of the new water policy, or at least help to prevent analogous and costly policy crashes in the future - costly in terms of money and prestige.

For that reason we will start in 2003 a research project to find out what went wrong and what went good in the Grensmaas-project, in the past years (Table 1). The focus will be on perception of the stakeholders. However, not the perspective of the policy makers will be the point of departure, but the perspective of the local people, in conjunction with the physical environment they live in, and the way they perceive this environment and act upon or in it.

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Position of ecology in interdisciplinary decision support systems for river basin management

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Introduction

Decision support systems (DSSs) are interactive computer based systems that can be used to support the solving of complex problems like in river basin management. With a DSS, the effects of measures on different aspects of the river system can be evaluated.

Since 1995, a series of DSSs for river basin management have been developed for the Rhine and Meuse branches in The Netherlands. The latest version of this DSS series, DSS Large Rivers, is now fully operational. DSS Large Rivers is considered to be a true interdisciplinary DSS, incorporating hydrodynamics, ecology and other aspects (Table 1). Attempts are made to construct interdisciplinary DSSs for the German rivers too. Two DSSs are currently under development: INFORM.DSS (for the Rhine in the Lower Rhine Embayment) and Elbe DSS (for the Elbe).

As ecology is considered an important aspect of sustainable river basin management, it is desired to incorporate ecology into an interdisciplinary DSS. However, it is still unclear which aspects of ecology are important for policy makers and which aspects of ecology (regarding to the objectives for nature, interactions between ecology and other functions of the river system etc.) should be incorporated in a DSS for river basin management.

A PhD study at the University of Twente recently started with the aim to focus on this problem. As an introduction into the subject the role of ecology in DSS Large Rivers and INFORM.DSS was investigated. A description of the ecological modules of both DSSs is presented and the gaps and shortcomings are addressed.

DSS Large Rivers and INFORM.DSS

Description of the ecological modules

The objective of the ecological module of DSS Large Rivers is to assess and evaluate the effects of land use changes and other landscape planning measures on the vegetation distribution and fauna habitat suitability (Schielen *et al.*, 2001). INFORM.DSS evaluates the effects of changes in the mean water level of the river on the vegetation distribution (Fuchs *et al.*, 2000).

The ecological modules of both DSSs calculate the vegetation distribution on the basis of the local physical conditions, using the same a-biotic parameters (flood duration, soil texture and groundwater level). For each location the probabilities for different vegetation types are determined. The output is a vegetation map, in which for each cell the vegetation type with the highest potential (highest probability) is displayed. DSS Large Rivers uses the vegetation

Table 1. Comparison of DSS Large Rivers and INFORM.DSS, two interdisciplinary DSSs for river basin management.

	Subject	Dimension	Area	Objective
· **DSS Large Rivers (Dutch equivalent: BOS-IR)** · **1999/2001**	interdisciplinary model (hydrodynamic, ecological, costs etc)	1D/2D	· Rhine and Meuse branches in The Netherlands · generic	· to evaluate the effects of spatial planning interventions on hydraulics, morphology, and ecology and the costs of these interventions · to design and refine measures
· **INFORM.DSS** · **under development**	ecological and hydraulic model	2D	· Rhine in the Lower Rhine Embayment · possibly generic in the future	· to evaluate the effects of engineering measures in the river channel on floodplain ecology

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map to calculate roughness coefficients, which are used as an input for the hydrodynamic models SOBEK (1D) and WAQUA (2D).

Gaps and shortcomings

When considering the position of ecological data in the ecological modules of both DSSs, the following remarks can be made:

- Only three a-biotic parameters are used for calculating the vegetation distribution. It is unclear how many and which a-biotic parameters should be used to produce reliable results.
- The connection between nature on the floodplains with nature in adjacent areas is not considered, while this may be important for the formation of ecological networks.
- The effects of morphodynamics (morphological processes like erosion and sedimentation) on ecology are not incorporated. This is mainly because the precise relation between morphodynamics and ecology is largely unknown.
- Variability (e.g. annual variations in flood duration, or seasonal changes in vegetation cover) is not incorporated in the calculations.
- The vegetation map is used for further analysis (e.g. determination of the fauna habitat suitability or calculation of the roughness coefficients). Hereby the vegetation type with the highest probability is used, and the probabilities of the other vegetation types are ignored. The effect of this approach on the reliability of the results is unknown.
- The results are not accompanied by indications of uncertainty.

Discussion and conclusions

A comparison of the ecological modules of DSS Large Rivers and INFORM.DSS revealed a number of gaps and shortcomings regarding to the way ecology is incorporated in the DSS. Aspects like morphodynamics, connection to nature in adjacent areas and variability are not incorporated in the ecological modules of both DSSs. These aspects are likely to be important for floodplain ecology. It is not easy to solve these shortcomings, as guidelines on how these aspects should be incorporated in ecological models are not available and some of these aspects suffer from lack of knowledge about the process.

Other problems rise because of using a limited number of a-biotic parameters as input variables and because of using the vegetation with the highest probability instead of the probability distribution for further analysis. The effects of these approaches on the reliability of the results are largely unknown.

The intention of the PhD research will be to focus on some of these aspects, leading to recommendation for improving ecological modules being part of interdisciplinary DSSs.

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Multiple spatial planning: living in harmony with the river

Model experiments on innovative groynes

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Abstract
The primary functions of groynes are to guarantee the discharge of water and ice and keeping the main navigation at proper depth and location. Three new groyne designs were built in a physical model, scale 1:40. The behaviour of the three new designs is compared with the behaviour of the reference groyne. From this comparison became clear that a groyne with a less steep slope of the groyne head gives a smaller scour hole, a higher discharge a high waters and smaller velocity gradients. The same partly counts for a permeable groyne but these groynes will give some sedimentation in the main channel and less bank protection than the reference groyne. The hybrid groyne has no really negative points but gives no improvement of the high water discharge. Prototype research is now necessary to measure the effects of ships on the flow and for a quantification of the effects of the new designs on the riverbed morphology.

Introduction
In the Netherlands rivers are equipped with groynes since the end of the 19th century. The primary functions of groynes in the Dutch rivers are: (1) Discharge of water and ice; (2) Keeping the navigation channel at proper depth and location; (3) Bank protection; and (4) Ecology, creating of areas with low velocities. They were always designed using empirical rules for the height and shape of the groynes. The ministry of Transport, Public Works and Water Management is currently doing research at possible improvements of the standard groyne shape. The new innovative groyne designs should give:

- Less resistance when submerged;
- Smaller scour holes;
- Weakening of strong currents and large gradients around the groyne head;
- Decrease of building and maintenance costs;
- Better ecological functioning.

Possible changes of the groynedesign are:

- Lessening the slope of the groyne head;
- Changing the upstream and/or downstream slope of the groyne;
- Permeability of the groyne;
- Height of the groyne crest;
- Materials used for building the groyne.

Figure 1. Physical model scale (1:40) to test effects of groyne design on water velocity at various water levels.

Research
The emphasis in the experiments was on the slope of the groyne head en the permeability of the groyne. The next four groyne shapes have been tested in the physical model (Figure 1):

- Standard groyne: impermeable groyne with a rounded head of 1 over 3 (reference groyne);
- Impermeable 1:6 groyne with a straight head of one over six;
- Pile sheet: permeable groyne;
- Hybrid groyne: combination of a pile sheet on top of a lowered impermeable groyne with a head of 1 over 6.

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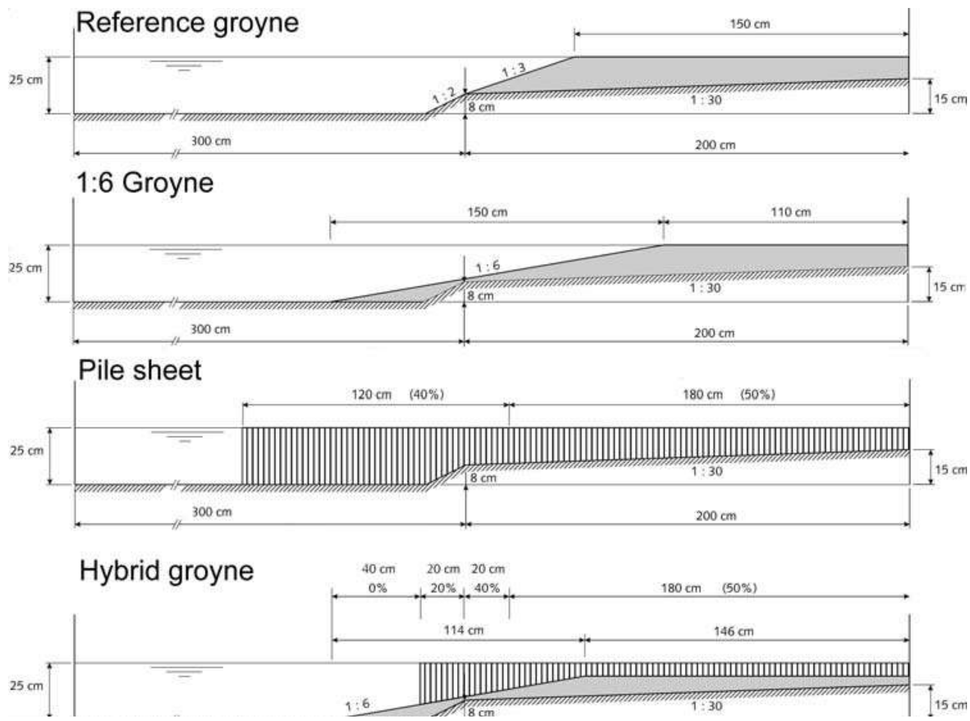

Figure 2. Cross-sectional views of the four different groyne designs.

Figure 2 shows cross-sectional views of the groyne designs.
Two water levels of 25 cm and 35 cm were chosen as representing normal and high water conditions. At the water level of 25 cm the crest of the groynes was just above the water. Velocities were measured at various locations with emphasis on the shear layer and the area around the groyne, using particle tracking velocimetry (PTV), laser doppler anometry (LDA) and electromagnetic flow meters (EMF). The data from these velocity measurements are translated to the influence on the discharge and the sediment transport and a qualitative comparison of the different groynes has been executed. The translated data cannot be used for predicting the exact behaviour of an innovative groyne in prototype.

Results

A qualitative comparison is made between the effects of the reference groyne and the influence of the innovative groynes. Table 1 gives positive and negative effects of the different groyne

Table 1. Effects of innovative groynes on discharge concentration, velocity field, depth of the navigation channel, scour hole and bank protection.

Effects	Impermeable 1:6 groyne	Pile sheet	Hybrid groyne
Discharge concentration at low discharges	+	-	++
Discharge concentration at high discharges	-	-	0
Weakening of strong currents and large gradients	+	++	+
Keeping the navigation channel at proper depth	+	-	+
Less resistance when submerged	+	+	0
Smaller scour holes	+	+	+
Bank protection	0	-	0

+: Positive effect compared to the reference groyne; 0: Same effect as the reference groyne;
-: Negative effect compared to the reference groyne.

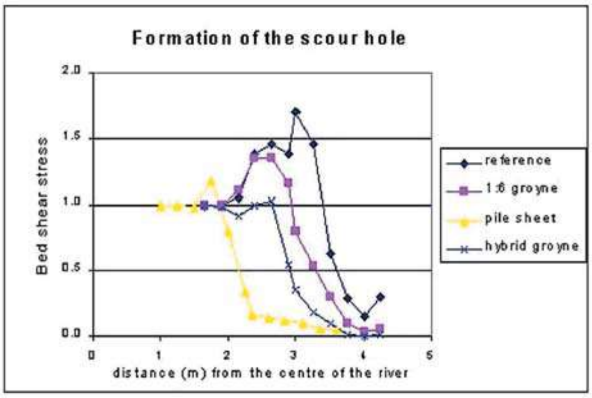

Figure 3. Bed shear as a measure for the formation of a scour hole. Higher bed shear stress gives a larger scour hole.

designs on the discharge concentration, the velocity field, the depth of the navigation channel, the scour hole and the bank protection. All the new designs will probably give smaller scour holes. Figure 3 shows that the scour hole will probably be smallest with the hybrid groyne.

Further research

It is not possible to translate the above results directly to prototype conditions. Therefore it will be necessary to do prototype research with innovative groyne designs. The above results can be used to optimise the groyne design before testing them in prototype. Some of the effects of the groynes that should be tested in prototype:

- The effect of ship induced water motion on the scour hole near the groyne head and piles;
- The morphology of the bed in the groyne field;
- The stability of the bank;
- The effect of changes of the bottom morphology on the discharge at low and high waters.

Conclusions

From table 1 it becomes clear that both the 1:6 groyne and the hybrid groyne give good results. The discharge concentration, the depth of the navigation channel and the bank protection is less for the pile sheet. This could become better when the design is optimised with a lower permeability at the bank side and a higher permeability near the navigation channel.

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Multiple spatial planning: living in harmony with the river

Development of decision-making within river management and flood protection

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Introduction

The recent floods in Northwest and Central Europe show again the introduction of some characteristic dynamics on the decision making process involved with flood protection. Floods deliver readiness to conquer and to achieve unanimity: No one dares to doubt the necessity of measures to be taken. The postponement of floods, on the contrary, reduces the readiness: Environmental values become more visible and gain influence. Social resistance grows: doubts rise about the necessity and strategy of measures.
In the summer of 2002 we started a research project on decision-making and flood protection. In this project, we specifically focus on:

- The role of the decision making process and the actors involved;
- The role of public interests;
- The design of the decision making process.

This paper briefly describes the starting point of the research. Subsequently, we deal with the three investigations we have started, e.g.:

1 Literature survey on decision making on flood protection and river management;
2 Research on decision making on dike-improvement and river enlargement;
3 Research on public interests within river management and flood protection.

Starting point

The starting point of our research was the following statement (Figure 1): *Decision making on flood protection always has the same construction, related to the moment of the flood. A flood reduces the scope and policy area of the decision-making. The postponement of a flood broadens the scope and the policy-area.*

Dutch flood defence plans, like the Master plan Large Rivers (in Dutch: Deltaplan Grote Rivieren), the Plan for Enlargement of the Meuse (in Dutch: Maaswerken), and the current plans for "Room for the river", seem to confirm this point of departure. Floods reinforce the hierarchic management and the importance of the public value 'safety' (Figure 2). In the absence of a flood the strength of both aspects declines and the part of 'network management' grows, as does the public value 'environmental quality'.
Decision-making on flood protection offers some interesting questions and angles of incidence:

- Does decision-making on flood protection differ from decision-making on infrastructure?
- Dynamics and networks around floods; the apparent rise of hierarchic management directly following the flood vs. network management later on.
- The effectiveness of network management and hierarchic management in the course of time.
- Which indicators ascertain the quality and progress of decision-making?
- The influence of the culture of an organisation on decision-making.
- The influence of technical designs, policies and strategies on decision-making; the relation between design and decision-making.

Literature survey

The literary survey started in September 2002. Some important investigations are the narrative analysis of dike-improvement Van Eeten (2000), the analysis of decision-making on the Scheldt-estuary (Meijerink, 1999) and the work of Weissfogel (1957) on water works. Policy making on international river issues has some specific characteristics:

- Absence of a central authority;
- Multi-level approaches;
- Structural and cultural differences between countries;
- Importance of the underlying hydrological structure of the basin;

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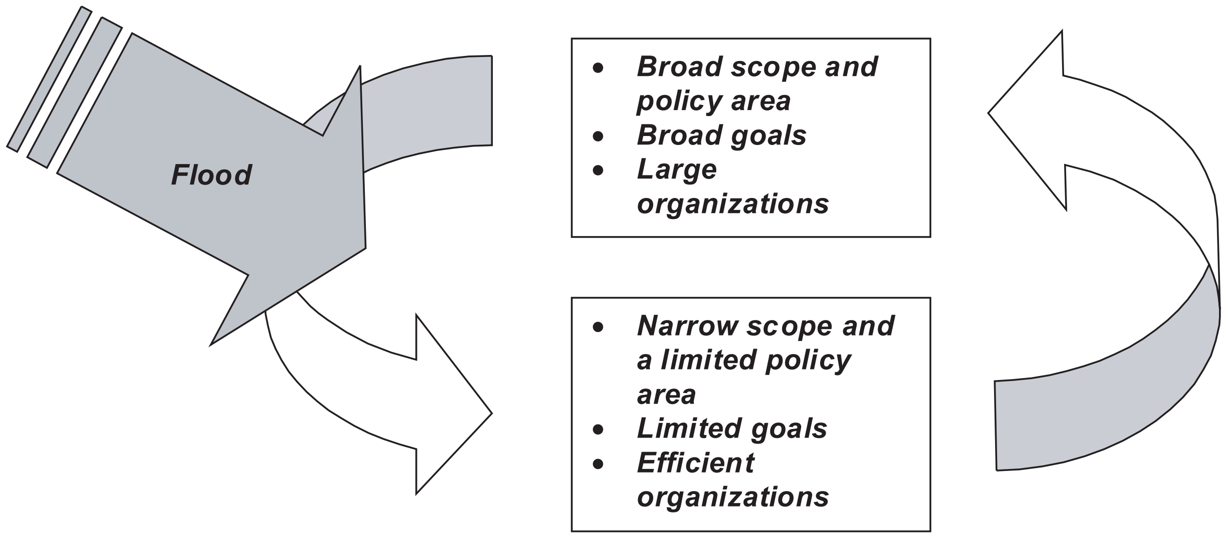

Figure 1. Policymaking becomes cyclic, driven by floods.

• Upstream-downstream issues;
• Policy window / the influence of disasters.

Weissfogel (1957) states that 'the more colossal the waterworks which a state power takes at hand, the more despotic its rulers are'. He also states that waterworks lead to hierarchic (totalitarian) regimes and vice versa. The literature research will be finished in the course of 2003.

Decision-making on dike-improvement and river enlargement

The research on differences between decision-making on dike-improvement issues and river enlargement deals with an evaluation of several cases concerning the Master Plan Large Rivers and the Room for the River-policy. The research was initiated by experiences gained during some projects concerning topics of public approval and decision-making on flood protection. The public approval for the type of flood protection measures seems to vary related to the scale of the decision making process. On a local scale there seems to be more approval of dike-improvement instead of river enlargement. On a more regional, national or international scale, the approval of river enlargement grows, and of dike-improvement declines. The research deals with questions such as:
• Which factors determine the decision-making?
• Have Room for the River and dike-improvement the same decision-making pattern, or do they differ?
• Which role do local actors play and what determines their effectiveness?
• Can we derive rules for the decision(making) process?
• What does 'the development of social approval related to the scale' signify for the decision-making process?

In this research we cooperate with Delft University of Technology in the framework of a graduation project. The results will become public in the course of 2003.

Security of public interests within river management and flood protection

Together with the Technical University of Delft we would like to participate in the programme 'Research on Public Interests'. After approval, the research will be started in 2003. The research focuses on the following main question:
Which public interests do play a role in river management and flood protection, and in which way are these interests safeguarded?

This can be specified with the following questions:
• Which strategies on flood-protection can be distinguished?

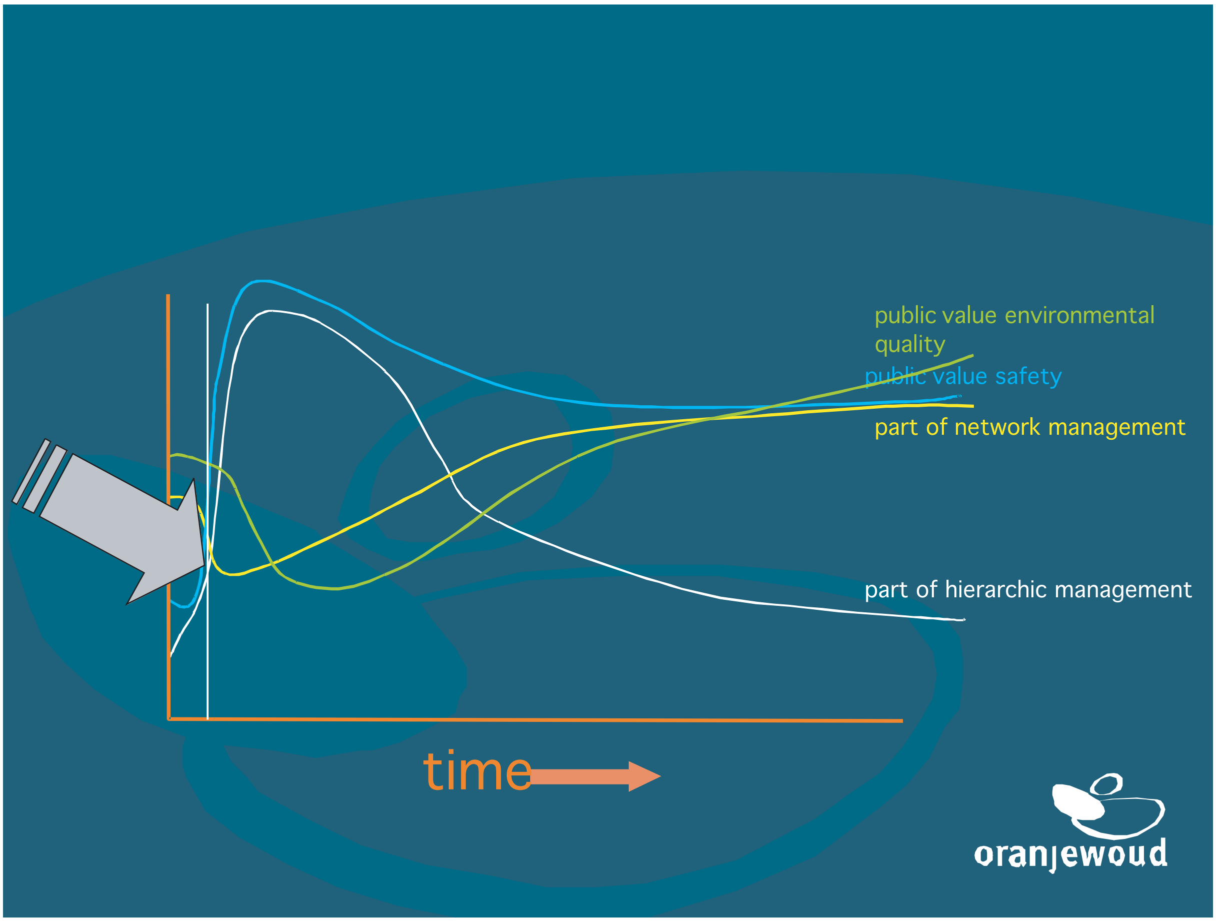

Figure 2. Development of public values (safety vs. environmental quality) and river management (hierarchic vs. network management) and after a flood.

- What are the public interests within flood protection, and how do these interests differ, depending-on the scale of decision-making?
- How do the public values differ depending on the actor?
- How do the public values differ depending on the risk and the perception of that risk?
- How do the public values differ depending on cultural differences?
- In which way does safeguarding of public interests take place?
- In which way do public interests influence the decision making process, and which are the differences between various types of the strategies on flood protection.
- Which management strategies and process designs can be used?

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Cyclic rejuvenation of floodplains

Introduction to NCR-research theme Cyclic Floodplain Rejuvenation

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Introduction

The Netherlands Centre for River Studies (NCR) has the objective to co-ordinate and to strengthen the Dutch research activities related to fluvial hydrosystems. In March 2001 the NCR board suggested to focus on some themes that are of scientific and public interest and have a multidisciplinary character. For each theme a coordinator was appointed. Dr. H. Middelkoop (Utrecht University) was asked to deal with the theme "Cyclic Floodplain Rejuvenation (CFR)".
Three steps can be distinguished in coordinating the research within the context of a NCR-theme. The first step focuses on listing the ongoing research activities related to the NCR-themes. The second step identifies the knowledge gaps and has the objective to stimulate co-operation between the members of the NCR to fill these gaps. The last, but not less important step is to facilitate the funding of the desired research activities. With respect to the theme CFR recently a list of ongoing activities and research initiatives has become available. Furthermore, in April 2002 a small workshop was organised with NCR-members who, one way or the other, were already involved in CFR research. This resulted in a preliminary list of knowledge gaps. Before the results of this workshop are discussed, we will explain the term CFR.

Ecological rehabilitation

After the publication of Plan Stork in 1987 and some environmental accidents such as the fire at the chemical plant Sandoz in Basel, Switzerland, the authorities of the Rhine riparian states acknowledged the vulnerability of the Rhine and Meuse river basins. It was decided that a comprehensive habitat rehabilitation plan should be carried out to increase the ecological resilience of both the Rhine and Meuse rivers. Hence, dams and locks were provided with fish passages and the spawning habitats of migrating fish species were restored. In addition, floodplains that for centuries were in agricultural use were bought from farmers and transformed into nature rehabilitation areas. The excavation of secondary channels and the removal of clay formed an important part of this rehabilitation strategy. The idea behind these measures was to stimulate the hydro-morphodynamic activity in the floodplains so that a diversity of aquatic, semi-aquatic and terrestrial habitats could be created (Figure 1).
In addition, so-called "low-maintenance" cows and horses such as Galloways and Koniks were introduced with the objective to diversify the vegetation patterns. This approach appeared to be successful. Biological monitoring programmes demonstrated that biodiversity increased significantly after agricultural management had

Figure 1. An example of a nature rehabilitation project along the Waal River (The floodplain Klompenwaard). Excavation of the top clay layer of the floodplain and a secondary channel will create more room for hydro-morphodynamics and suitable conditions for riparian biodiversity.

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Figure 2. The Millingerwaard floodplain during the flood of 1995 (Waal river). Fast growing softwood forests formed the rationale for the "nature-flood protection" discussions.

ceased and more space was given to natural processes. Encouraged by these results the national, regional, local authorities and NGO's have made considerable efforts to rehabilitate the ecological resilience of the Rhine and Meuse rivers. It is estimated that in the near future approximately 30% of the total floodplain area in the Netherlands will be transformed into nature-managed floodplains.

Nature restoration -flood protection dilemma

Unfortunately, after the near-floods of 1993 and 1995 a new dilemma appeared. The increased sedimentation of sand and clay and the fast growing soft wood forest in nature-managed floodplains caused an ongoing reduction of the water discharge capacity of river sections (Figure 2). Suddenly, nature was considered as a threat to realise the desired flood protection levels. The division East Netherlands of Rijkswaterstaat triggered the discussion related to this dilemma in 1999 (Smits *et al.*, 2000). This resulted in a research proposal written by the University of Nijmegen, Delft Hydraulics and Rijkswaterstaat in the year 2000 within the context of the IRMA SPONGE programme.

Management concept: cyclic floodplain rejuvenation

The management concept of CFR was based on the phenomenon that in pristine fluvial hydro-systems, erosion and sedimentation periodically reset the morphological and vegetation succession. For example, during the meandering of a river section, erosion of the outer bend occurs and substantial parts of the floodplain forest or other riparian vegetation, will be eroded (Figure 3). It is important to note that during this rejuvenation process the river has temporarily restored its water discharge capacity. This cyclic process of demolishment and succession is characteristic for pristine fluvial hydrosystems. However, it is completely absent in regulated river systems such as the Rhine where groynes prevent meandering. Within the concept of CFR it was suggested that controlled and by man conducted rejuvenation of floodplain habitats could be an interesting approach to solve the "nature -flood protection" dilemma in regulated river systems. Of course these CFR-measures should be tailor made taking account of present ecological values and design water levels.

Research questions and gaps

Implementation of CFR measures demands knowledge and expertise on different aspects of river dynamics and management. During the abovementioned workshop held in June 2002 at Utrecht University, an inventory was made of relevant research questions and research gaps were identified. These not only involve scientific research into the physical behaviour of rivers; putting theory in practice and up scaling of the concept is essential. To date, the river manager has to deal with more than six different floodplain managers! This brings about coordination and communication problems that

Figure 3. Natural erosion along the Morava river, Czech Republic. Further downstream the eroded material is deposited and succession with all its characteristic morphological phases and ecological sites will start all over again.

Table 1. Contribution of authors of present proceedings to various topics of NCR-theme cyclic floodplain rejuvenation.

	Morphology and hydrology	*Ecology and toxicology*	*Socio-economy*	*Management and practise*
Antheunisse *et al.*		x		
Baptist *et al.*	x	x		
Blom	x			
Buise & Van der Molen		x		
De Lange *et al.*		x		
Geerling & Smits		x		
Griethuysen				
Gruijters *et al.*				x
Hoffmann	x			
Keestra & Van Dam	x			
Kooistra *et al.*		x		
Maas & Makaske	x			
Nijhof & Hommel		x		
Nolte *et al.*		x		
Schoor *et al.*	x			
Schröder & Vink		x		
Smits, De Vriend, Vlasblom	x	x	x	x
Straatsma *et al.*	x			
Teuling *et al.*	x			
Thonon	x			
Van der Perk *et al.*		x		
Van Vuren	x			
Weerts & Clevinga	x			
Wijnhoven *et al.*		x		

need to be tackled before floodplain management strategies can be applied at a large scale. Also, the various scientific disciplines are interrelated. For example, the fast growing willows stimulate sedimentation and thus influence the morphological development of a floodplain. On the other hand sedimentation and erosion will also affect the vegetation succession. Finally, it is important to note that apart from typical nature-science questions also social sciences are involved in the NCR-theme CFR. After all, cyclic floodplain rejuvenation is meant as a management measure. Thus, social sciences such as communication strategies and socio-economics also need to be addressed. The research questions were clustered in the following topics:

Hydrology and morphology
- Cyclic behaviour (erosion/sedimentation) of natural rivers, and controls of processes;
- Interaction bio-geomorphology;
- Hydrological and morphological responses to CFR measures;
- Modelling aspects: validation, uncertainties, stochastic modelling.

Ecology / toxicology
- Vegetation development in response to morphological development and CFR measure;
- Assessment of ecological values and effect of moving polluted floodplain sediments.

Management and practice
- Implementation instruments and ‘eco-engineering’: how can we simulate natural floodplain processes (erosion, grazing) using artificial equipment;
- Management and measures (e.g. grazing intensity) required to achieve the desired floodplain development;

- Monitoring: development of rapid monitoring techniques at adequate temporal and spatial scales.

Socio-economics and social sciences
- Ecocentric cost/benefit analysis;
- Management of interrelated factors (safety, ecology, spatial planning) over large areas, organisation structure;
- Communication between different fields of sciences, application, stakeholders and to society.

Ongoing and proposed research activities within NCR can be grouped according to these themes. An example is given in Table 1. It is important to note that in contrast to the social sciences, the nature-sciences are well represented. In the near future groups researchers from the NCR institutes will elaborate different research themes into more specific proposals for which funding will be applied. Special attention will be given to the knowledge gap with respect to the socio-economic sciences.

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Monitoring floodplain vegetation dynamics using remote sensing in the context of cyclic floodplain rejuvenation

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Traditional versus dynamic river management

In contrast to traditional river management, dynamic river management is based on applying tailor-made, recurring measures to meet the various demands of shipping, flood protection, agriculture and ecological rehabilitation. The type of measures vary in time and space and have a small-scale character instead of the traditional far-reaching civil works designed to bridle complete river sections. On the one hand dynamic river management provides more room (degrees of freedom) for hydromorphological and vegetation dynamics and thus provides better perspectives for ecological rehabilitation. On the other hand it makes river management more complex. Because of the relatively fast changing conditions it is necessary to monitor the changes of the riverbed and its floodplains regularly and within short time intervals. Additionally, unambiguous information related to the main feature of entire river sections should be collected in order to determine the river discharge capacity, shipping route conditions and to determine the ecological status. Also in the context of cyclic floodplain rejuvenation (CFR) such a monitoring technology is needed (Smits et al., 2000; Duel et al., 2002)

The CFR strategy is the central theme of a PhD project (Figure 1). It is used as a starting point for identifying knowledge gaps. These knowledge gaps have to be researched for a scientifically sound application of this river management strategy.

Hypothesis: Spatial heterogeneity and scale of CFR

Along a natural river one will find patches of vegetation and side channels of various ages and in different stages of succession. Important is to notice that the spatial heterogeneity on the small scale may look like chaos, but seen on the larger scale the system seems quite stable. Continuous succession and disturbance ensure that no place remains stable for long, although one will always find pioneer stages, full grown softwood forests or closed side channels on the river stretch scale. It is hypothesised that the spatial patterns are dynamic but the acreage of each patch type is rather stable on the scale of a river stretch. In the ideal situation, the overall roughness is constant or fluctuating between upper and lower boundaries, although it might be irregularly fluctuating on the floodplain scale. As a consequence, the scale on which management by rejuvenation will work is that of a river stretch because only then enough natural elements are present for a dynamic, stable and ecologically rich system.

Hypothesis: Temporal scale of CFR

Under natural conditions each type of habitat has its own cycle of establishment, development and resetting by morpho-dynamic processes. Knowledge related to the phases and time

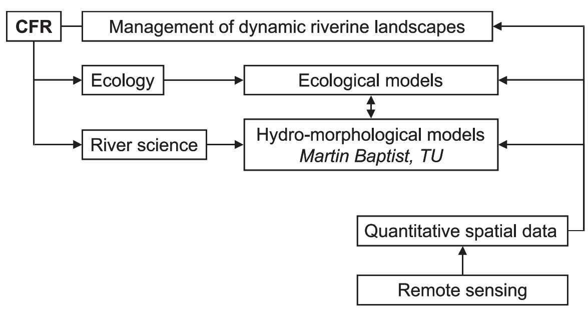


Figure 1. Research framework: Remote sensing as tool for river management, validation of spatial ecological models and input in hydro-morphological models (CFR: cyclic floodplain rejuvenation; TU: Delft University of Technology).

schedule of these cycles are crucial in determining an optimal CFR-strategy. Ideally, from an ecological point of view, each type of habitat and vegetation succession phase should be present along the stream corridor. This can only be achieved if the required water discharge capacity of a river section can be met. The longest ecological cycles determine the temporal scale of the CFR strategy. The longest cycles are development of hardwood forest and sedimentation of side channels. These cycles were expected to be at least a hundred years.

Research outline

The temporal and spatial heterogeneity and scale of vegetation are the subject of this study and summarised in the term vegetation dynamics.
In order to investigate the results of riverine processes, i.e. the state of morphology and vegetation on a certain moment, a monitoring technique has to be developed. This monitoring technique has two functions. Firstly it is a means to investigate the speed of riverine changes, i.e. vegetation succession and morphological developments. Secondly is should be an instrument for the river manager and as such an integral part of a river management system, see figure 1. The scale and purpose of the monitored information suggest remote sensing as an appropriate tool. (Leuven et al, 2002).
The speed and direction of succession determine the management activities needed. Knowledge on this subject has to be generated. Investigating existing time series of remotely sensed data will give quantitative information on the speed and direction of succession.

The stepwise outline of the research programme is:

1 Development or adapting of a mapping technique for vegetation monitoring based upon remote sensing.
2 Application of the mapping technique in remotely sensed time series. Testing the consistency of the mapping method and producing information of the vegetation development.
3 Using existing remotely sensed data sets of selected floodplains to produce time series of vegetation dynamics in a fixed river situation.
4 Using existing remotely sensed data sets of selected floodplains to produce time series of vegetation dynamics in a natural situation.

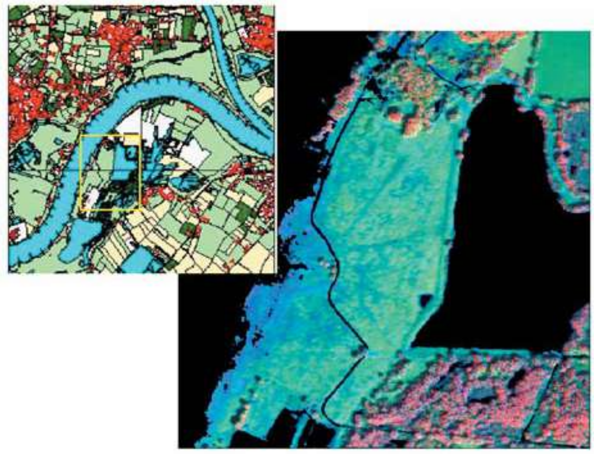


Figure 2. Example of data-fusion: In the image: green intensity = red-reflection; blue intensity = IR-reflection; red intensity = standard deviation LIDAR. Clearly the forested areas stand out having a high LIDAR standard deviation (Geerling, unpublished data).

5 Explore possibilities for ecological monitoring using remote sensing data for use in river and nature management.
6 Combine knowledge of processes in natural and bridled situations to build a CFR strategy for river management.
7 Apply the CRF-strategy to the Dutch river system. Integrate the RS mapping tool with existing flood protection instruments of the river manager (RWS) into a practical management support system for dynamic river management. This instrument should combine hydraulic and ecological remotely sensed data for evaluation of the present state and proposing management activities.

The results so far are briefly summarised below. The number between brackets indicates the connection with the above given outline.

Remote sensing (1&2)
In Geerling & van den Berg (2002) different spectral sensors (LANDSAT, IKONOS and airborne scanner CASI) are briefly examined for the Gelderse Poort area (NL). One of the conclusions is that combination of 2 different remote sensing sources by data-fusion seems a promising direction for mapping vegetation.
At the moment data-fusion of a 3 m resolution 10 spectral band dataset (CASI sensor) and a Laser altimetry dataset (or light detection and ranging, LIDAR) is being researched (Figure 2). We try to achieve data-fusion by applying neural networks and a pixel based approach of data-fusion. The first results are expected in January 2003.

Figure 3. Location of Ewijkse Plaat along the river Waal.

Ewijkse Plaat:
vegetation dynamics in a fixed system (3)

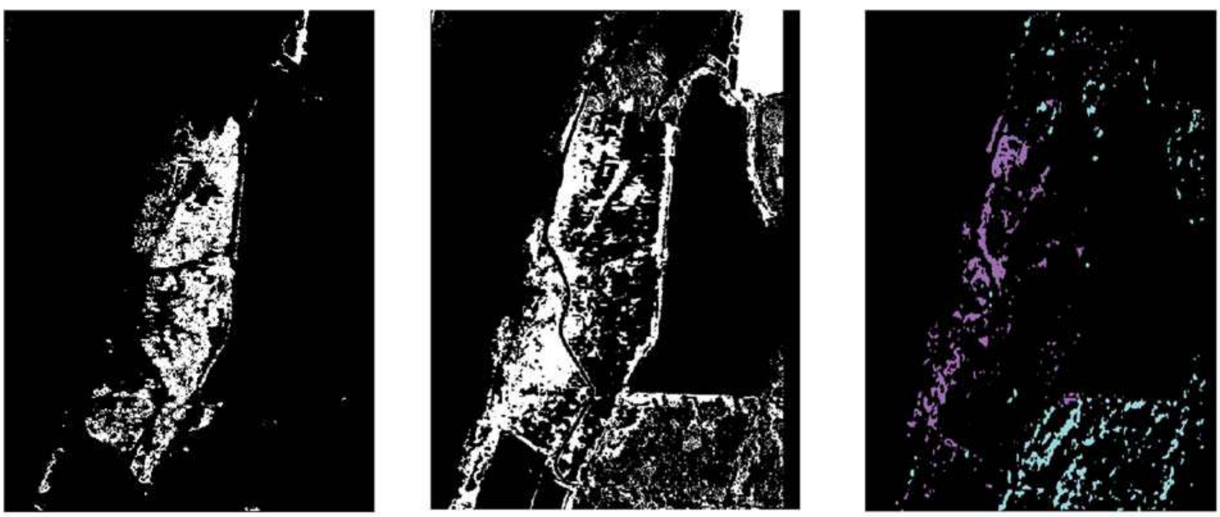
The aim of this research is to get insight in the development of hydraulic roughness as a result of the development of the vegetation structure of the Ewijkse Plaat based on series of aerial photographs of the area. The Ewijkse Plaat is a sand island in the fixed river Waal (Figure 3) of which the western part has been excavated in the autumn of 1988. After that the vegetation could develop freely. After a few years adjacent parts of grassland were combined with the excavated area and the whole area became a nature reserve.
For this research the Ewijkse Plaat could be divided into two areas: an area in which development of vegetation could take place from bare substrate and a second area with development of vegetation with grassland as starting point.
From a series of aerial photographs maps of vegetation structure are made. These maps of vegetation structure are translated to maps of hydraulic roughness. Classes of the vegetation structure were coupled with values of hydraulic roughness from the literature and RWS RIZA.
The research shows the importance of the starting point for the succession of vegetation. In the western part with bare substrate as starting point softwood forest development take place. Bare substrate is an important condition for the development of this type of forest. As a result the roughness of this part of the Ewijkse Plaat develops faster and is higher compared to the roughness of the eastern part, see table 1.

Table 1. Hydraulic roughness (k values) development as a consequence of spontaneous vegetation succession starting from pioneer and grassland.

	1989	1991	1997	2000
Pioneer	0,53	1,98	6,78	7,11
Grassland	0,52	0,65	0,86	0,81

Natural rejuvenation alongside the
Allier river (4)

Using the Allier as a system theoretical reference, the process of natural succession will be investigated. This should result in an understanding of the dynamics of natural rejuvenation. Fieldwork for identifying vegetation types, sequential mapping based upon older photographs (1940-2000) and incorporating morphological developments as well, provide insight in the spatial and temporal change of the



Bankvole *(Clethrionomys glareolus)*

Common Vole *(Microtus arvalis)*

Blue: Common shrew *(Sorex araneus)*
Purple: White-toothed Shrew
(Crocidura russula)

Figure 4. Results mice habitat mapping using high resolution RS data (3 m pixel, 10 band CASI image and LIDAR data).

surface area of the vegetation types present. This can be a guideline for natural management practices along regulated rivers (For more information see Baptist et al., 2003).

Ecological monitoring: habitat mapping (5)

By combining expert knowledge of mice habitats and high-resolution remote sensing data it should be possible to remotely sense potential mice habitats.

Based upon detailed habitat descriptions consisting of vegetation type and vegetation structure the remote sensing datasets are explored. Two types of remotely sensed data are combined: (1) laser altimetry data (lidar) for information on vegetation structure and (2) spectral reflectance data for information on the vegetation type. This approach can be of interest for evaluating ecological consequences of management practices.

The first results are shown in figure 4. The floodplain is located along the river Waal (Figure 2). A first quick validation of the results indicated that the approach worked. A more extensive validation will take place during the winter of 2002/2003.

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Cyclic rejuvenation of floodplains

The interaction between hydrodynamics, morphodynamics and vegetation in the Allier River, France

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Abstract
The universities of Delft, Nijmegen and Utrecht co-operate to gain more insight in the interactions between hydrodynamics, morphodynamics and vegetation in a natural gravel-bed river, the Allier River in France.

Introduction
In July 2002, the universities of Delft, Nijmegen and Utrecht carried out a multi-disciplinary field study in the Allier River in France (Participants: M.J. Baptist, J. van den Berg, L. van den Bosch, J. Dijkstra, G.W. Geerling, H. Havinga, S. Kapinga, J. de Kramer, E. Mosselman, H. de Vriend, S. Vos & A. Wilbers). This river is considered as a reference river for the future Border Meuse in the Netherlands.
The Allier River is highly dynamic, large amounts of sand and gravel are transported during floods and its morphology changes considerably from year to year. The vegetation that grows along the Allier River is characterised by pioneer species on the low-lying dynamic point-bars, herbaceous vegetation and grass on the higher parts and extensive softwood floodplain forests, mainly consisting of poplars, on the older and higher floodplains. Due to the river dynamics, this river shows natural rejuvenation of vegetation such that older forests are removed by erosion and young pioneer vegetation starts growing on the point-bars. This also brings large woody debris, i.e. trees, in the river that settle on the point bars.
Objectives of the field study were:

1 Generating a detailed digital terrain model (DTM) for later use in a numerical hydrodynamic model.
2 Measuring scour holes around tree trunks to investigating the relationship between flow velocity and scour depth.

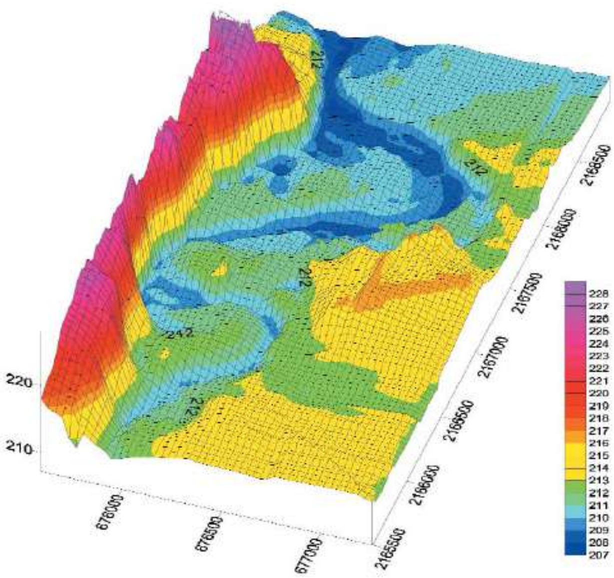

Figure 1. Digital terrain model of the study area.

3 Mapping vegetation structures for classification from aerial photos.
4 Measuring the position of meander bends to investigate the ratio between outer bank erosion and inner bank sedimentation.

Material and methods
A Real-Time Kinematic Differential Global Positioning System (RTK-DGPS) was applied to obtain terrain co-ordinates in x, y and z direction in the study area of 6 km^2 around Chateau de Lys, with an accuracy of about 20 cm. The morphology of the riverbed was obtained using levelling. Levelling was also applied in a number of meander bends, to describe the position of the

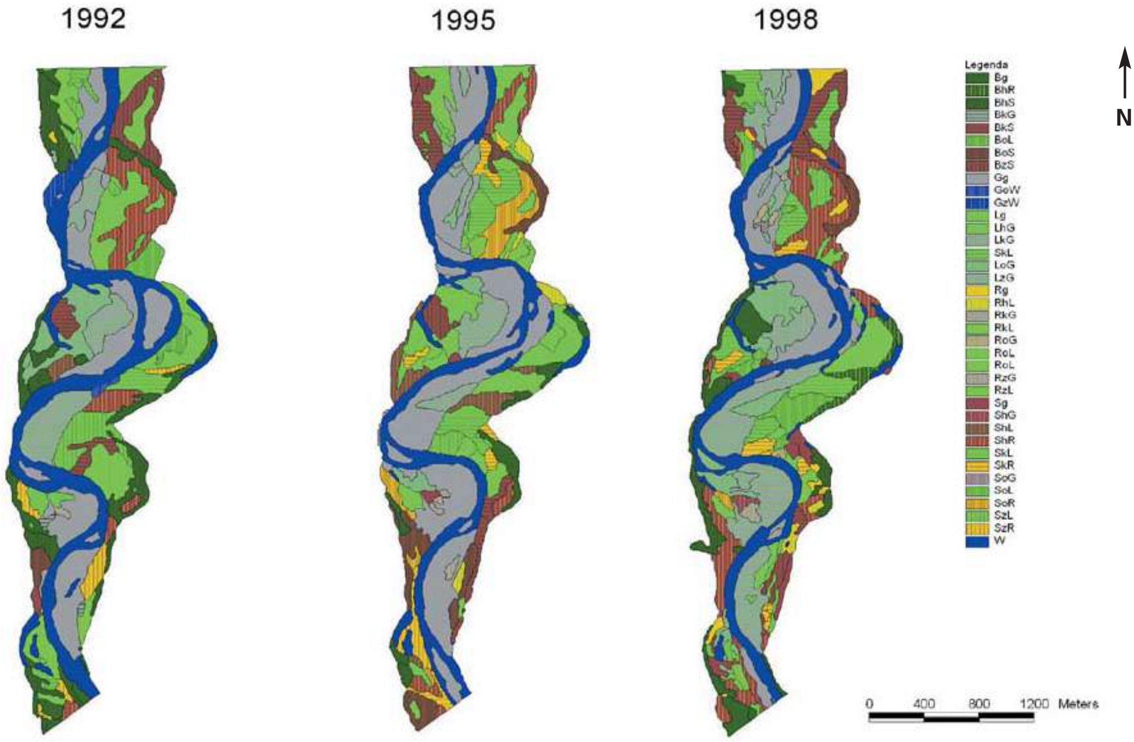

Figure 2. Vegetation structures in 1992, 1995 and 1998. Classification based on horizontal densities of the vertical structure classes forest, bush, herbaceous vegetation, gras, moss and bare soil.

inner and outer banks of the meanders, to be used for later analysis of the meander morphology. The detailed morphology around 15 scour holes formed at tree trunks was measured using the RTK-DGPS with an accuracy of 3 cm. Vegetation structures were identified and mapped in the field to obtain a ground truth for the analysis of stereoscopic aerial photos.

Results and discussion

The DTM of the study area. (Figure 1) will be used to generate a two-dimensional hydrodynamic model. The maps of vegetation structures derived from aerial photos are presented in figure 2. The changes in vegetation structure and succession in relation to river morphology are analysed using these maps. The map of vegetation structures will also be used to obtain a map of the hydraulic roughness for the 2D-model. The analysis of scour holes around tree trunks will deliver estimates of the flow velocity during the previous flood of May 2001, since accurate data of this event is missing. All in all, the analysis of time-series of aerial photos, in addition to the hydrodynamic model results and the analysis of the rate of change of meander bends (Figure 3) will generate knowledge on the cyclic rejuvenation patterns and frequencies of this river system.

Conclusion

Multidisciplinary co-operation between university departments proved to be essential to analyse the intricate abiotic and biotic interactions of river systems.

Figure 3. Meander bend in the Allier River.

Morphological change and vegetation succession on a pointbar of the lower Volga near Volgograd, Russia.

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Abstract

Morphological change of the lower Volga is studied and quantified in a pilot area downstream of Volgograd, with special emphasis on the Zakrutsky pointbar and the influence of vegetation.

Introduction

The Lower Volga is a large lowland sand-bed river with natural morphology and extensive floodplains with natural vegetation of shrubs, trees and meadows. It is a 300-km long single to multi channel system. The main channel often shows meander characteristics. Since 1959 the discharge is regulated by a dam at Volgograd. The minimum discharge through the dam is about 5000 m^3/s. Every year, a 6 weeks flood is allowed in May/June of about 25.000 m^3/s. Before dam construction peak discharge could reach 65.000 m^3/s. The floodplain is about 30 km wide. The main Volga flows in the south-west of the

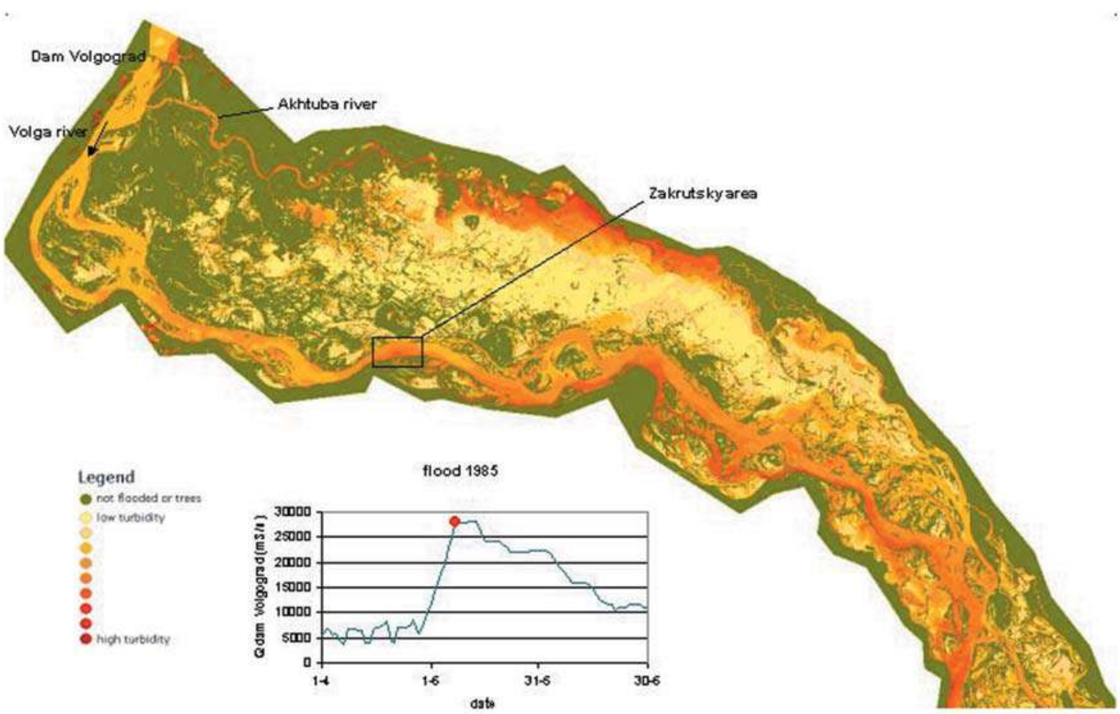

Figure 1. Turbidity of the north western part of the Volga-Akhtuba floodplain during flood, based on Landsat image of May 08, 1985 (after Van de Ven, 2002). Note that the flood is on the start of its top and that abundant overbank flooding, resulting in high turbidity in the floodplain, occurs from both Volga and Akhtuba rivers. Further away from the river, the floodplain width is 30 km, sediment falls out which results in low turbidity. Higher places in the western part of the floodplain do not inundate.

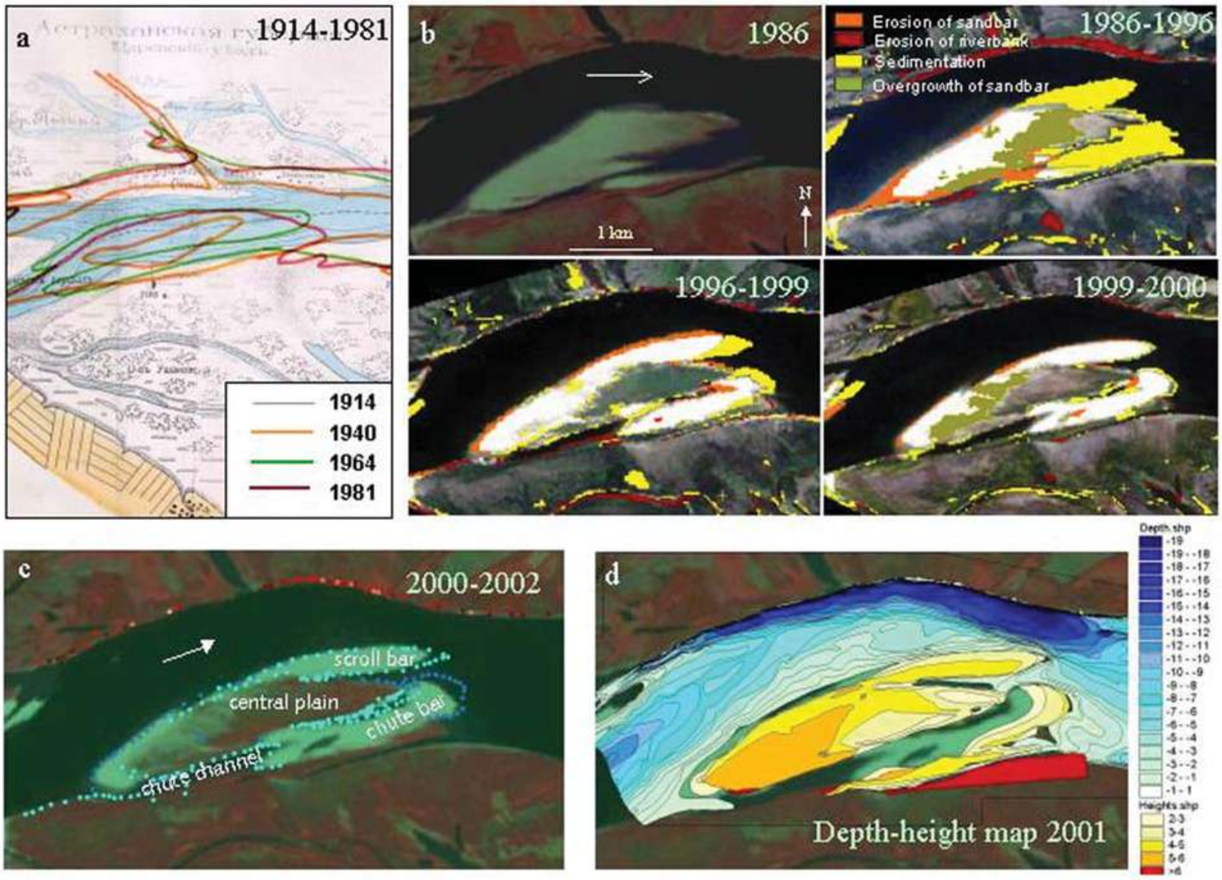

Figure 2. Morphodynamics of the Lower Volga near Zakrutsky. a) Contours of sandbar on navigation maps of 1940, 1964 and 1981 on a map of 1914. b) Development of Zakrutsky area between 1986 and 2000, analysed from Landsat images. Note the growth of a scroll bar in the northeast together with erosion of the left bank of Volga, formation of a bar in the downstream part of the high water channel and expansion of vegetation from east to west. c) Development of Zakrutsky area between 2000 and 2002, based on field positioning of banks with GPS in 2002, plotted on a Landsat false color image of 2000. d) Depth-height map 2001. Note the deep narrow part of the river between the scroll bar and the eroding left bank.

floodplain, while a much smaller branch, the Akhtuba, flows in the north-east (Figure 1). In the present analysis it was aimed to determine (1) morphological processes in the floodplain and (2) study in more detail the interaction of morphological change and vegetation succession in an inner bend of the Volga near Zakrutsky. This study is part of ongoing research of a co-operative project of Dutch and Russian institutions concerning the morphology and ecology of the Volga-Akthuba floodplain.

Material and methods

Low water satellite images (1986, 1996, 1999, 2000) are used to investigate the morphological activity in the last 15 years while turbidity differences in high water images of 1985 and 2001 are used for detecting flooding patterns and processes of sedimentation. During the fieldwork some cross-sections in the study area floodplain have been levelled, some kilometres of the riverbed have been sounded and vegetation and sediment texture is described. The age of trees was established by counting tree rings from sawed stems or, in case of big trees, by counting rings from cores obtained with a tree-auger

Results

After the construction of the dam, parts of the floodplain between the Volga and the Akthuba have not been flooded anymore, because of lower flood levels. At present only a small part of the western part of the floodplain is flooded, as is shown clearly on a satellite image of 1985 (Figure 1). This suggests that the Volga and Akthuba channels have incised downstream of the dam,

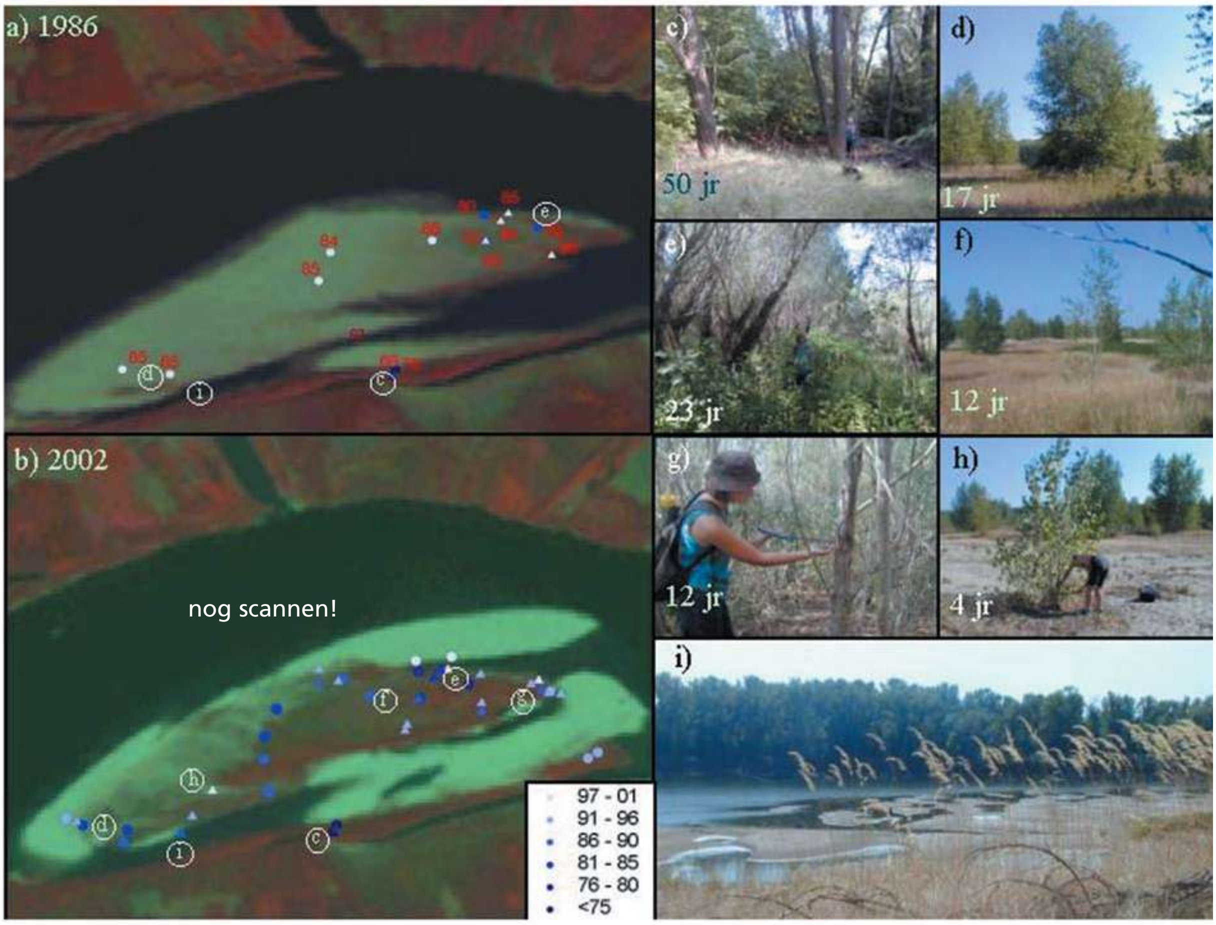

Figure 3. Ages of trees near Zakrutsky, Lower Volga. a) Sampled trees germinated before 1986 plotted on false colour Landsat image 1986. Blue dots refer to trees germinated before 1980, white dots to younger trees. b) Year of germination of sampled trees in 2001 and 2002, plotted on false colour Landsat image 2000. c) 50 year old Populus - Salix forest with several hardwood species in secondary wood layer, growing south of the chute channel. d) some poplar trees germinated in 1985 and 1986 on the bare sandbar of Zakrutsky, now growing in a savannah-like vegetation type. e) in 1979, very dense *Salix* forest germinated on the former lower banks of Zakrutsky. About 20 years later, *Fraxinus* appeared in open places in undergrowth. f) Big parts of Zakrutsky are vegetated with savannah-like grasslands with up till 12 year old *Populus nigra* and *Salix triandra*. As d) but with younger trees. g) 12 year old very dense *Salix alba* forest with no undergrowth. On the photo, the tree aging is shown. h) Where fresh sand is deposited, poplars are germinating. Therefore a mixture of older and younger trees grows in the area. i) View on the over 50 year old floodplain forest on the south bank of the chute channel.

because of depleted upstream sediment supply. Figure 1 also shows the turbidity of the flooded part of the plain. Settling of suspended sediment on the riverbanks possibly causes the low turbidity in the central part of the floodplain. This is consistent with substrate information that indicates very little actual deposition in the interior floodplain.

Near the Zakrutsky study area the river shows a low sinuosity meandering pattern. During the past century the amplitude of the bend in the main channel at this location increased, allowing the development of a 4 km long pointbar in the inner bend (Figure 2). The pointbar itself can be differentiated in a scroll-bar, a central plain, a chute channel and a chute bar (Figure 2c). Satellite images indicate that after 1986 the central plain developed into a young, vegetated floodplain. Nowadays this plain is covered by rough herbage with up to 5 % trees and some strips of dense willow woods. The age of the trees showed that although the bar was mentioned on navigation maps of 1940 (Figure 2a), the first trees settled in 1979 (Figure 3). Between 1986 and 1996 a distinct scroll bar formed, followed by the development of a chute bar. Due to the development of the willow forest the hydraulic resistance of part of the central plain has increased considerably. As a result, flow on the pointbar is concentrated in a chute channel, promoting the development of the protruding chute bar. Both the scroll bar as the chute bar are still expanding. On the opposite side of the river, the outer bend is eroding at a rate up to about 25 m per year. Bank erosion, however, is modest as compared with bank migration rates. In the study area the downstream accretion of the scroll bar amounted to 150 m/yr.

Willows settle along the less dynamic riverbanks, especially where thin clay layers are deposited, resulting in small strips with very dense bushes of *Salix alba*. Poplars (*P. nigra*) and *S. triandra* together with pioneers, settle more scattered on the sand bars and on fresh deposited sand sheets. When sand deposition diminishes, grasses and herbs grow on the high parts of the pointbar, with species depended on soil moisture and texture. In lakes and marshes of abandoned channels, helophytes are found. After about 20 years after the first settlement of willows and poplars, hardwood species, mainly ash (Fraxinus langustifolia) appear in open places between the softwood vegetation. After 40-50 year, hardwood floodplain forest with *Populus*, *Fraxinus* and *Ulmus* are present, alternating with savannah-like grasslands and herbages with *Populus*, *Fraxinus* and *Ulmus*.

Conclusion

During the past century the main channel of the Volga near Zakrutsky increased its meander amplitude, allowing the growth of a 4 km long pointbar. This bar remained a bare feature for many decades. However, after 1986 a rapid succession of vegetation occurred, that in a few years resulted in small strips of dense bushes parallel to the alignment of the pointbar. It is expected that a final savannah-like hardwood floodplain may establish half a century after the first pioneer vegetation settled. After 1986 also a new scroll bar evolved. Due to increase in hydraulic roughness by vegetation a chute channel was activated and a protruding chute bar developed. Morphological changes in the position of bars and the main channel occur at a much higher rate as compared to riverbank changes.

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A flume experiment on sediment transport with flexible, submerged vegetation

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Abstract

This study aims at improving insight in the sediment transport characteristics over a vegetated bed. A laboratory experiment was carried out in which flow, turbulence characteristics and sediment transport were measured in a flume with flexible, submerged vegetation. Results of this experiment show a reduction in sediment transport of 43 to 74% and a reduction of the bed shear stress with about 96%, compared to a situation without vegetation.

Introduction

'Room for the river' measures provide opportunities for ecological rehabilitation of the floodplains. However, the interaction between sediment transport and vegetation in river floodplains is to a large extent unknown. This study aims at improving insight in the sediment transport characteristics over a vegetated bed by executing an experiment on sediment transport with flexible, submerged vegetation.

Material and methods

Experiments were conducted in a 35-m long by 80-cm wide, straight, horizontal open channel with concrete bottom and glass walls. The flume set-up is presented in figure 1. A longitudinal section of artificial, flexible vegetation was installed over a length of 15.85 m. In total 4755 plants of 27 cm length were mounted onto 18 mm wood-cement boards in a rectangular pattern of 5 by 5 cm by sticking the upper end of the plant into 2.0 mm diameter drilled holes. A 9-cm thick layer of sand was distributed evenly between the submerged plants using a carrier with a perforated metal box that drives on top of the flume. The upright plant height is 18 cm. The D_{50} of the sand is 321 μm with a uniformity of 1.19, defined as the square root of D_{84} over D_{16}.
The amount of sediment that was transported out of the section with the moveable bed was determined as measure of sediment transport. Mean and turbulent velocity statistics were obtained using electromagnetic flow meters and an immersible laser doppler anemometer. Water

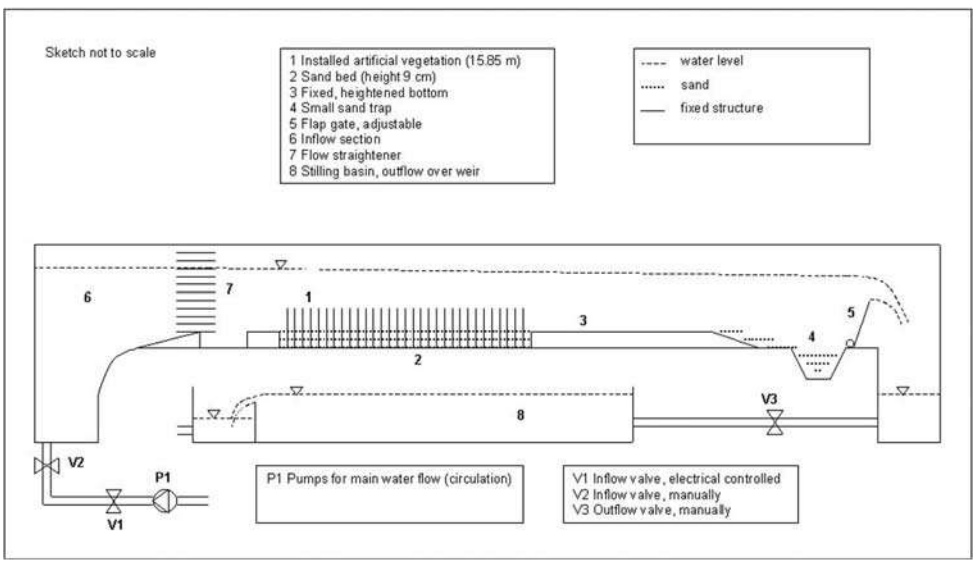

Figure 1. Flume set-up.

level slope was measured with a dynamic liquid-level meter. Two series of experiments were conducted; first three with and than three without plants (Table 1).

Table 1. Hydraulic conditions for the test runs.

	Discharge (m^3/s)	Depth (m)	Velocity (m/s)
Test 1	0.072	0.27	0.33
Test 2	0.130	0.32	0.51
Test 3	0.103	0.31	0.42
Test 4	0.075	0.27	0.35
Test 5	0.106	0.31	0.43
Test 6	0.134	0.32	0.52

Results and discussion

The observed profiles for horizontal velocity and Reynolds stress show the typical profiles found for depth-limited, submerged canopy (Ikeda & Kanazawa, 1996; Nepf & Vivoni, 2000), i.e. deceleration of flow within the vegetation layer (Figure 2) and a maximum Reynolds stress near the tops of the plants (Figure 3). The bent plant height was visually determined at about 12 cm.
The total shear stress α and the bed shear stress α_b as derived from the measurements are presented in table 2, together with the reduction factor α_b/α. These results show that the total shear stress increases with flume discharge, the bed shear stress stays rather constant and the reduction in bed shear stress as a result of the presence of the plants is about 96%.

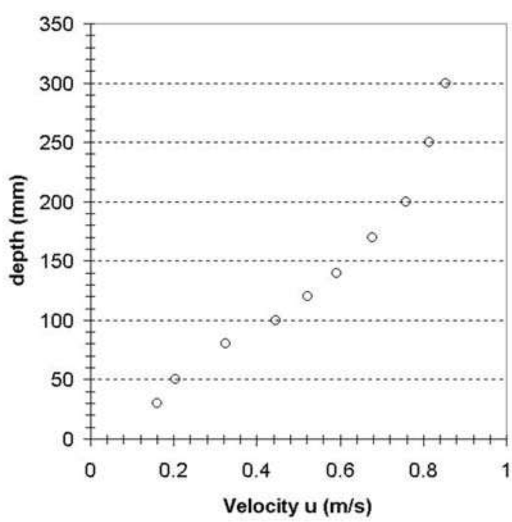

Figure 2. Vertical profile of velocity (Test 2).

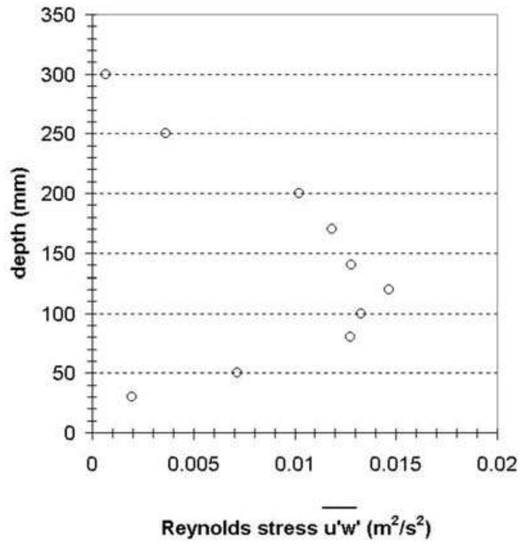

Figure 3. Vertical profile of Reynolds stress (Test 2).

Table 2. Values for total shear stress, bed shear stress and reduction factor.

	τ (N/m^2)	τ_b (N/m^2)	τ_b/τ (-)
Test 1	18	0.8	0.044
Test 2	25	0.9	0.036
Test 3	21	0.9	0.043

The sediment transport was measured and compared between Test 3 with vegetation, Sv, and Test 5 without vegetation, S and compared between Test 2 and 6, with and without vegetation. The reduction in transport was expressed as S_v/S (Table 3).

Table 3. Values for sediment transport and reduction factor.

	Sv (kg/h)	S (kg/h)	Sv/S (-)
Test 3 & 5	5.9	10.4	0.57
Test 2 & 6	11.6	44.0	0.26

Conclusions

The presence of vegetation in floodplains may reduce the bed shear stress with approximately 96% and the sediment transport with approximately 43 to 74%.

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Cyclic rejuvenation of floodplains

The neglect of vertical sorting in morphological models

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Abstract
In rivers with non-uniform sediment, vertical sorting mechanisms may play an important role in the large-scale river morphology, viz. through affecting the small-scale morphology (bedforms and bed roughness) and the sediment transport. An important source of uncertainty in the prediction of morphological changes is the inadequate description of these sorting mechanisms in present morphological models systems. The author proposes an improved method to account for vertical sorting in the riverbed.

Introduction
Degradation or aggradation of the riverbed results from spatial gradients in the total sediment transport rate, which is expressed by the mass balance equation. In rivers with non-uniform sediment, spatial gradients in the grain size-specific transport rates will result in a change in the composition of the bed surface and often degradation or aggradation of the riverbed. A further complication in the mass balance is the organisation of grain size fractions over bed elevations, i.e. the vertical sorting. A plane bed is often covered with a coarse bed layer (mobile pavement or armour layer), whereas in bedform-dominated conditions the coarse size fractions are mainly found in the lower parts of the bedforms.
In a morphological model system for non-uniform sediment, the above interaction is described in terms of sediment continuity models. Hirano (1971) was the first to develop such a model. Yet, the Hirano active layer model and its variants suffer from a number of shortcomings. Most of them do not account for vertical sorting other than through a change in time of the mean bed level, whereas flume experiments have shown that vertical sorting also occurs through bedform migration and the variability in trough elevations (Blom *et al.*, 2003). Hirano's assumption that the bed elevations interacting with the flow constitute a distinct surface layer seems too limited to adequately account for these sorting processes. A final problem of these models with discrete bed layers is that in certain situations the set of equations becomes elliptic in parts of the space-time domain and thus unsolvable.

New continuum sorting model
The author has developed a new continuum vertical sorting model for bedform-dominated conditions. It is based on 1) the Parker-Paola-Leclair framework for sediment continuity, 2) the Einstein step length formulation, 3) a newly-developed lee sorting function, and 4) a newly-developed method to account for the variability in bedform trough elevations (Figure 1). Parker *et al.* (2000) developed a new type of framework for sediment continuity that no longer distinguishes discrete bed layers, thus enabling us to relate entrainment and deposition fluxes in the bed to the likelihood of a bed elevation being exposed to the flow. In this Parker-Paola-Leclair framework, parameters such as the grain size-specific entrainment and deposition rates vary continuously over depth, but are horizontally averaged over a large number of bedforms. The present study comprehends the derivation of formulations for the grain size-specific and bed elevation-specific entrainment and deposition fluxes as required for the Parker-Paola-Leclair framework.
For equilibrium conditions, the continuum sorting model is reduced to an equilibrium sorting model, which comprises two methods to solve for the

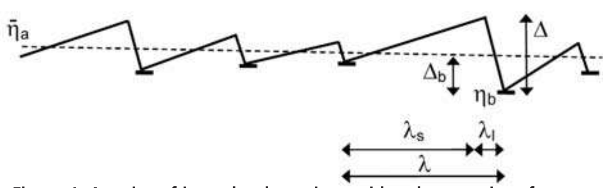

Figure 1. A series of irregular dunes is considered as a series of triangular dunes with varying trough elevations.

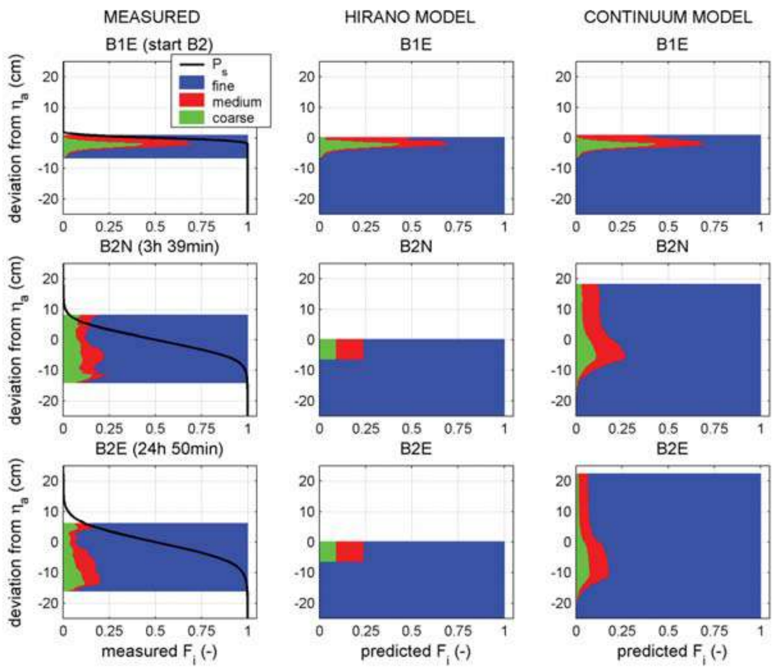

Figure 2. Left-hand plots: measured time evolution of sorting in experiment B2 (Blom et al., 2003). Middle plots: time evolution of sorting as computed by the Hirano active layer model. Right-hand plots: time evolution of sorting as computed by the new continuum sorting model. F_i denotes the proportion of size fractions at a certain elevation of the bed, η_a the mean bed level, and P_s the probability distribution of bed surface elevations.

equilibrium sorting profile. For non-equilibrium conditions, the continuum sorting model is reduced to a sorting evolution model. It solves for the time evolution of both the vertical sorting profile and the bed load transport composition from the following parameters: the initial sorting profile, the total bed load transport rate, and the probability density function (PDF) of trough elevations.

The equilibrium sorting model was calibrated and verified against flume experiments. Two constants in the newly developed lee sorting function were used as calibration constants. The sorting evolution model was verified by comparing the computed time evolution of both the vertical sorting profile and the bed load transport composition to measured data from flume experiments. The computations agree reasonably well with the measured data (Figure 2).

Discussion and conclusions

The new continuum sorting model is deterministic in the computation of the vertical sorting profile, but probabilistic in terms of the bed surface. This probabilistic element arises from the fluctuations of the bed surface due to the presence of bedforms. The continuum sorting model is the first to incorporate sediment sorting fluxes through bedform migration, the variability in bedform trough elevations, and changes in the mean bed level. Because of its better description of the vertical sorting profile, the continuum sorting model yields better predictions of the average bed surface composition than the discrete bed layer models presently available. Since the average bed surface composition plays a crucial role in the sediment transport, it is believed that the model will also lead to improved predictions of sediment transport rates and thus morphological changes, although testing of the model as part of a morphological model system was beyond the scope of the present study.

In a morphological model system, the equilibrium sorting model may be applied instantaneously, if the morphological time scale is much larger than the time scales of vertical sorting, bed surface elevations, and bedform migration. This constraint may well be satisfied in situations with large-scale morphological changes, such as long-term bed degradation after a river bend cut-off or long-term morphological changes due to river training works. For situations with local small-scale morphological changes, e.g., in river bends, it is likely that the time evolution of sorting needs to be accounted for when computing changes in morphology. In that case, the sorting evolution model must be applied.

In order to use the new continuum sorting model in predictive applications, the model needs to be extended to plane-bed conditions and a sub-model for the PDF of relative trough elevations needs to be developed.

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Probabilistic modelling of morphological impact of flood protection measures along the Waal

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Introduction

In the Netherlands a new flood protection policy, called Room for the Rivers, is implemented. Measures, other than dike strengthening, are considered in order to increase the flood conveyance capacity in the rivers. Examples of such measures are floodplain lowering and summer dike removal. This present project investigates to what extent these measures in the river Waal (Figure 1) may lead to more bed level variability.

Three cases are considered:

1 Reference case showing further evolution of the system without any additional human intervention.

2 Case with floodplain lowering in the Waal: over a distance of 45 km (between St Andries and Nijmegen) the floodplains are lowered with 1.5 m.

3 Case similar to case 2, but the summer levees are removed.

Monte Carlo simulation, applied to a 1D model of the river Waal, is utilised to quantify the uncertainty in the morphological response to these measures given an uncertain river discharge.

Method

Sobek Rhine branches model

A 1-D Sobek model (WL | Delft Hydraulics, 2001), the Sobek Rhine branches model (Jesse & Kroekenstoel, 2001), is used to analyse the morphological response to floodplain lowering and summer levee removal.

In reality many irregularities are noticed in the river Waal. Irregularities are present, such as variations in geometry, in floodplain width, in floodplain vegetation type and variation in the presence or absence of summer dikes, flood-free areas and storage and conveying parts in the floodplains. Each irregularity is a generator for

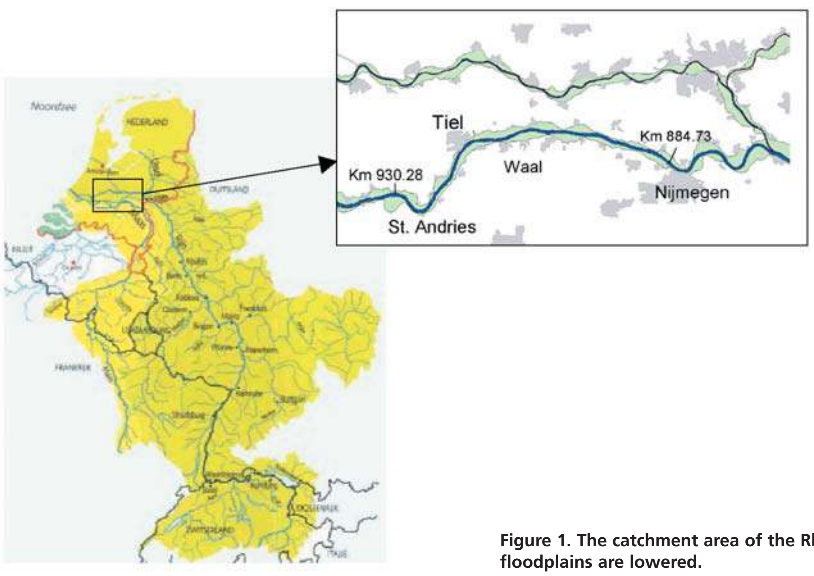

Figure 1. The catchment area of the Rhine and the section in the Waal in which the floodplains are lowered.

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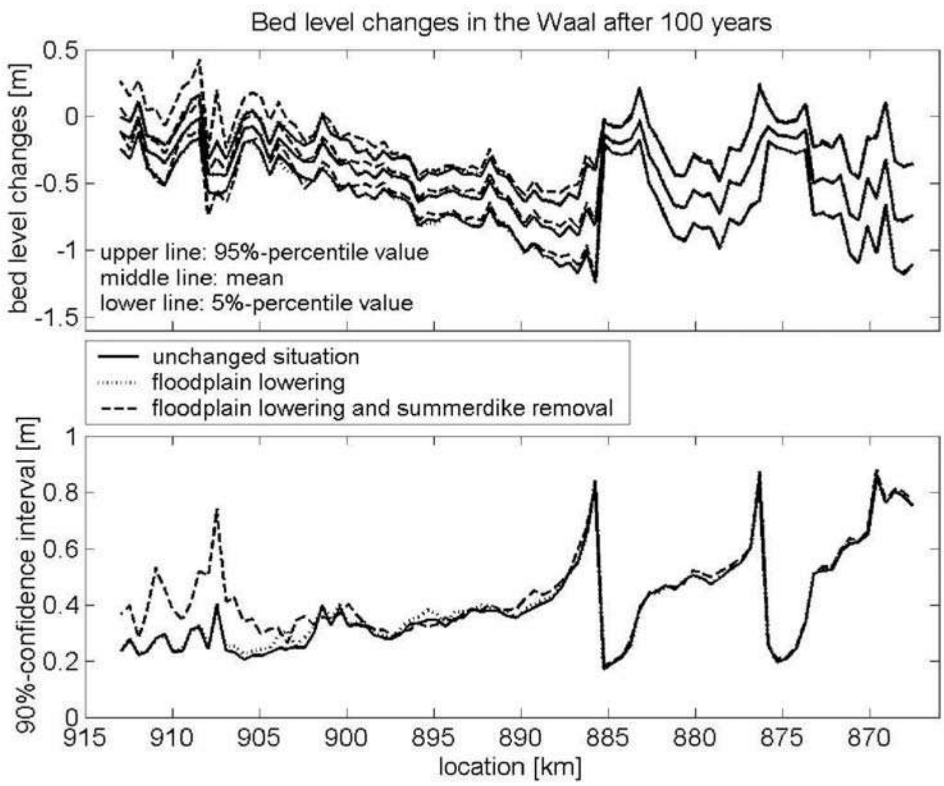

Figure 2. Spatial variation of statistical properties of the bed level change after 100 years in the Waal section between Pannerdense Kop (km 886) and Tiel (km 915).

new bottom waves. Irregularities such as variations in river geometry, bottom vanes (Erlecom) and fixed bottom layers (Nijmegen and St. Andries) are included in the Sobek Rhine branches model. The morphological model is calibrated on the basis of bathymetric data in the period between 1987 and 1997. The model predicts for the period between 1997 and 2097 large-scale erosion in the upper part (867 km - 915 km) and large-scale sedimentation in the lower part (915 km - 963 km) of the Waal.

Uncertainty

In the model schematisation and the specification of model input- e.g. boundary conditions, initial conditions and model parameters- uncertainties are introduced. This paper does not consider uncertainties introduced by the model schematisation. Van der Klis (2000) and Van Vuren *et al.* (2002) showed that the relative contribution of an uncertain discharge to the uncertainty in the morphological predictions is large. Therefore, in this paper the impact of an uncertain river discharge to the uncertainty in the morphological response is analysed. Monte Carlo simulations are made with the Sobek Rhine-Branches model to quantify the uncertainty in the morphological response.

Monte Carlo simulation

Monte Carlo simulation (Hammersly & Handscomb, 1964) involves a large number of model runs with statistically equivalent inputs. For each run a discharge time series of a hundred years duration is randomly generated according to the prescribed probability distribution. This distribution accounts for the seasonal dependency of the discharge and the correlation of the discharge in successive periods. On the basis of the outputs of 300 of these model runs the morphological response statistics (e.g. the expected value and 90% confidence band of the bed level change) are analysed.

Results

Spatial variation of statistical properties

Figure 2 shows the morphological response statistics in the main channel for the three cases after 100 years in January. This figure presents the mean bed level changes and the (size of the) 90%

confidence interval of the bed level changes in the Waal section between the Pannerdendse Kop (km 886) and Tiel (km 915). The 90% confidence interval means that with a probability of 90% the bed level changes are within this range. Note that the lines of the confidence interval represent the envelopes of all realisations.

In the reference case, various irregularities in the river (such as width variation and river construction works like riverbed protection) in combination with an uncertain river discharge lead to an uncertain morphological response. Each irregularity in the river is a generator for new bottom waves and might lead to large uncertainties. At locations with large discontinuities a local increase in bed level variability is observed - namely an increase in confidence band is noticed (Figure 3).

If floodplains are lowered and the summer levees are maintained, the response is similar to the reference situation, because of the infrequent flooding of these floodplains.

If floodplains are lowered and the summer levees removed, the morphological response is stronger, due to the more frequent flooding. Not only does the mean bed level increase at the location of the floodplain lowering, also the size of the confidence band increases and has more pronounced peaks. The latter is especially noticed in the river sections with large variation in floodplain width (Figure 3). To avoid a strong morphological response with a large variability and uncertainty, the summer levees should be maintained.

Temporal variation of statistical properties

In addition to the spatial variation of the morphological response to floodplain lowering and summer levee removal statistics a temporal variation is noticed. Figure 4 shows the temporal variation of two locations: location 907.4 km with a large change in floodplain width and location 906.9 km with a small change in floodplain width. Especially at the location with the large change in floodplain width (907.4 km) the temporal variation in morphological response statistics is considerable. This temporal variation reflects the seasonal variation of the river discharge. The seasonal fluctuation of the 90%-confidence band is significant. The largest 90% confidence interval is found in the high water period. The smallest interval is found in the low water period.

At this location (the transition from a narrow to a wide cross section; Figure 3) sedimentation in the main channel takes place. The 95%-percentile strongly oscillates, while the 5%-percentile is more or less constant. This can be explained by the fact that during discharges higher than the bankfull discharge bottom waves (sedimentation) are initiated in the main channel. These bottom

Figure 3. River section "Willemspolder" (km 906 - 908) with large variation in the floodplain width (Courtesy of DON).

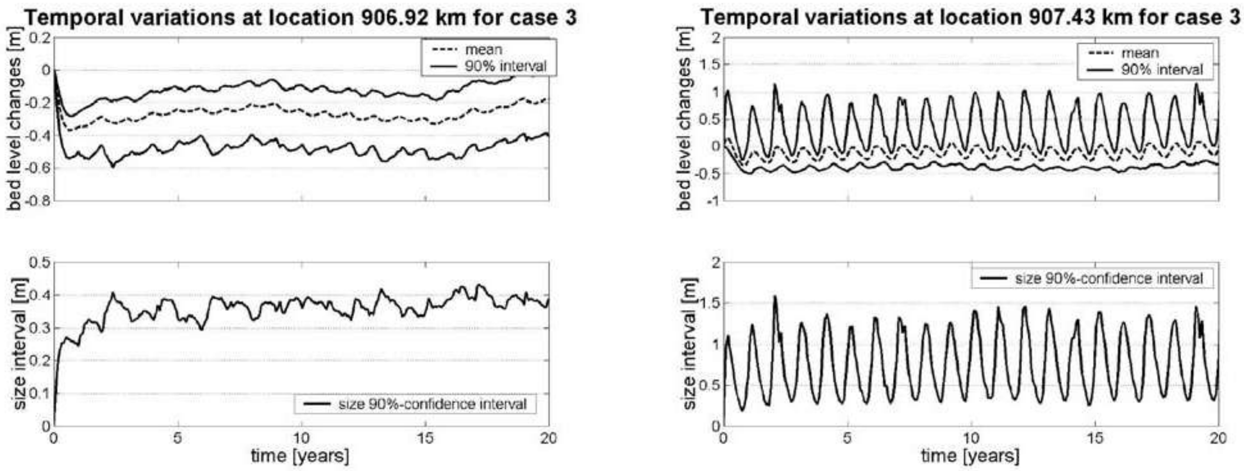

Figure 4. Temporal variation at location 906.92 km and 907.43 km.

waves migrate downstream and (partly) damp during discharges lower than the bankfull discharge. Therefore, the seasonal variation in the 5%-percentile is limited.

At the location (906.9 km) with a small change in floodplain width the seasonal signature is less noticed. The uncertainty in the bed level change at this location is affected by the bottom waves initiated at other locations in the river, propagating downstream.

Further research

The morphological response statistics are strongly space and time dependent. The probabilistic approach offers a different perspective on the morphological response to floodplain lowering and summer levee removal at different locations. Not only does this approach show that many possible morphological states can occur. It also shows that some locations have a larger bed level variability (with possibly a larger seasonal variation) than others do.

Large seasonal variation in response statistics is noticed at locations with large variation in floodplain width and other irregularities (e.g. riverbed protection). At other locations the seasonal signature of the morphological response statistics is less (or hardly) noticed.

Knowledge on the spatial and temporal variation of bed level uncertainty can be of importance to the decision on where to implement future flood protection measures. Some locations could develop into nautical bottlenecks, which may be maintained against high costs. At other locations the uncertain morphological response may have impacts on the design flood level and on operational predictions. During flood waves, the riverbed is very active, meaning a large uncertainty range in the bed level, which may affect the predicted height of the flood wave. This shows the importance and the need for research into uncertainties associated with modelling of river morphology.

Further research is focussed on the impact of uncertainty in morphology on the extreme flood level predictions and the prediction of navigability (and dredging required) in the Dutch rivers.

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A physical explanation for the geometric similarity of regular meander bends

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Abstract

Meandering is not restricted to rivers or the presence of sediment; it has also been reported in laboratory flumes, water rivulets on glass plates, supraglacial streams, ocean currents, density current, and even in lava channels on Venus. All these meanders, covering a wide range of spatial scales, show remarkable geometric similarity in their planform (Leopold, 1994; see also Figure 1). Here it is argued that the typical meander planform corresponds to a state of maximum entropy. From the second law of thermodynamics applied to open dissipative systems it follows that along a meander bend the variance of the production of entropy should be minimum. Theoretically derived maximum entropy curves are in good agreement with regular meander bends found in nature. We showed that complex pattern of a meandering river can be explained by applying a simple but general physical principle.

Figure 1. Frozen meanders, Tanana flats, Interior Alaska, USA. Frozen by winter ice, recent cut-offs reveal that this river is all but frozen in time. Variation in discharge forces meandering rivers to continuously adjust to new constraints by migration and creating cut-offs, thereby often forming oxbow lakes (top of figure) or shortcuts (bottom of figure). In spite of this dynamic behaviour, the meanders in this figure show remarkable geometric regularity and similarity. Unfortunately, for those interested in meandering, the world's finest meandering rivers are often found in remote areas, revealing their beauty only from a bird's-eye perspective (Courtesy by D. Zagorodnov).

Probable state of a river meander

Our physical explanation for the typical planform of meanders starts from the second law of thermodynamics applied to open dissipative systems. Prigogine discovered that these systems evolve towards a most probable state corresponding to maximum entropy (Prigogine & Stengers, 1984). This near-equilibrium state corresponds to a minimum *production* of entropy, subject to the constraints imposed upon the system. In fluids, entropy is produced when ordered energy (kinetic energy) is irreversibly converted into disordered energy (heat) due to viscous effects. Applying this concept to rivers leads to the hypothesis that the most probable state of a river meander is one in which the variance of entropy production is minimal. Langbein & Leopold (1966) already proposed a similar hypothesis, but they provided no proof for this hypothesis.

Test of hypothesis

To test our hypothesis we derive an expression for entropy production along arbitrary river bends.

Assuming an incompressible fluid and isothermal conditions, the production of entropy per unit volume and per unit time (σ) is given by:

$$T\sigma = -(\boldsymbol{\tau} : \nabla \boldsymbol{v})$$

where is the, T is absolute temperature, (τ is the stress tensor and v is the velocity vector. We can simplify (1) for moderately meandering, shallow rivers with steady, subcritical flow. Under these conditions σ depends only on the vertical gradients of the longitudinal and transverse velocity components (v_s and v_n). Integration of the simplified expression of (1) over a river cross-section A in a curvilinear orthogonal coordinate system with a downstream s-axis, a cross-stream n-axis and a vertical z-axis yields:

$$\sigma_{cs} = \frac{\rho}{T} \int_A \varepsilon \left(\left(\frac{\partial v_s}{\partial z} \right)^2 + \left(\frac{\partial v_n}{\partial z} \right)^2 \right) dA$$

in which σ_{cs} is the entropy production for a given cross-section, ρ the fluid density and ε the kinematic eddy viscosity. Because the typical meander planform manifests itself at different scales we solved (2) independent of scale. We use ξ to indicate the variance of the dimensionless cross-sectional entropy production for one wavelength. At maximum entropy, the value of ξ is minimal.

Meander bends can well be described by the Kinoshita-function (Parker *et al.*, 1983):

$$\Theta(s) = \Theta_0 \cos\phi - \Theta_0^3 (c_f \cos 3\phi + c_s \sin 3\phi)$$

in which θ represents the angle between the tangent to the curve and the downvalley axis, and $\phi=\pi s/L$ is the phase along the curve; θ_0 is the initial angle at s=0 and c_f and c_s are shape parameters defining the amount of fattening and skewing, respectively, of the sine generated curve (Langbein and Leopold, 1966). Equations describing the spatial variation of the flow variables involved were obtained from literature (Odgaard, 1986) and solved numerically for bankfull discharge along different Kinoshita-curves of constant sinuosity (k) but with different shape parameters.

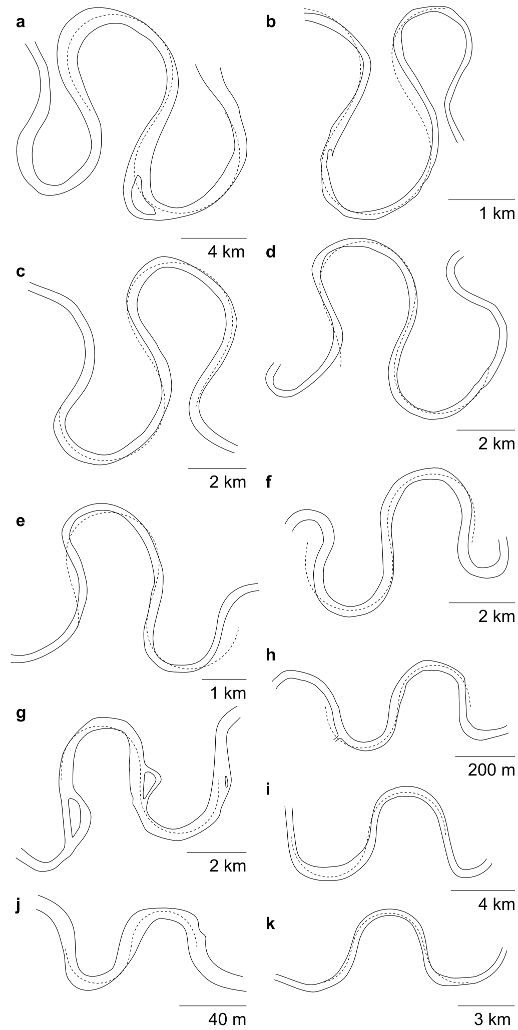

Figure 2. Results expressed in shape parameters of the Kinoshita-curve. (a) Variance of dimensionless cross-sectional entropy production (ξ) as a function of the shape parameters of the Kinoshita-curve (k=π), showing one global minimum in the physical parameter space [-0.1,0.1]; (b) Dependence of the optimal shape parameters of the Kinoshita-curve on the sinuosity.

Results

The results are shown in Figure 2. For a constant sinuosity ξ shows one unique minimum in the (c_f, c_s)-space (Figure 2a, k=π). This shows that, for a given sinuosity, there is one most probable meander planform. The "maximum entropy" shape parameters vary with sinuosity (Figure 2b). At low sinuosities (1.5-1.8) a small negative skewing results, while at sinuosities higher than 1.8 skewing increases with sinuosity until it reaches a constant value. This is in agreement with both empirical (Carson & Lapointe, 1983) and theoretical (Parker *et al.*, 1983) evidence concerning meander asymmetry. The constant skewing at higher sinuosities partly explains the frequently observed similarity in meander planform. Fattening is more pronounced at lower sinuosities and almost constant at high sinuosities. We compared our maximum entropy curves with natural regular meanders (Figure 3), which can be assumed closest to equilibrium. Only few examples of regular meanders have been well documented, as many meandering rivers are found in remote areas or have been straightened in the past century. We therefore also used satellite images and old maps to identify regular meander reaches. Our maximum entropy curves show striking similarity with regular meanders, for all sinuosities and for spatial scales covering at least two orders of magnitude. We can thus conclude that the similarity in planform of regular meanders reflects a state of maximum entropy. Our results generalise the theory of minimum variance (Langbein & Leopold, 1966), interpreted in terms of entropy production, and unite the conflicting points of view expressed in the literature (Carson & Lapointe, 1983).

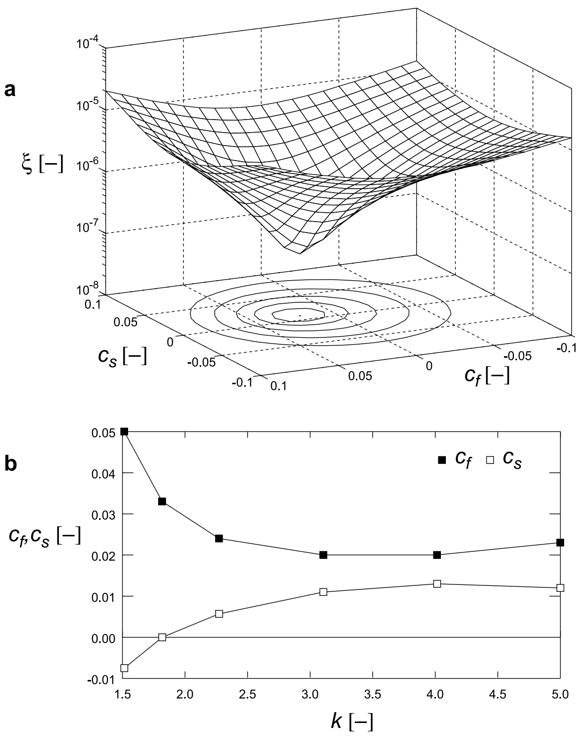

Figure 3. Examples of natural meander bends of different scale and sinuosity compared with the theoretically derived maximum entropy curves (dotted lines). In all cases flow is from left to right. An aster indicates the situation before regularization. (a) Mississippi River* near Greenville, Miss., USA, k=4.0; (b) Incised Colorado River at The Loop, Utah, USA, k=4.0; (c) Juruá River, southern central Amazon basin, Brazil, k=4.0; (d) Jutai River, southern central Amazon basin, Brazil, k=3.1; (e) Meuse River* near Nijmegen, The Netherlands, k=2.6; (f) Jutai River, k=2.3; (g) Rhine River* near Speyer, Germany, k=1.9; (h) Popo Agie River near Hudson, Wyo., USA, k=1.7; (i) Juruá River, k=1.6; (j) Geul Brook near Valkenburg, The Netherlands, k=1.6; (k) Juruá River, k=1.5.

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Changing sediment generation and supply due to natural reforestation in the Dragonja catchment, SW Slovenia

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Abstract

In the Dragonja catchment in SW Slovenia, reforestation has been proceeding since the 1960's. Although the effects of deforestation on catchment hydrology are extensively studied (Globevnik & Sovinc, 1998), the effects of reforestation on a rivers sediment budget are less well known. To reconstruct the change in the sediment budget of the catchment of the river Dragonja due to reforestation, information about both sediment supply as well as sediment deposition is needed. Land use change in the catchment over the period 1954 to 2002 was used to reconstruct the sediment supply.

We mapped the land use in 1954 and 1994 using aerial photographs and carried out a field survey in 2002. This spatial information was used as input to an erosion model (RUSLE) to calculate the amounts of sediment production in the different years. Sediment production decreased with 79% over the period 1954 to 1994 and with 82% over the period 1954 to 2002. With the sediment deposition rates calculated in previous research and the sediment production estimated in this study, we now have a first approximation of the sediment budget of the river Dragonja of the past 50 years.

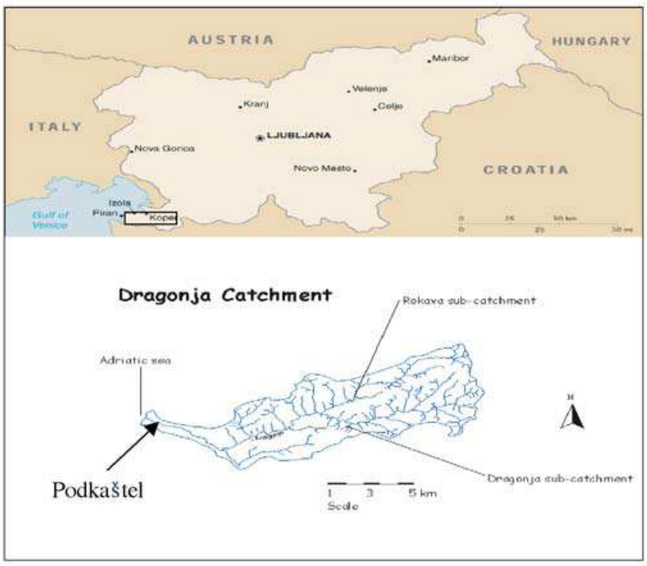

Figure 1. The study area: the Dragonja catchment, Southwestern Slovenia.

Introduction

Rivers react on deforestation with higher erosion rates, higher sedimentation rates and larger floods. However, the effects of reforestation on a rivers sediment budget are less well known. To reconstruct the change in the sediment budget of the catchment of the river Dragonja due to reforestation, information about both sediment supply as well as sediment deposition is needed. In earlier research (Keesstra, 2002) the sediment deposition rate in the floodplain was estimated. In this research we used the change in land use as input for an erosion model (RUSLE) with which we estimated the sediment production on the hill slopes.

The 30-km long Dragonja River, situated in the southwestern part of Slovenia, has a drainage basin area of approximately 91 km^2. This research was done in the upstream part of the Dragonja, which consists of two sub-basins, the Rokava drainage basin (20.1 km^2) in the north and the Dragonja drainage basin (31.8 km^2) in the south (Figure 1). Over the last 50 years agricultural land has been abandoned due to economic changes in the region, resulting in widespread natural reforestation in the catchment.

Methods

Land use mapping

From aerial photographs of 1954 and 1994 we derived the historical land use of the Dragonja and Rokava sub-catchments. The present situation

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was mapped during a field survey in 2002. We mapped the following units of land use in 2002: fields, pasture, young forest and forest (Figure 2). The aerial photographs of 1954 were of poor quality and therefore only forest could be distinguished as opposed to non-forested land. We assumed that in 1954 no agricultural land was abandoned yet, therefore the non-forests area consists only of pastures and fields. The aerial photographs of 1994 were of much better quality, but it was not possible to distinguish between fields and pastures.

To compare each map, we estimated the missing land use units for 1954 and 1994 on the basis of their distribution in 2002. Since the distribution of land use units is dependent on the slope, the percentages were calculated per slope class. The map of 2002 was subdivided into 6 slope classes (FAO, 1977). For each slope class the percentages of the different land use units were calculated. The map analysis was carried out with the ArcView GIS software. The hill slopes were calculated from a digital elevation model (DEM) of the, which was based on contour lines each 5 m. This vector map was converted to a 5 by 5 m grid DEM.

Erosion model

Erosion was calculated with the revised universal soil loss equation (RUSLE; Renard *et al*., 1996), which is an empirical equation designed for the computation of average soil loss in agricultural fields. The equation has the following form:

$$E = LS\ R\ K\ C\ P$$

where E ($ton.ha^{-1}.yr^{-1}$) is the mean annual soil loss, LS (dimensionless) is the topographic (upslope contributing area) factor, R ($MJ.mm.ha^{-1}.hr^{-1}$) is the rainfall erosivity factor, K ($ton.ha.hr.ha^{-1}.MJ^{-1}.mm^{-1}$) is the soil erodibility, C (dimensionless) is the vegetation cover factor and P (dimensionless) is the erosion prevention practices factor.

The upslope contributing area (LS) was derived through calculation the flow accumulation in each grid cell multiplied by the cell dimension (equals 5 m). The rainfall erosivity factor R was calculated using precipitation data collected in 7 rain stations throughout the study area. A spatial coverage of $R_{(x,y)}$ was obtained after analyzing R and the altitude H (m) of the rain stations. A good linear fit was obtained according to:

$R_{(x,y)} = 0.0159\ H_{(x,y)}\ 19.844$ ($R^2 = 0.7134$). In total 96 topsoil observations were made that were used to calculate the erodibility factor K. There are only three main soil units and the average K factor of these observations was assigned to each soil unit, since no other spatial pattern could be distinguished: Carbonate Rendzina 0.019, Eutric Brown soils 0.020 and Fluvial soils 0.028. Landuse determined the crop factor C: forest 0.004, young forest 0.003, abandoned fields 0.023, pastures 0.006, fields 0.666 and the grouped pastures and fields 0.336 (Morgan, 1986). There are no erosion prevention practices so P was set to 1.

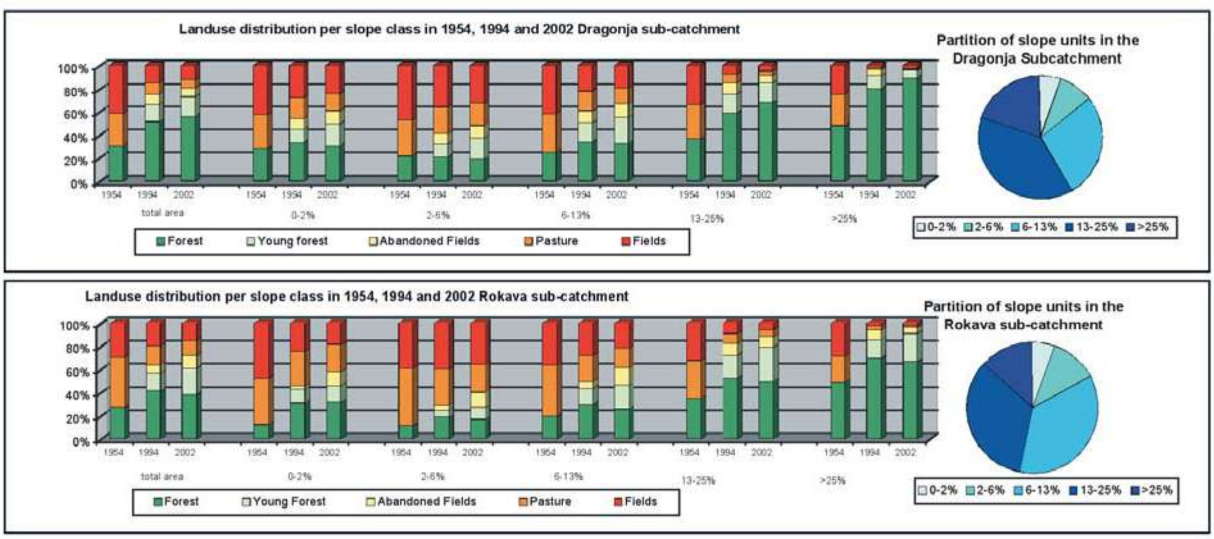

Figure 2. Land use distribution per slope class (bar graph) and slope unit partitioning (pie chart) in 1954, 1994 and 2002 in the Rokava and Upper-Dragonja catchment.

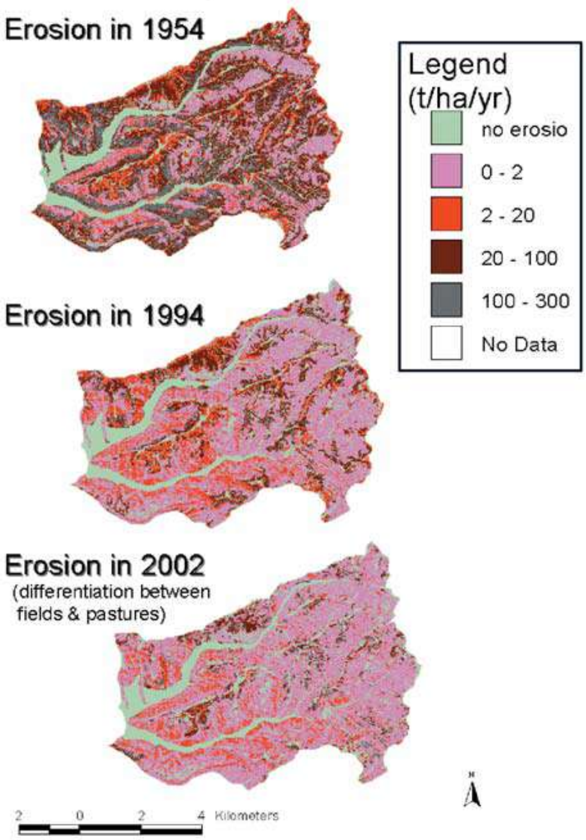

Figure 3. Erosion in ton ha-1yr-1 as calculated with the RUSLE model (Renard *et al*., 1997).

Results

Land use change

The forested area (young and mature forest) in the Rokava sub-catchment has increased with 109% from 1954 to 1994 and with 125% from 1954 to 2002 (Keesstra & van Dam, 2002). The forested area in the Dragonja sub-catchment has increased even more: 115% from 1954 to 1994 and 135% from 1954 to 2002. The increase in forest occurred mainly on the steepest slopes (>13%), which accounted for approximately 55% of the entire study area (Figure 2). In general, the Dragonja sub-catchment is steeper than the Rokava catchment.

Sediment supply

Figure 3 shows change in erosion rates between 1954, 1994 and 2002. In the Dragonja sub-catchment, the annual soil loss decreased by 79% from 1954 to 1994 and by 82% from 1954 to 2002. In the Rokava sub-catchment the decrease in soil loss is 71% from 1954 to 1994 and 77% from 1954 to 2002. The erosion on the steepest slopes caused the largest reduction in sediment supply.

Discussion and conclusion

Economic changes in the coastal region of Slovenia have led to widespread reforestation in the Dragonja catchment. Because of a lower average slope angle and a more favorable position to the larger cities at the coast, the Rokava sub-catchment is less reforested compared to the Dragonja sub-catchment. The RUSLE erosion model shows that an increase of forest in favor of fields causes erosion to drop. An increase of 125% of forest cover causes a 77% drop in soil loss in the Rokava sub-catchment. In the Dragonja sub-catchment a 135% increase of forest cover results in 82% less soil loss. This decrease in soil loss can be connected to a 50 % decrease of the sedimentation rates on the floodplains of the Dragonja and Rokava, over the period 1960 to 2000.

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Cyclic rejuvenation of floodplains

The Vecht river; sedimentation under human influence between the Rhine and the Zuiderzee

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Introduction

At the end of the Weichselian, the Rhine flowed through a vast alluvial plain from the present German border towards the west and debouched outside the present coastline southwest of Den Haag (Figure 1). The rising sea-level during the Holocene forced the Rhine to aggrade. Simultaneously, peat growth started. Around 5600 BP the alluvial plain was filled as far east as the area between Utrecht and Arnhem. Due to a partial avulsion the Rhine created a new branch to the north of its former alluvial plain; the Oude Rijn. Around 4300 BP the Oude Rijn had become the most important Rhine distributary (Berendsen & Stouthamer, 2001).

Around 2600 BP, a partial of the Oude Rijn avulsion took place near Utrecht, where the Vecht/Angstel developed. This new river flowed to the north through a peat area and finally debouched in the North Sea by the Oer-IJ.

Age and importance of the Vecht river

The Vecht/Angstel did not become a very important branch of the Rhine distributary system, as is shown by its size and by the relatively fine sand in the channel body. Only in a short reach downstream of Utrecht, the channel body coarse sand is found. Further downstream, the sand becomes finer and contains more silt. Everything points to a gently flowing river in a peat area (Van de Meene et al., 1988). The age of the Vecht/Angstel river has been dated at several locations (Table 1, Figure 2 and 3). An age between 2900 and 2600 BP seems likely for the Angstel, the oldest distributary. The beginning of the clastic sedimentation of the Vecht near Nigtevecht has been dated at 2270 BP, clearly younger than the Angstel. Two ^{14}C dates of a wooden canoe that was found in channel sediments of the Vecht near Nigtevecht reveal that the Vecht was navigable here around 2600 BP (pers. comm. Prof. Dr. R. Reinders, B.A.I., Groningen University). The onset of peat formation on top of the fluvial deposits of the Vecht/Angstel is dated at 1700 BP (330 - 410 AD) near Nigtevecht. This indicates that sedimentation must have stopped some time before. After the sedimentation had ended, the Vecht continued to discharge seepage water from the higher Pleistocene grounds (Utrechtse Heuvelrug) to the north.

Fluvial or marine?

The deposits of the Vecht downstream of Nigtevecht have been interpreted by as marine sediments of the "Westfriese II Afzettingen"

Figure 1. General map of the Netherlands and the research area.

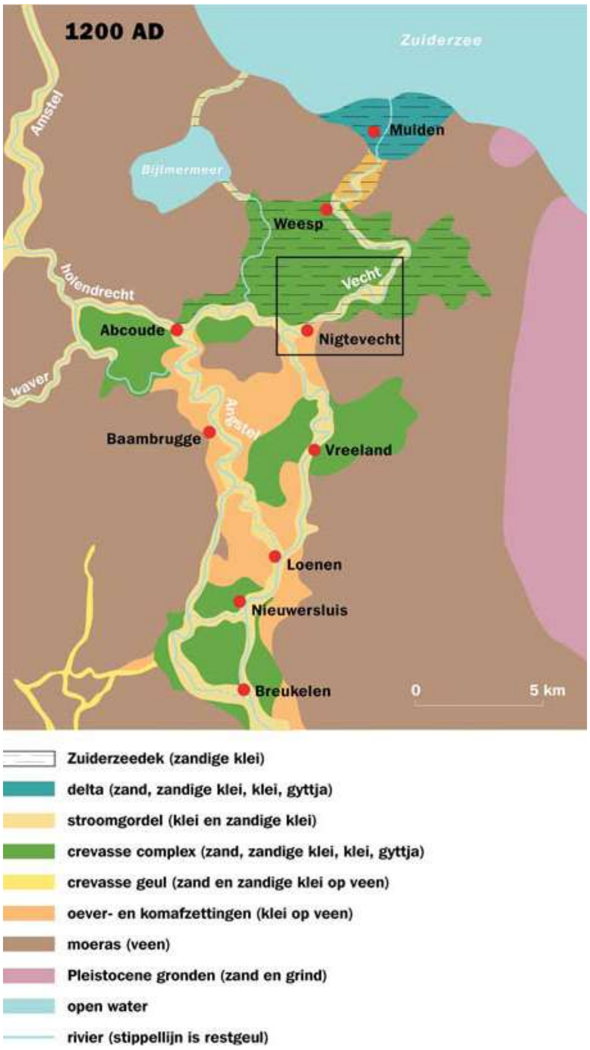

Figure 2. The Vecht/Angstel area around 1200 AD.

(Pons & Wiggers, 1959; 1960) that are correlated to the Duinkerke 0 deposits (Stiboka, 1965). However, recent research shows that nearly all the deposits are fluvial. They form a large "crevasse-complex" that is characterised by small-scale variations in lithology and the presence of many small crevasse channels that have filled in with sand. The presence of remnants of sweet water molluscs is typical (Gouw, 2000). A marine clay covers a thin peaty / humic bed at the top of the "crevasse-complex" deposits (Figure 2 and 3). This marine clay was deposited during floods from the Zuiderzee after 1170 AD when brackish water intruded deep into the Vecht during storms. The presence of salt water shells (fragments) confirms the marine character of this clay (Gouw, 2000). Figure 3 shows the extent of the marine clay.

Vecht and Man

Sedimentation by the Vecht river stopped during the Roman period in Holland. At the same time, the activity of the Oude Rijn between Utrecht and the North Sea increased. It is tempting to speculate on the possible activities by the Romans related to these phenomena, because of their excellent hydrological knowledge. It is well known that the Romans moved back behind the Oude Rijn after the Frisian uprising. For the Romans, a well-defended border was vital. It may well be the case that they ensured the discharge by the Oude Rijn by regulating at the discharge distribution of the Vecht and the Oude Rijn near Utrecht, thereby minimising the discharge

Table 1. The ^{14}C dates of the Vecht/Angstel.

Location	^{14}C number	^{14}C age	Surface level (m in relation to NAP)	Sample depth (cm below surface)	Name	Material	Stratigraphic position	Reference
Zuilen	UtC-1900	2650 ± 80	-0.1	43-46	Oud-Zuilen I-1b	Alder wood	Top peat layer	Törnqvist (1993)
Zuilen	UtC-1901	2620 ± 50	-0.1	43-46	Oud-Zuilen I-1a	Alder wood	Top peat layer	Törnqvist (1993)
Breukelen	GrN-13482	2895 ± 35	-0.76	224-229	Breukelen 2	Woodpeat	Top peat layer	Van de Meene *et al.* (1988)
Baambrugge	GrN-10222	1890 ± 30	-1.46	66-69	Baambrugge I	Peat	Top peat layer	Van de Meene *et al.* (1988)
Baambrugge	GrN-10224	2620 ± 35	-1.46	215-217	Baambrugge III	Clayey peat	Top peat layer	Van de Meene *et al.* (1988)
Vreeland	GrN-10226	3260 ± 35	-1.04	345-347	Vreeland 1	Claygyttja	Top gyttja	Van de Meene *et al.* (1988)
Nigtevecht	GrN-6761	2270 ± 35	-1.3	137-141	Nigtevecht II	Clayey gyttja	Top gyttja	De Jong, (1974)
Nigtevecht	GrN-6718	1695 ± 30	-1.3	75-80	NIgtevecht I	Clayey peat	Base peat layer	De Jong, (1973)

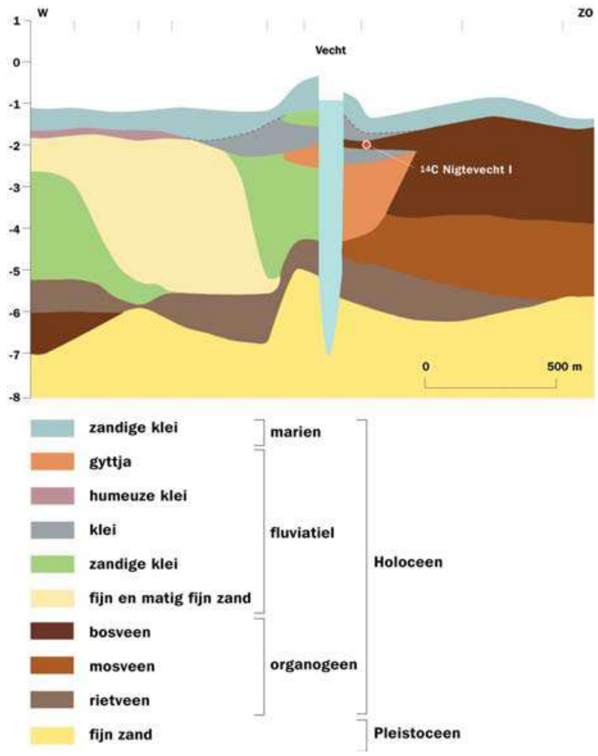

Figure 3. Section Nigtevecht (see figure 4 for exact location).

through the Vecht. Unfortunately, there is no direct evidence for these assumptions (yet), so they remain speculative.

As mentioned above, the areas along the Vecht downstream of Nigtevecht suffered from marine flooding during storms after the Zuiderzee had formed in the 12th century. During severe storms, the floods reached as far upstream as Utrecht. The bishopric Utrecht finished these floods on her territory by damming the Vecht around 1438 AD

Figure 4. Map of the Nigtevecht area, showing the location of figure 3 and 5.

(Figure 5; Hinderdam). Instead of a more logical location near Muiden, the Hinderdam location was chosen because Muiden was not under the bishops control; it was a city in the county of Holland. The dam and sluices at Hinderdam were not only important to him for safety reasons but also because of the tolls that he could levy there. For this reason, Holland was forbidden to build a dam on her territory. The Hinderdam worsened consequences of the floods in the county of Holland downstream of the dam, because the Vecht still had an open connection with the Zuiderzee. The construction of dikes along the Vecht could not solve these problems; they often broke during severe storms as is illustrated by the dike-breach scars in figure 5. Finally, the problems were solved in 1674 after the political conditions had changed: the power of the bishopric Utrecht in the Republic of Holland became restricted. Under the pressure of Amsterdam a new dam with sluices was built at Muiden. Subsequently the Hinderdam was removed.

Figure 5. Map of the Hinderdam at approximately 1621 AD.

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Sedimentation on embanked floodplains of the rivers Waal and IJssel

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Abstract
Sedimentation on embanked floodplains was measured in three study areas along the rivers Waal and IJssel, in order to investigate its influence on vegetation succession. The amount of sedimentation during the flood season of 2001 was measured using sediment traps. Grain size analysis was carried out on each of the trapped sediment samples. Average sedimentation rates for the period 1960-2001 were deduced from radiometric properties (^{137}Cs activity) of undisturbed sediment cores. Preliminary results show relatively small amounts of trapped sediment for 2001, when compared to average annual sedimentation for the period 1960-2001. Whether this difference is real or (partly) reflects differences in methods, needs further study. The data show strong decrease of sedimentation with increasing distance to the river channel. Additionally, texture of the trapped sediment samples fines with increasing distance to the channel. A subordinate trend at each study location is the decrease of sedimentation with increasing altitude. In general, the results of the study indicate the time scales involved in the morphological evolution of embanked floodplains. This information helps to determine recovery times for ecotopes after stripping of superficial floodplain sediments that may take place in the context of cyclic floodplain rejuvenation.

Introduction
Sedimentation on embanked floodplains has various effects that must be taken into account in river management strategies. Most importantly, sedimentation reduces the flow area between the dykes, thereby leading to higher risks of flooding due to overtopping of dikes. Additionally, deposition of polluted sediments may be a serious problem. Sedimentation also plays a crucial role in natural floodplain ecosystems. It creates natural floodplain morphology leading to ecological diversity, and it interacts with vegetation succession. The latter effects of sedimentation were the main reasons for the present study. The objective was to collect and analyse field data on sediment deposition with respect to: (1) quantities, (2) texture and (3) spatial trends (in transects across the floodplain). The three study locations comprise the Rijswaard (along the Waal River), the Cortenoever and the Vreugderijkerwaard (both along the IJssel River) (Figure 1). These locations represent morphologically and ecologically rich areas that have been managed by nature conservation organizations for decades.

Methods
Eighty-five sediment traps, consisting of artificial grass mats, were installed across levelled floodplain transects. This field method was earlier used and tested by Asselman & Middelkoop (1995). After flooding (period January-April 2001), the mats were collected, the sediment was removed, dried, weighed and subsequently subject to grain size analysis, using a Coulter LS laser particle sizer (sediment analysis was carried out at the Laboratory of Physical Geography of Utrecht University). At each study location, five undisturbed sediment cores (diametre 10 cm) were collected from one transect by mechanical hammering of a 1-m long steel sampler (carried out by NITG-TNO). These cores were radiometrically analysed in an experimental set up at the Kernfysisch Versneller Instituut (KVI) of the University of Groningen. The result of this analysis is a graph showing ^{137}Cs activity concentrations with depth measured along

Figure 1. The location of the study areas in the Netherlands.

the core (Figure 2). Peaks in ^{137}Cs activity concentration can be interpreted as representing the radioactive material brought into the atmosphere by nuclear bomb tests around 1960 and the Chernobyl reactor accident in 1986. When deposited on the ground, this atmospheric fall-out was bound to clay minerals and fixed in the soil profile, while being buried by periodically deposited sediment beds. Average sedimentation rates for the period 1960-1986 and for the period 1986-2001 can be derived from the sediment thickness between the peaks and the sediment thickness between the upper peak and the surface, respectively. Laboratory methods and applications to sedimentation were described by Van Wijngaarden & Van den Berg (2001) and Rigollet & De Meijer (2002).

Results

The results from the Cortenoever study area are shown in figure 3. The studied transect is located in the inner bend of a large meander of the IJssel River, with the transect being oriented more or less perpendicular to the channel. The floodplain topography (Figure 3a) features ridges and swales, marking successive former positions of the IJssel channel during lateral migration. Sediment trap measurements indicate a general trend of decreasing sedimentation with increasing distance to the channel (Figure 3b). Near the channel, about 2 to 4 mm of sedimentation was measured, whereas 0.5 to 1 mm of sedimentation are typical values for the distal part of the transect. Apart from this general trend, it appears that depressions received more sediment than neighbouring ridges. Thus, sedimentation to some extent was negatively coupled to floodplain elevation. Texture of the trapped sediment samples basically shows a trend of decreasing sand and increasing silt and clay content with increasing distance to the channel (Figure 3c). However, strong local increase of sand content characterizes the sediment trapped on the highest ridges. This is attributed to the occurrence of mole-heaps in the vicinity of the sediment traps. Moles, preferring the higher ridges as habitat, bring up sand from the subsurface, which is eroded during flooding and redeposited on the neighbouring floodplain.

The radiocesium activity concentration profile in Figure 2 relates to a core extracted from the ridge immediately next to the IJssel channel (Figure 3a). The distribution of peaks in the graph suggests a more or less constant sedimentation rate of 7 mm/year over the period 1960-2001. Only 2 mm of sedimentation was measured at this location for the 2001 flood season. Comparable differences between radiometrically derived average sedimentation rate and measured 2001 flood sedimentation apply to other locations in the transect, with the radiometric data also indicating a general trend of decreasing sedimentation rates away from the channel. The difference between both types of sedimentation data suggests that

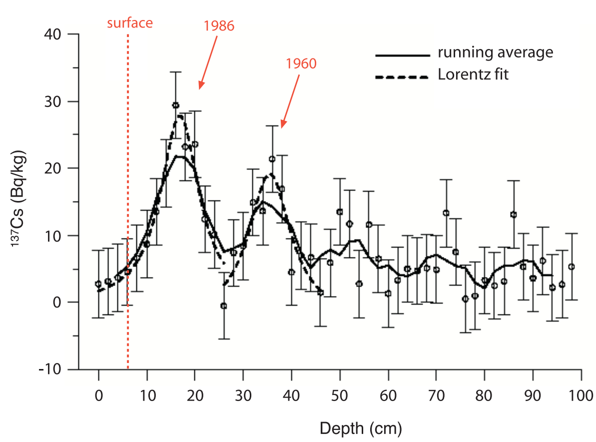

Figure 2. Radiocesium profile of core 103 from the Cortenoever study area (see Figure 3a for location). Measured activity concentrations of ^{137}Cs are plotted against depth measured along the core. Note that the surface is located at 6 cm and not at the zero of the depth scale. Peaks are interpreted to relate to the Chernobyl reactor accident in 1986 and nuclear bomb testing around 1960.

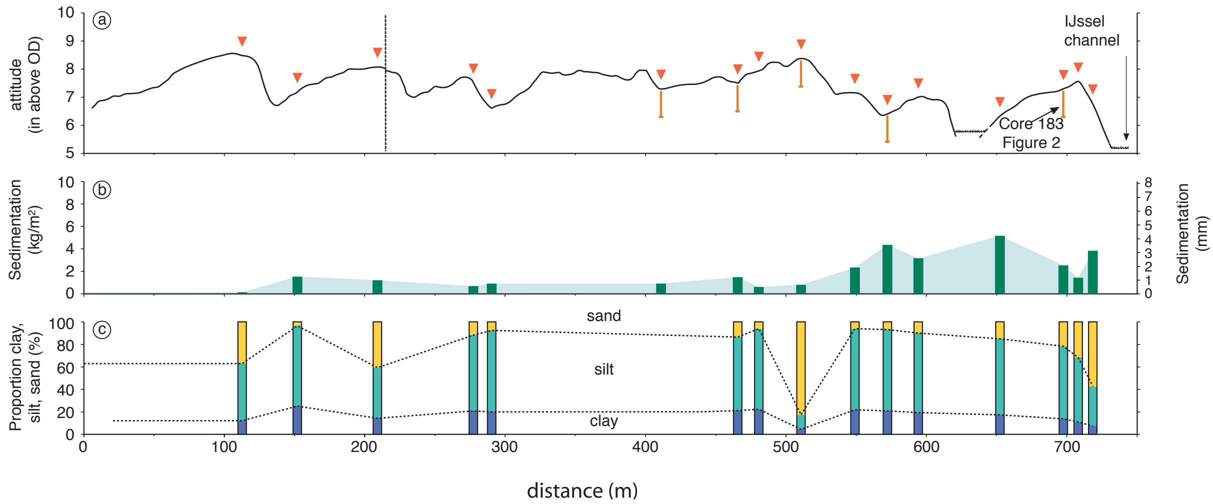

Figure 3. (a) Surface topography in the studied transect in the Cortenoever study area. Triangles indicate locations of sediment traps. Vertical bars indicate locations of radiometrically analysed cores; (b) Sedimentation in the transect during the flood season of 2001 measured with sediment traps; (c) Proportions of sand, silt and clay of the samples from the sediment traps.

2001 flood season contributed little to the process of floodplain aggradation at the decades time scale. Since maximum flood levels of 2001 are reached only once every four years (26 times in the 20th century), it seems that most of the sedimentation at the decades time scale occurs during few large floods. However, it cannot be excluded that the discrepancy between the two types of sedimentation data also (partly) reflects methodological differences; especially the radiometric dating method needs further validation. The results from the Rijswaard and Vreugderijkerwaard study areas basically show the same characteristics as described above for the Cortenoever area, although amounts of sedimentation in 2001 in the Vreugderijkerwaard were substantially less since a part of the embanked floodplain was not flooded.

Final remarks

The sedimentation rates following from this study can be used to evaluate the influence of sedimentation on the distribution of rare vegetation types that occur at the research locations. This is a subject of ongoing study. Besides a possible direct influence of the sedimentation process on vegetation succession, sedimentation also causes morphological evolution, thereby indirectly controlling vegetation development. The results of this study provide a basis for estimating the recovery times of ecotopes after stripping of superficial floodplain sediments that, for example, may take place in the process of cyclic floodplain rejuvenation. Especially high sandy levees represent the endpoint of long floodplain evolution and therefore rare vegetation types specifically tied to these environments deserve special attention in floodplain reconstruction works.

Acknowledgements

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Geological modelling of the subsoil in riverbeds for mineral extraction: an optimum of field measurements and geological expertise

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Introduction

For the last few decades several periods of high discharge in the river Meuse resulted in the flooding of the riverbanks. The Directorate-General of Public Works and Water management (RWS) had to develop a plan in which changes in the riverbed would diminish the chance of flooding and simultaneously sand and gravel can be excavated for commercial use. Furthermore the riverbed of the bifurcation of the Rhine at Pannerdensche Kop is subjected to great morphological changes due to high discharges. Again RWS would like to understand the different mechanisms involved in order to predict the morphological changes in the future. For both problems a geological model of the subsoil is needed.

This paper describes two methods to construct a geological model to be used for predictions on grain size distributions in the subsoil. Both methods use geophysical measurements (seismic surveys or geoelectrical measurements) and (vibrocore) drillings to construct the geological frame of the model. The grain size parameters of each unit within this frame are estimated using statistical techniques on measured grain size distributions. Both methods differ in the use of statistical techniques.

Case: river Meuse

In 1993 and 1995 the banks of the river Meuse were flooded, resulting in large-scale material damage in the area on private houses and industrial complexes. The project organisation Maaswerken had to construct a number of physical alterations of the riverbed of the river Meuse in order to diminish the change of flooding of the riverbanks in the future. Almost all these alterations involved excavation on a large scale. For the southern part of the river Meuse in total about 55 million m^3 will be excavated (divided in approximately 20 million m^3 clay and loam, 35 million m^3 sand and gravel) divided over 14 locations, varying in size from 10,000 to 20,000 m^2. The costs for this operation had to be balanced by the revenues of the excavated sand and gravel. In order to predict these revenues geological models for every excavation location were necessary.

For the river Meuse the yield of sand and gravel at a certain excavation location was estimated using the following approach (De Maaswerken, 2000):

- Perform several drillings in the area off interest (1-2 drilling for each 10,000 m^2, that is one for every soccer field). At various locations geo-electrical and seismic surveys were used to get a better grip on the spatial variation of the thickness of a certain layer.
- Determine the geological units within each drilling (using lithological descriptions of the drillings and geological expertise on the area).
- Take representative samples for each lithological unit within the geological layers and determine the full grain size distribution for each sample (about 100 for each location).
- Construct a 2D map for the base of each geological layer using Kriging interpolation
- Quantify the uncertainty in the spatial variation of this map using Conditional Gaussian Simulation.
- Select all the grain size distributions within every geological unit and calculate the average grain size distribution (the individual grain size distributions were weighted by their representative sample interval).

NCR is a co-operation of the universities of Delft, Utrecht, Nijmegen, Twente and Wageningen, UNESCO-IHE Institute for Water Education, RIZA, ALTERRA, TNO-NITG and WL | Delft Hydraulics

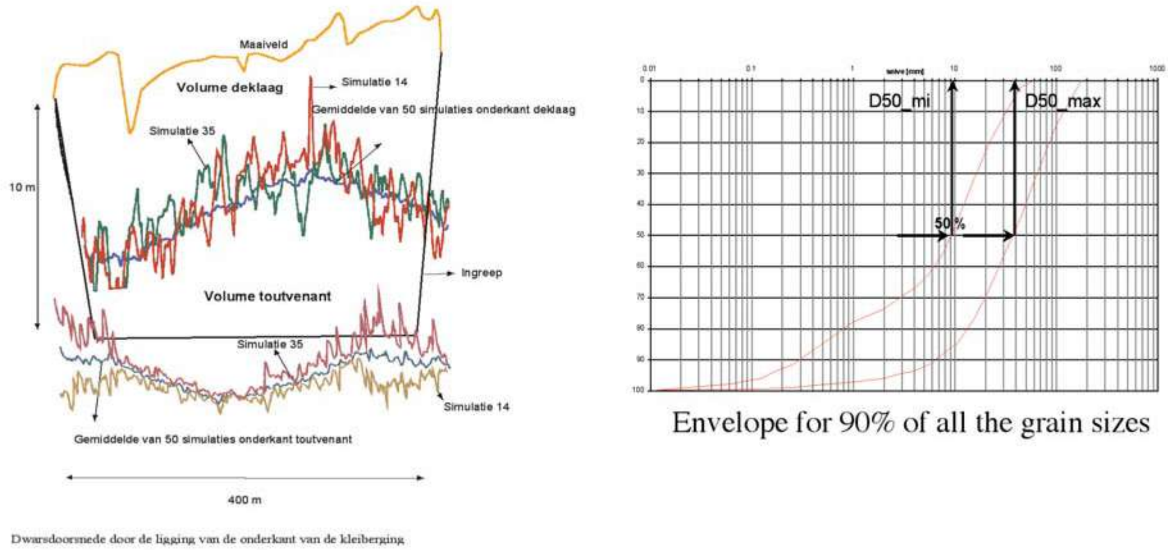

Figure 1. An example of a 2.5 D model results. Left: a cross section showing the average depth of the base of a geological layer and several realisations of this layer. On the right the 90% envelope enclosing 90% of the grain size data within the geological layer of interest.

- Quantify the spatial uncertainty in the average grain size distribution using student-t reliability intervals for each fraction.

Figure 1 shows an example of a 2D map of the average base of a geological unit, a cross section of several realisations of this unit and an envelope enclosing 90% of the grain size data within the geological layer of interest.

The goal of the Maaswerken project was not only to predict the average outcome of sand and gravel but also to quantify the uncertainties involved. For this project we focused on the uncertainty in the depth of a layer, the grain size distribution within this layer and the bulk density of the material. Together with data on economical aspects these uncertainties were used in a level 2 risk analysis.

The Kriging Standard Deviation is not to be used to estimate the uncertainty of an estimation at a certain point but rather as an average value of the variation of all the data in the area who are spaced a certain distance. Therefore a alternative technique had to be used to predict the uncertainties at a certain point in the area: conditional Gaussian simulation. This technique produces a large number of equi-probable realisations of a 2D map which honours the spatial structure of the data and takes into account the actual variation within the dataset involved (Figure 1). The net volume of a certain geological stratum within a design of an excavation is calculated by intersecting each realisation and the design. This results in a large number of the volume, together forming an expectation curve of the excavated volume. Although the actual local variation of the location off the base of a geological stratum at a certain point was considerable (up to 2 meters for an average thickness of the unit of 10 meters) the effect of this variation on the average volume that had to bee excavated was negligible (< 1%). This effect is caused by the averaging of all simulations.

The average grain size distribution for every location was divided into industrial fractions of gravel and sand. The variation coefficient resulting from the variation in grain size within the location was calculated as 10-20%.

In the end the calculated volume of each industrial fraction was multiplied by the bulk density of the gravel, estimated from a combination of large scale field measurements (where about 3 m^3 was excavated and weighted) and geophysical well logging) adding another 4% of uncertainty.

Ultimately these parameters were used in a level II stochastic calculation where also other uncertainties were accounted for (variations in the economical price for sand and gravel and uncertainties due to the excavation and processing of the sand and gravel). It seemed that the geological uncertainties are certainly not to be neglected and dominated by the variation in grain size over the area.

Case: river Rhine

The bifurcation at the Pannerdensche Kop is a very important distribution point of the river Rhine in the Netherlands. Besides the distribution of water, the morphological behaviour of the riverbed at the bifurcation has been the subject of study for years. Two important parameters for morphological calculations are the median grain size (D50, the mesh diameter of an imaginary sieve at which only half of the material in a sample would sift through) and sorting (a measure of the range of grain sizes). The RIZA wanted to use field measurements to construct a three-dimensional database of the lithologic characteristics and the grain size distribution of

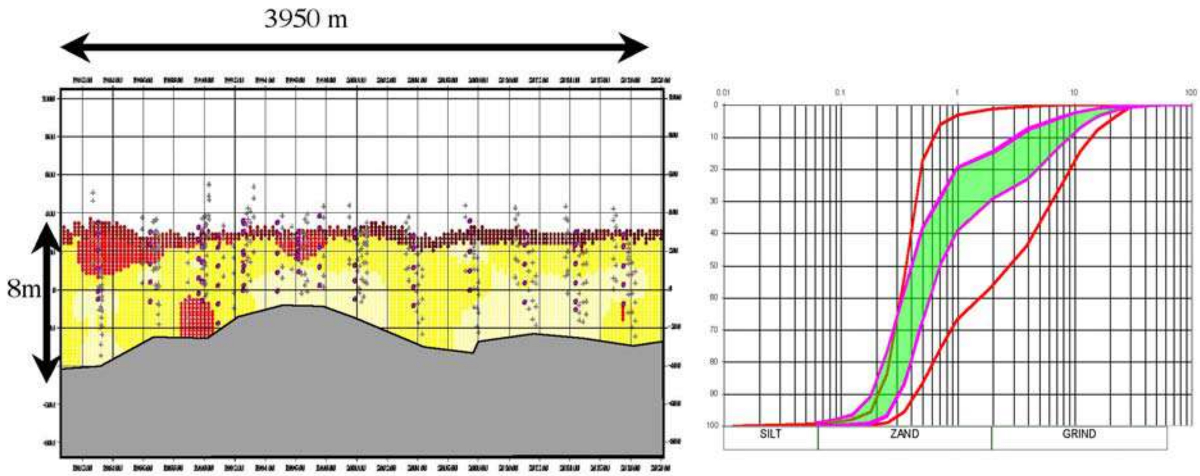

Figure 2. A cross section through the 3D grain size model (left): red=gravel, yelow=sand, crosses = sample location. and the smoothing effect of the Kriging interpolation method used (right): the 90% envelope of the measured grain size distributions (read lines) and the 90% envelope of the interpolated grain size distributions (green shape). (Zand: sand; grind: gravel).

the riverbed for the upper four meters of the riverbed. RIZA uses this database to construct maps of the D50 (or any other fraction of the grain size distribution) at any chosen depth, which can be used for morphological models. The project was also a pilot study in terms of using modern technologies to map the subsurface of the waterways in the Netherlands. Although the project was initiated to produce a reliable 3D database for morphological computations, the techniques used are applicable for any mineral-planning project.

For the river Rhine a 3D grain size model was constructed using the following approach (Gruijters *et al.*, 2001):

- Perform field measurements. From August 2000 through late September 2000, TNO-NITG performed 102 vibrocore drillings (A vibrocore drilling uses a vibration unit to drill a PVC core four meters deep into the riverbed). In addition, seismic recordings were taken along almost 35 km of waterways using both Xstar and Seistech Boomer techniques. RIZA itself performed additional measurements on the elevation of the riverbed and the lithological composition of the shallow subsurface.
- Determine the geological strata within each drilling and the seismic data (using advanced software programs all the research information combined with existing geological knowledge).
- Take representative samples for each lithological layer within the geological strata and determine the full grain size distribution for each sample (about 550 in total).
- Construct a 2D map for the base of each geological layer using Kriging interpolation.
- Construct a detailed 3D database containing full grain size data for each grid cell of 25x25x0.25 meters within.

The main parameter for morphological calculations is the D50. There are two alternative ways for computing a 3D model of the D50:

1 Calculating this parameter from each measured grain size distribution and interpolating this parameter to the 3D grid.
2 Interpolate each fraction of all the measured grain size distributions to the 3D grid and calculate the D50 afterwards from the interpolated grain size fractions at each grid node.

The first method is very fast, but incorrect. Because the D50 is calculated using the log of the grain size directly above and below the 50% sieve rest, a linear interpolation of this parameter is invalid. Because the second method is far more elaborate, the difference between both methods was evaluated for a limited set of grain size distributions (293 sets of 4 grain size distributions each). For each set of 4 grain size distributions the D50 was calculated by interpolating the measured D50's directly (method 1), and by interpolating all fractions and calculating the D50 from the interpolated fractions (method 2). This showed that the first method overestimates the D50. The overestimation varies from about 10 to 20% for relatively similar grain size distributions to 200% when the differences between the grain size distributions involved are greater (e.g. mixed sand and gravel samples). This overestimation was considered to be intolerable. Therefore the second was used.

For the interpolation of each fraction a Kriging algorithm was used. There is an obvious statistical dependency between the separate fractions of a grain size distribution. For 10 fractions incorporating this statistical dependency would result in 45 cross variograms, resulting in longer computation times.

We “bypassed” this problem by not using every single fraction, but the cumulative fraction (sieve rest). The results of this assumption were quite satisfying. Only a few interpolated grain size distributions had to be adjusted to fulfil the restrictions (total sum for each grain size distribution between 0 and 100%, every next fraction should be larger than the former).
It is well known that Kriging can result in considerable smoothing of the data, depending on the variogram model used. For the Pannerdensche Kop this smoothing is considerable (Figure 2). To get a better understanding of the actual spatial a more advanced technique should be used, combining conditional simulations and full size grain size interpolation. In 2003 an attempt will be made to develop such a method, financed by both RIZA and TNO-NITG.

Conclusions

Case river Meuse

The Kriging Standard deviation is not suitable for the calculation of the uncertainty of an estimation at a certain point within the area of interest. Therefore conditional Gaussian simulation (CGS) should be used to make an accurate estimation of the spatial uncertainties in the base of geological layers.
When CGS is used the overall uncertainty in the excavated volume of a certain geological layer based on a single design is negligible (< 1%). The uncertainty in the estimation of the volume of industrial fractions of sand and gravel is dominated by the spatial variations of the grain size distribution. The effect of uncertainty within the production process (excavation, washing, sieving) should be incorporated in the final estimations of the yields of sand and gravel.
Accurate knowledge of the in-situ density is crucial for calculating tons from m^3, however the effect of uncertainty in this parameter can be neglected. Large-scale field measurements, combined with well loggins provide reliable values for in situ density of gravel.

Case river Rhine

The combination of shallow seismic survey and vibrocore drillings provide an excellent framework for constructing a geological model of the subsoil of a riverbed up to 4 metres below the riverbed.
Direct interpolation of the median grain size is incorrect. Interpolation of all fractions of the measured grain size distributions and the calculation of the D50 from these data is a solution.
Actual 3D model of full grain size distribution provides excellent input for grain size related calculations (both morphological as mineral). However, using a Kriging interpolation for each fraction smoothes extreme values in the measured data. This aspect should be kept in mind when using the constructed 3D database.

Future developments

In 2002-2003 the study for the bifurcation Pannerdensche kop will be repeated for on other bifurcation: IJsselkop. For this project the positive aspects of combining seismic surveys, vibrocore drillings and grain size distributions to construct a full 3-D grain size model will be used again.
In addition a research project will start in 2003, financed by both RIZA and NITG. The aim of this project is to develop a method for calculating a 3D model with at each point an estimation of the grain size distribution and the uncertainty using conditional simulations.
Furthermore within TNO-NITG several studies will be set up to try to use geophysical measurements (both geo-electrical as seismic) to estimate grain size parameters between detected layers.

Acknowledgements

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The relation between the Medicagini-Avenetum vegetation and sedimentation

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Introduction

Natural river systems distinguish themselves from other ecosystems by their large temporal and spatial variation in river dynamics and related geomorphological processes. During high water erosion might take place as well as sedimentation (sand and silt). These processes can influence the natural succession of vegetation. Succession might be stopped or even put back in time, creating space for the pioneer stages of the ecosystem. This all results in a unique nature and high biodiversity. In many present day river systems, including the Dutch one, most of these geomorphological processes have been altered. This results in ecosystems disappearing and biodiversity decreasing. More over problems arise in managing the water flow in these rivers. Several ideas have been formed on how to prevent disasters, like the floods of 1993 and 1995, from happening. These ideas mainly focus on storing the increasing quantities of water transported by the Dutch rivers. Examples of these ideas are 'Komberging' (Rooij *et al.*, 2000; Klijn *et al.*, 2002), Living With Floods (Vis *et al.*, 2001) and Cyclic Floodplain Rejuvenation (Duel *et al.*, 2001). The latter one, which is discussed extensively during the NCR-days of 2002, is a larger method of lowering the floodplain flats and in this way creating bigger storage capacity. In the whole river system different floodplain flats will be lowered in different years. There is a circulation in floodplain lowering between the floodplain flats. The question is however what the consequences of all these activities are for the vegetation? Especially rare vegetation types, like the Medicagini-Avenetum that has a very specific flooding regime, might disappear. Besides the uncertainty if the Medicagini-Avenetum can spontaneously develop elsewhere (depending among others on dispersion of seeds and specific abiotic circumstances), it can be questioned how this vegetation type is related to the amount of sedimentation and composition of the sediment.

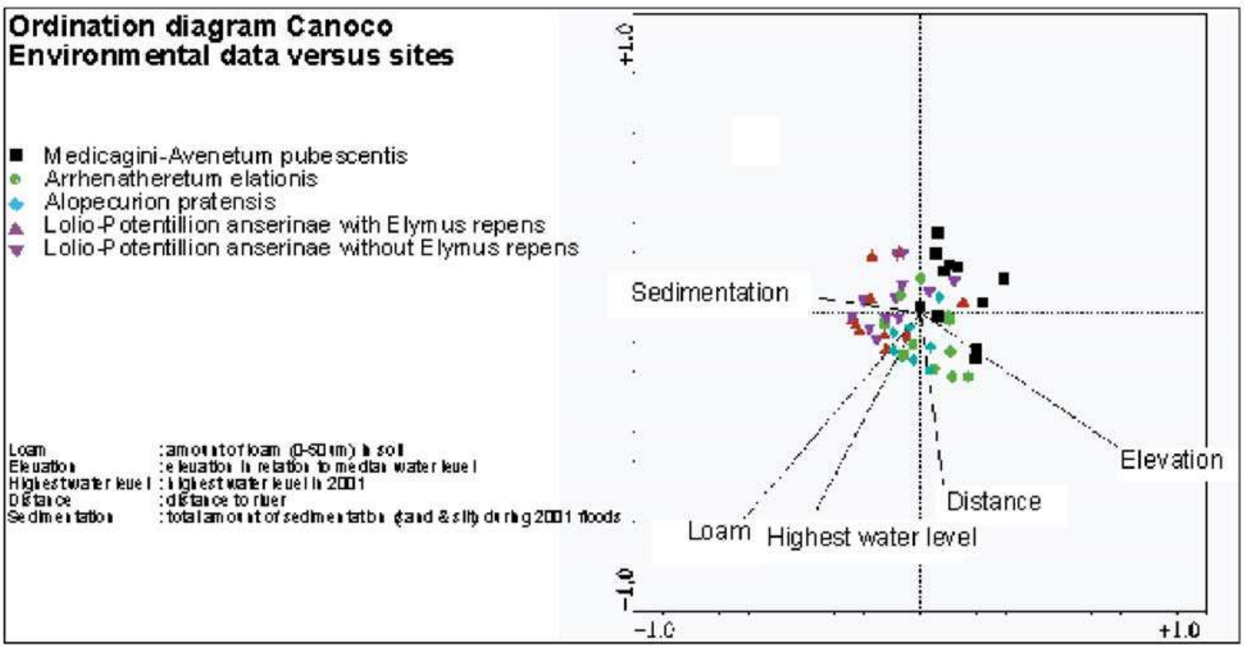

Figure 1. Canoco results: ordination diagram of environmental data versus sites.

NCR is a co-operation of the universities of Delft, Utrecht, Nijmegen, Twente and Wageningen, UNESCO-IHE Institute for Water Education, RIZA, ALTERRA, TNO-NITG and WL | Delft Hydraulics

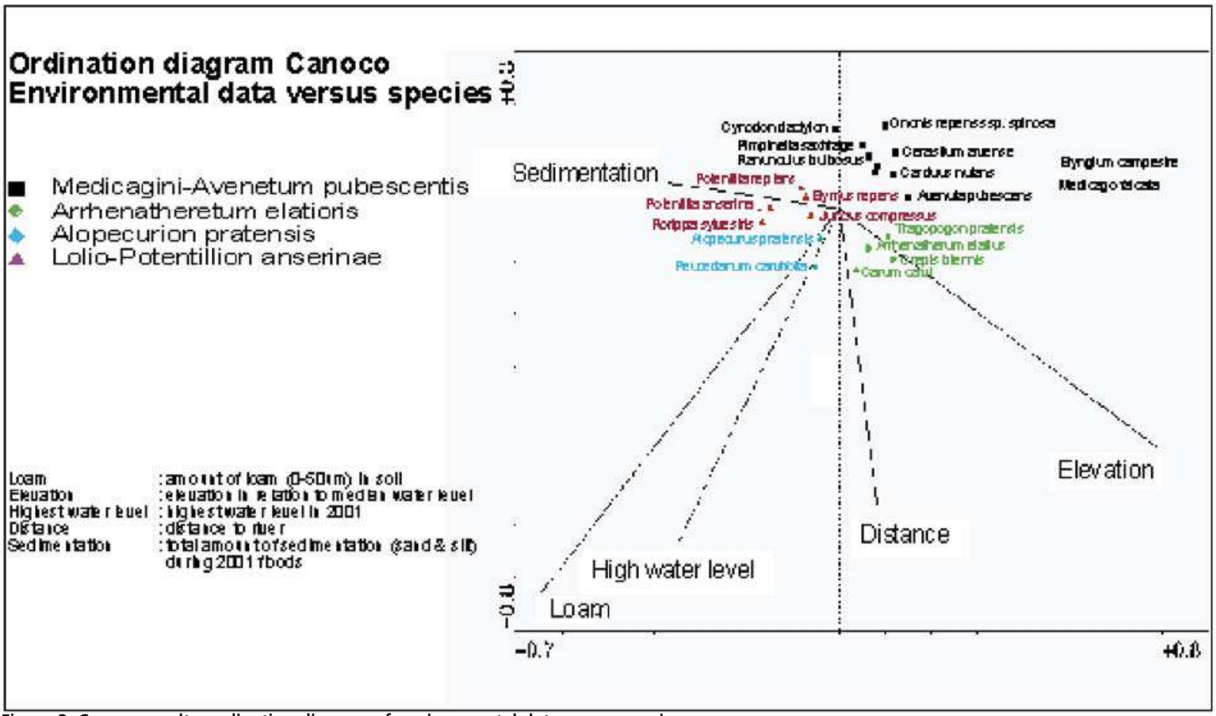

Figure 2. Canoco results: ordination diagram of environmental data versus species.

Within these plans for increasing the water storage capacity of the Dutch river system the uniqueness of the river related nature is taken into account as well. A good knowledge on the interaction between geomorphology and ecological processes is essential.

In the Nature Balance 2001 (RIVM *et al.*, 2001) the rarity of the Medicagini-Avenetum (In Dutch: Stroomdalgrasland) is stressed and the several actions in floodplain flats, for example with regard to the Note on Water-Management 21st century (Rijkswaterstaat, 2000), are seen as a threat to their subsistence. Relating the management in the river system with the Medicagini-Avenetum the following questions can be specified:

- Where can the Medicagini-Avenetum, regarding the sedimentation regime, develop within the Dutch river system?
- When is the amount of sedimentation destroying the Medicagini-Avenetum?

Method

In the winter of 2001 sediment traps were put down in three floodplain flats along the river IJssel (Vreugderijkerwaard, Cortenoever) and the river Waal-Merwede (Rijswaard) to catch sediment during flooding. During springtime vegetation relevées have been made on the locations of the sediment traps. The temporal and spatial variation of sedimentation is discussed by Maas & Makaske (2003). In this presentation the focus will be on the relation of the Medicagini-Avenetum, being a specific and rare river related vegetation type, with sedimentation.

Results

In total 62 vegetation relevées, following the simplified Braun-Blanquet methodology, were made distributed over three floodplain flats: Vreugderijkerwaard, Cortenoever and Rijswaard (For geographical location: Maas & Makaske, 2003). These were clustered by Twinspan and further ordinated by hand resulting in a classification into 6 classes

- Medicagini-Avenetum pubescentis (in Dutch: Stroomdalgrasland);
- Arrhenatheretum elatioris (in Dutch: Glanshavergrasland);
- Alopecurion pratensis (in Dutch: Vossestaartgrasland);
- Lolio-Potentillion anserinae with *Elymus repens* (in Dutch: Overstromingsgrasland met Kweek);
- Lolio-Potentillion anserinae without *Elymus repens* (in Dutch: Overstromingsgrasland zonder Kweek);
- Rest group.

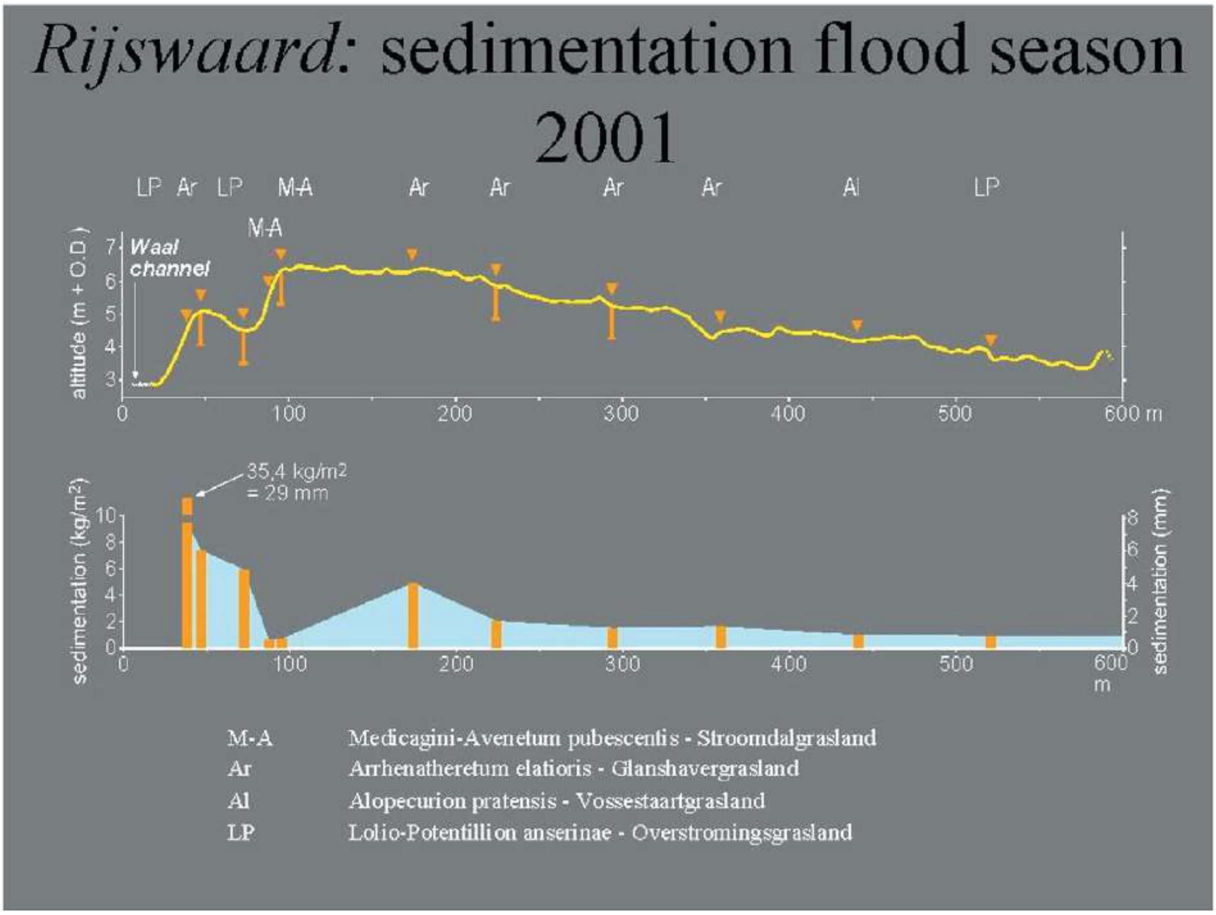

Figure 3. The amount of sedimentation in the Rijswaard of the 2001-flooding season with the locations of the different vegetation types.

Furthermore abiotic data was collected: amount of sedimentation and grain size composition, soil texture, elevation in relation to the median water level, pH-KCl and humus profiles from two depths (0-5 cm, 5-25 cm) were analysed for CaCO3, organic matter, P-anorganic and P-organic, C/P.
These factors were used in the program Canoco (Ter Braak & Smilauer, 1997; 1998) to find those factors best explaining the present variation in vegetation. This resulted in two ordination diagrams (Figure 1 and 2). The correlation between the abiotic factors is dependent on the vegetation.
The amount of loam (0-50 μm) in the soil shows the strongest correlation followed by the elevation in relation to the median water level, highest water level in 2001, distance to the river and the total amount of sedimentation (sand and silt) during the 2001 floods. Figure 1 shows the distribution of the five vegetation types according to these factors. Plotting a selection of plant species characterising the five vegetation types (Figure 2) versus these environmental factors illustrates the importance of the different factors for the separate vegetation types even better.
A clear distinction can be made between the Medicagini-Avenetum and Arrhenatheretum on the one hand the Alopecurion and Lolio-Potentillion on the other hand based on the elevation and the total amount of sedimentation

Ordination diagram of Canoco:

- length of the arrow is a measure for the contribution of the variable to the total explained variance;
- angle in between two arrows is a measure for the correlation between the two variables (small angle means high correlation);
- projection of a point on an arrow is a measure for the relative value of that point, in other words for the position of that point on the gradient described by the arrow.

(sand and silt) during the 2001 floods. The small angle between the two lines shows that these two factors are strongly correlated when explaining the variance in the vegetation. The Medicagini-Avenetum and Arrhenatheretum both occur more elevated in the floodplain and subsequently were subject to a lesser amount of sedimentation during the 2001 floods. They can be distinguished by the fact that the Medicagini-Avenetum prefers sandier locations found closer to the river. The ordination diagram shows the correlation between the amount of loam in the soil and the distance to the river when explaining the variance in the vegetation.

Conclusions

The Medicagini-Avenetum can be distinguished from the Arrhenatheretum because:

- Medicagini-Avenetum occurs on sandier locations;
- Medicagini-Avenetum is found on more dynamic locations.

Although they show some similarities as well:

- they occur on locations with the same elevation;
- both do prefer locations with little sedimentation in the case of the 2001 floods.

It should be taken into account that the lack of sedimentation on the locations where the Medicagini-Avenetum occurs is characteristic for the 2001 floods. Averages over several years show a different picture of more sedimentation (Maas & Makaske, 2003).

Application within cyclic floodplain rejuvenation

As an example the vegetation types occurring in the Rijswaard along the Waal-Merwede are

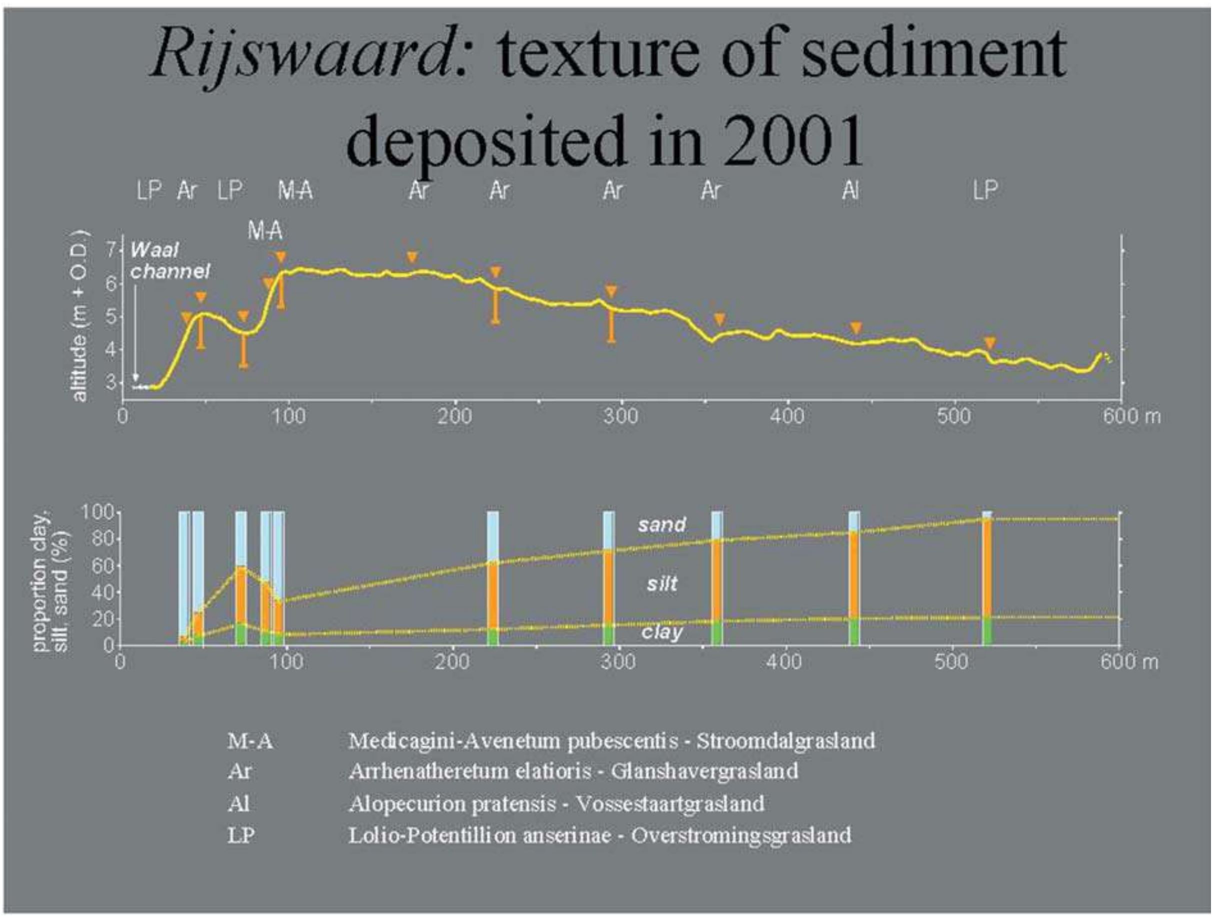

Figure 4.The texture of the sedimented material in the Rijswaard of the 2001-flooding season with the locations of the different vegetation types.

plotted on the sedimentation of the 2001-flooding season (Figure 3). The Medicagini-Avenetum is found on the locations with the least sedimentation.

The Medicagini-Avenetum occurs on a certain elevation relative to the river. When lowering the floodplain flat by one meter it takes a century to reach the altitude again where the Medicagini-Avenetum is able to develop (Maas & Makaske, 2003). The vegetation of the Arrhenatheretum in the Rijswaard closest to the river nowadays contains some characteristic species of the Medicagini-Avenetum but is not classified as such yet. By the time it reaches the altitude of the nearby levee, where nowadays a vegetation of the Medicagini-Avenetum is present, the circumstances might enable the development of a vegetation of the Medicagini-Avenetum. The texture of the sedimented material at this location at the moment is sandy (Figure 4), corresponding with the preferences of the Medicagini-Avenetum in what is the most important factor explaining the variation in the studied vegetations of the floodplain flats.

The pathways of succession towards a Medicagini-Avenetum with regard to flooding are described in Nijhof (2001). This research contributes to filling in the gaps mentioned in that report.

Consideration

The presented research explains part of the abiotic circumstances related to the presence of the Medicagini-Avenetum. Leaving the questions on distribution and establishment possibilities open. But knowing the preferences of the Medicagini-Avenetum, being sandy and more elevated sites at dynamic locations with little sedimentation (2001 floods), as well as the present situation in the very much regulated Dutch river system, meaning less dynamics, the question arises how the Medicagini-Avenetum can be maintained within this very tight straitjacket.

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The effect of biogeochemical processes on development of nature in floodplain areas: a field survey

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Introduction

In the last decade, frequent flooding events in the riverine parts of the Netherlands led to the insight that the strategy of reinforcement of dikes was insufficient to exclude excessive water from inhabited areas. New strategies, for example the creation of retention zones to slow down the flood pulse, provide an opportunity to combine water management with the development of potentially ecologically valuable floodplains. However, the development of biodiverse riparian wetlands, especially the establishment of characteristic species-rich vegetation types, which has started more than ten years ago, often appears to stay behind the formulated ecological targets. River water quality has changed over the past century, which has resulted in higher concentrations of sulphate, nitrate, phosphate and chloride (Caraco & Cole 1989; Lamers *et al.*, 1998; Van der Velde & Leuven, 1999). Most of the new nature reserve areas along the rivers have developed on former meadows and croplands, which had been fertilized for decades. The soils in these floodplains have become heavily enriched with phosphorus and nitrogen (Lamers *et al.*, 2001; Verhoeven *et al.*, 1998).

Phosphorus and nitrogen are the major eutrophicating nutrients in wetlands. Not only will seasonally flooding with eutrophic river water lead to an excess of N and P in the floodplain soil, it also causes internal eutrophication through high sulphate concentrations (Lamers *et al.*, 2001). Sulphate competes, after reduction to sulphide, for binding with iron. Under reducing conditions present in waterlogged soils, sulphide and ammonium can be formed, which are toxic to both plants and animals (Smolders & Roelofs 1996).

Table 1. Parameters to be studied within the field survey.

Soil
- extractable N (NO3, NH4) and P (PO4)
- total N and P
- mineralization rate
- organic matter content
- particle size (i.e. sand, silt or clay)
Water
Surface water
- pH, alkalinity
- water quality parameters (SO4, NO3, PO4, Na, K, Ca, Mg, Cl, Fe conc.)
- turbidity
Interstitial water
- pH, alkalinity
- SO4, NO3, PO4, Na, K, Ca, Mg, Cl, Fe conc.
- S2- conc
Groundwater
- water quality parameters (SO4, NO3, PO4, Na, K, Ca, Mg, Cl, Fe conc.)
- infiltration
Vegetation
- diversity and abundance; Braun-Blanquet method
- maximum standing crop
- N/P-ratio in living tissue
Other
- flooding duration and frequency
- management (grazing, mowing)

Field survey

The objective of the field survey carried out in 2002 and to be continued in 2003 is to characterize differences in abiotic and biotic variables within and between selected floodplain plant communities. With this characterization it should be possible to identify the key biogeochemical parameters driving the development of characteristic riparian plant communities in these floodplain areas. The importance of the selected parameters and their relationships will be investigated by a Detrended Component Analysis (DCA). The studied variables include soil, water, vegetation and other parameters (Table 1). The measurements are

Table 2. The number of selected vegetation types per floodplain, see figure 1 for the location of the selected floodplain areas.

River	Floodplain	Number of vegetation types selected
Meuse	HEI-Heinenoord	2
	SPI-Spijkenisse	4
	MEG-Megen	2
	KON-Koningsteen	1
Rhine	ROZ-Rozenburg	4
	STW-Steenwaard	3
	BLK-Blauwe Kamer	2
	EWK-Ewijk	2
	OUW-Oude Waal	3
Overijsselse Vecht	HDD-Huis den Doorn	4
	STR-Streukel	2

replicated in time to monitor also seasonal effects. Water parameters are investigated every two months; soil as well as vegetation parameters two or three times per year.

For the field survey in 2002 eleven floodplain-areas have been selected within three different river systems (Figure 1); four floodplains alongside the river Meuse, five locations under the direct influence of the river Rhine and its tributaries and two areas along the Overijsselse Vecht. The last river is small, compared to the other two and also the nitrate and phosphate loads of the river water are expected to be less. Table 2 gives an overview of the selected locations.

Within these locations several vegetation types where selected. Among the criteria for selection were vegetation structure (only herbaceous) and dominant plant species. Vegetation types dominated by species characteristic for an eutrophicated environment (i.e. *Gyceria maxima*) as wells as communities dominated by less fast-growing plant species (i.e. *Carex* species) where chosen. The major part of the selected field sites in 2002 contains marshy plant communities with waterlogged soils.

Processing data

At the end of 2002 the first data will be ready to process and preliminary results can be used to perform the DCA. The information will be used to evaluate the experimental set-up of the field survey and make adjustments for the continuation in 2003. When the most important biogeochemical parameters have been identified, experiments will be carried out to quantify the effects of these parameters on the establishment, development and performance of characteristic plant species and characteristic floodplain plant communities.

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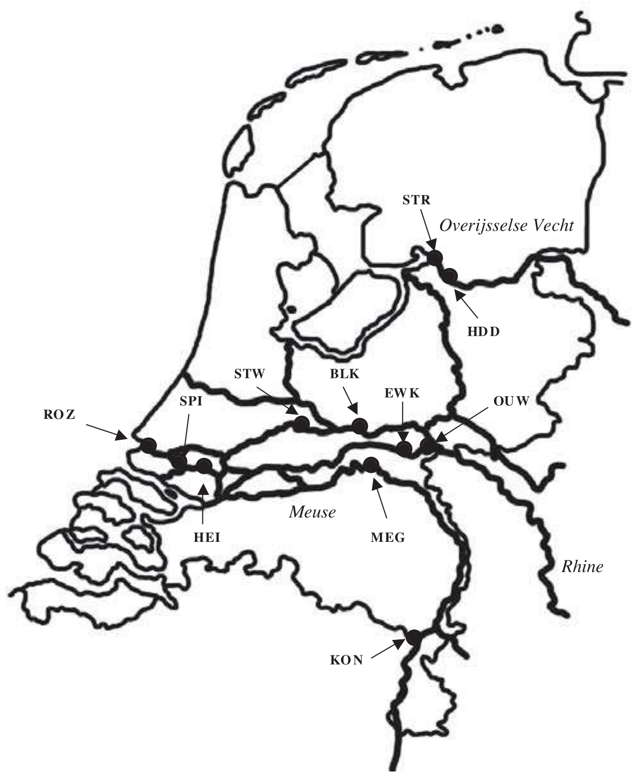

Figure 1. The locations of the research sites alongside the river systems. The abbreviations used in the map stand for the location names: Meuse: HEI-Heinenoord, SPI-Spijkenisse, MEG-Megen, KON-Koningsteen; Rhine: ROZ-Rozenburg, STW-Steenwaard, BLK-Blauwe Kamer, EWK-Ewijk, OUW-Oude Waal and Overijsselse Vecht: HDD-Huis den Doorn, STR-Streukel.

Fluxes and retention of nutrients and contaminants in river basins

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Introduction

The conveyance of nutrients and contaminants across land surfaces, into receiving waters, and through the river network is governed by complex interactions amongst water, sediment, and biotic components, which operate at various spatial and temporal scales. These interactions include wash-off of nutrients and contaminants from catchments due to runoff and soil erosion, and nutrient and contaminant retention due to retardation, biogeochemical decay, and floodplain deposition. Understanding of these interactions is essential for an appropriate assessment of spatial patterns of soil and water pollution, and nutrient and contaminant fluxes from land to oceans. This paper gives an overview of research on transport and retention of nutrients, heavy metals, and radionuclides, currently being carried out at Utrecht University.

Redistribution of copper-fungicides in vineyards

Copper fungicides such as Bordeaux mixture are frequently applied in vineyards to protect young grapes from mildew after periods of rainfall. This results in a diffuse pattern of copper contamination in the topsoil layer. Part of the copper is redistributed over the vineyard due to overland flow and soil erosion and deposition. Part of the copper leaves the vineyard and is transferred to the surface water. By means of runoff experiments and mapping of copper redistribution patterns in selected vineyards in the Ouvèze catchment, southern France, the redistribution of copper within vineyards and the transfer of copper from land to surface water are assessed. Figure 1 shows the geographical location and copper deposition in a vineyard.

Nutrient retention in lowland streams

The collapse of agriculture in Central- and Eastern Europe in the late 1980s and early 1990s has resulted in a considerable reduction in diffuse nutrient emissions. Also in the catchment of Lake Peipsi at the border of Estonia and Russia, fertiliser application was dramatically reduced (Figure 2). Although this reduction caused a corresponding reduction in nitrogen load in the rivers draining this area, the phosphorous load

Figure 1. Total copper deposition in a vineyard in the Ouvèze catchment (southern France).

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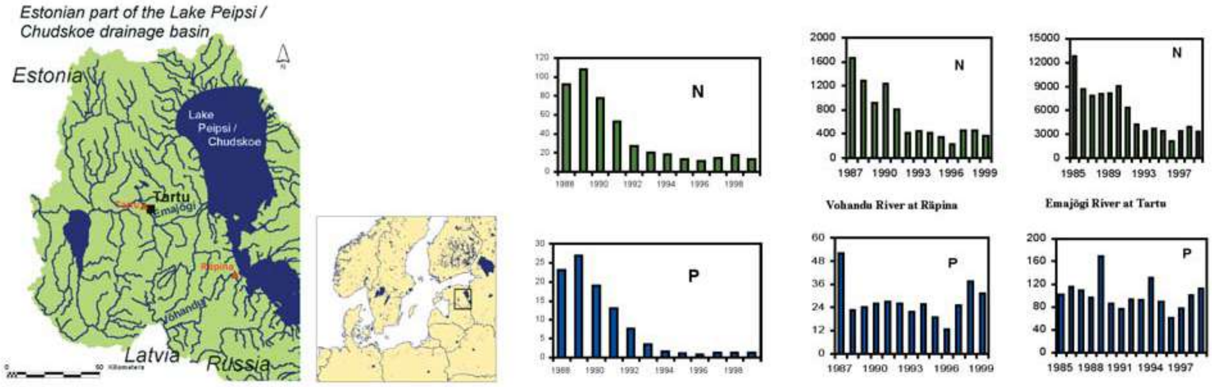

Figure 2. Fertiliser application (ton/ha/yr) in the catchment of Lake Peipsi and nutrient load (ton/yr) of Vohandu River at Räpina and Emajõgi River at Tartu.

remained large due to retention in, and delayed release from the soil root zone, river and lake bed sediments, and floodplains. A combination of field studies and GIS-based modelling is currently being performed to identify the landscape compartments, which play a key role in nutrient retention at the river basin scale.

Transport and fate of radionuclides in the Yenisey River

The radionuclide releases from the nuclear fuel reprocessing plants of Krasnoyarsk Mining and Chemical Combine (KMCC) into the Yenisey River, Russia, have resulted in radioactive contamination of its floodplains over a few hundreds of kilometres downstream of the KMCC. The behaviour and fate of particle-reactive radionuclides (e.g. 239,240Pu and 137Cs) is governed by the physico-chemical characteristics and the transport of river sediment. At present, the transport of radionuclides is primarily due to secondary transport of radionuclides accumulated in bed sediments and floodplains. To quantitatively estimate the dispersal of radionuclides in the Yenisey River, the dynamics of radionuclide inventories in the floodplain soils are mapped by using observed radionuclide activities in the floodplain sections combined with geo-morphological maps derived from satellite images.

Fate of sediment-associated heavy metals in the Rhine-Meuse Delta

Lowland floodplains are natural sinks for sediment and sediment-associated contaminants. To assess the role of floodplain deposition in retention of heavy metals in the Rhine-Meuse delta, field experiments are performed during

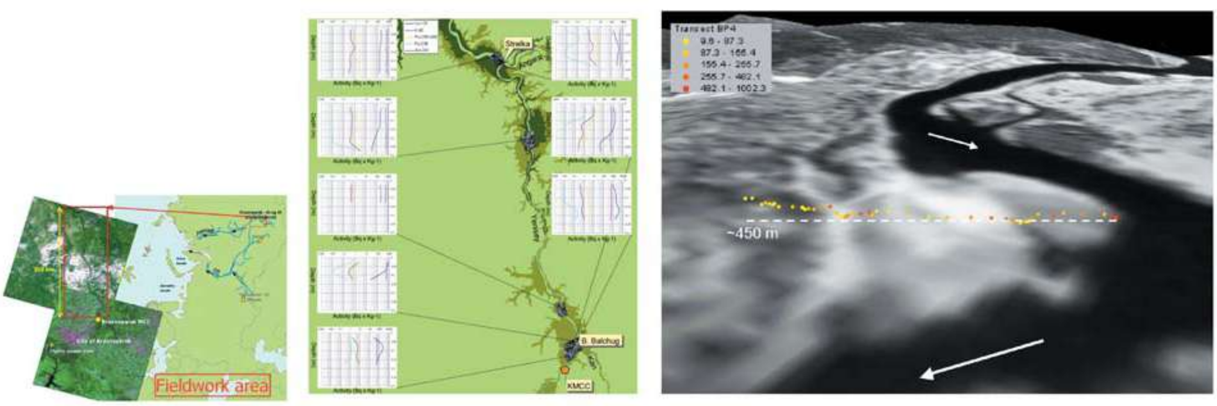

Figure 3. Transport and fate of radionuclides in the Yenisey River. Geographical location of the study site, depth-activity relations of various radionuclides and Cs-137 activities in soil.

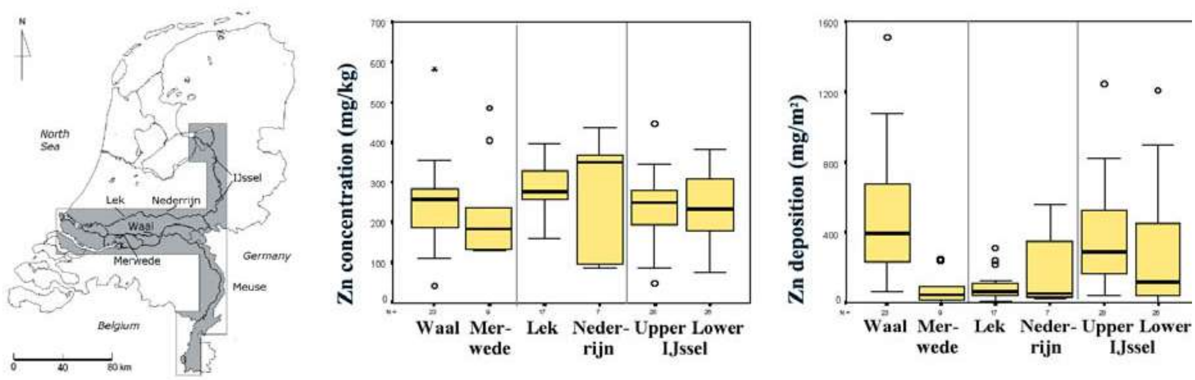

Figure 4. Concentration and deposition of sediment-associated zinc in the Rhine-Meuse Delta.

inundation periods. During a flood event in spring 2001, sediment traps in floodplain sections along the main Dutch distributaries of the River Rhine were installed. Subsequently, the sediment traps were analysed for the amount of sediment deposited and the concentrations of heavy metals. This permits to estimate the median deposition rates of heavy metals and their variability along the branches of the River Rhine during a single flood event. The values found are related to floodplain characteristics and comprise an important data set to calibrate a GIS-based model of heavy metal retention at the scale of the entire Rhine-Meuse delta.

Acknowledgements

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The effect of river rehabilitation projects on the sediment-associated heavy metal pollution of the Dutch floodplains

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Abstract

Due to climate change, the discharges of the rivers flowing through the Netherlands will most probably increase. Measures are currently underway or undertaken to increase the flow capacity of the rivers. However, these measures may have adverse effects on floodplain soil quality, since they increase the number and extent of floodplain inundations. This hypothesis was studied using presently non-embanked and embanked floodplains. We deployed sediment traps to measure the amount of sedimentation during low to moderate floods and determined the amount of heavy metals attached to the sediment in the laboratory. Results of the analyses show that a low flood inundating a non-embanked floodplain early in the hydrological year caused a higher input of both sediment and heavy metals than a moderate flooding of an embanked floodplain later in the season. This indicates that input of pollutants may rise if embankments are removed.

Introduction

The government of The Netherlands is currently taking measures to prevent the country against predicted higher discharges. Examples are the lowering of floodplain levels; the removal of minor embankments; the digging of side channels et cetera. The increasing discharges and the higher sediment loads combined with more inundations will eventually lead to a higher sedimentation rate, combined with a possible increase in rate of pollution with heavy metals and organic micro pollutants.

Materials and methods

In co-operation with the Wageningen Universiteit & Research Centre (WUR) and the University of Nijmegen (KUN), we placed 125 sediment traps in different parts of the embanked floodplain Afferdensche & Deestsche Waarden (ADW) near Druten along the river Waal in February and March 2002. 20 Sediment traps were flooded twice. Earlier that season (December 2001), we placed 24 sediment traps on the unprotected floodplain Rijswaard, which is adjacent to the ADW.

The sediment traps were gathered after the retreat of the water and transported to the laboratory. From every sediment trap the sediment was collected. Samples were analysed on grain size (with a Coulter LS), organic matter content (loss-on-ignition) and heavy metal (Zn, Pb, Cu and Cd) concentrations (digestion of 2 g sediment in 25 ml 2 M HNO3 in combination with 45 minutes heating in a microwave oven).

Results and discussion

In figure 1, the amount of sediment deposited per flood is depicted. The thick black line denotes the

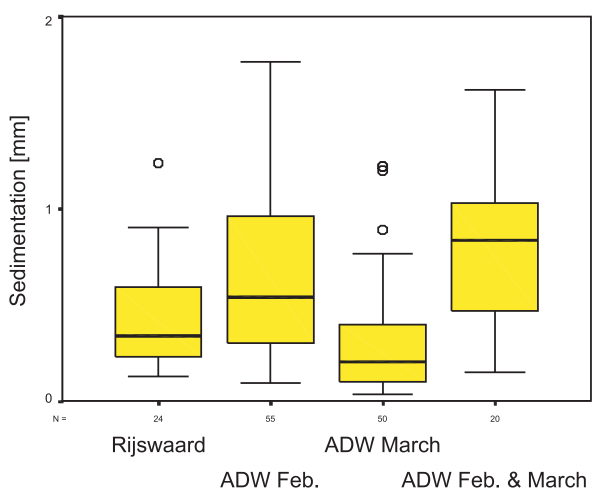

Figure 1. The amount of sedimentation during the different floods.

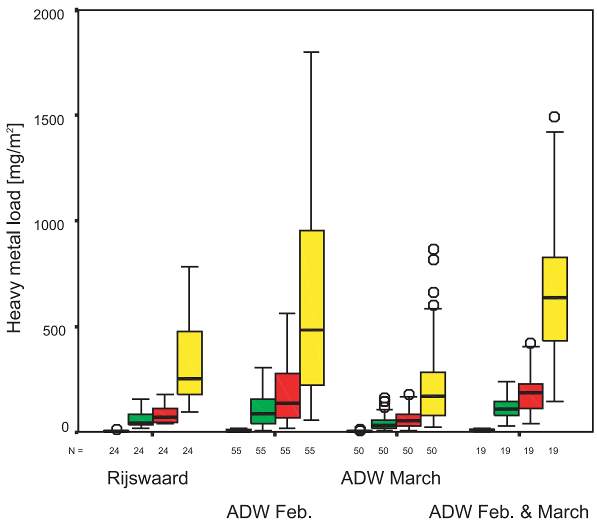

Figure 2. The heavy metal loads for Zn (yellow), Pb (red), Cu (green) and Cd (black).

median value, and 50% of the observations lie within the box. In the case of the Rijswaard, the flood reached a peak of 5289 m^3/s at the Dutch-German border, whereas the February flood reached 8054 m^3/s and the March flood 7064 m^3/s. In spite of the fact that the flood that inundated the Rijswaard was much smaller, the amount of deposition was generally larger than during the March flood in the ADW.

Figure 2 shows that this higher amount of deposition resulted in a higher amount of pollution per unit area on the Rijswaard during the January flood than in the ADW during the March flood. Part of the lower amount of sedimentation and pollution in the ADW during the March flood can be explained by the 'flushing' of the riverbed by the earlier February flood, removing fine particles, which carry a large part of the pollutants. The January flood, on the other hand, was the first in the season, and probably removed the pollutants that had built up in the riverbed during the low flow season.

Conclusions

It is shown that an early low flood inundating a low-lying floodplain has larger adverse effects on soil quality than a late moderate flood. This is due to the fact that floods remove part of the pollution out of the riverbed before later floods can do so. It is to be expected that, when river dikes are removed, the whole floodplain experiences both early and low floods, rendering higher inputs of heavy metals, thereby deteriorating the soil quality with possible adverse effects on plants and animals.

Acknowledgements

S. Wijnhoven (KUN) and P. van Vliet (WUR) are thanked for their help during fieldwork. K.J. Niesink (UU), S. Keesstra (VUA) and K. Tromp (UU) helped to remove the sediment from the sediment traps.

Linking sedimentation and ecology in riverine landscapes: influences of climate change and physical reconstruction measures

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Introduction

Floodplain soils along the rivers Rhine and Meuse in the Netherlands play an important role as sinks of suspended sediment and pollutants and have a key role in ecological transformation processes along the river continuum. These soils show a large spatial variability in pollution. Climate change and physical reconstruction measures for increasing the discharge capacity are expected to cause considerable changes in sedimentation processes. Therefore the Universities of Utrecht and Nijmegen initiated a project that aims at (1) quantification of the interactions between sediment transport and ecosystem functioning of floodplains and (2) assessment of human interference and climate change on the fine sediment transport and ecological transformations. This project is part of the NWO-LOICZ programme "Bio-geomorphological interactions within floodplains and their role in sediment transport and ecological transformation processes in the lower Rhine delta". The sub-project of the University of Nijmegen focuses on the ecological functioning and transformation of sediment-food web interactions in the floodplain. This paper presents a procedure for a GIS-based ecological risk assessment (ERA), which takes into account changes in sedimentation processes and related impact of these changes on (bio) accumulation of pollutants in the riverine food chain.

GIS-based ERA

For accurate risk estimation, heterogeneity of soil pollution has to be included into the risk assessment. Kooistra *et al.* (2001, 2003) has implemented an ERA into GIS using ArcView software technology. This procedure already incorporates spatial components of exposure into the ERA by linking GIS-data with external risk models (Figure 1). In the present project ERA will be implemented in several modules of ArcInfo and used to estimate the exposure of riverine foodwebs (including focal species of river management) to pollutants, based on the current body of knowledge of risk assessment in riverine ecosystems. The implementation of the ERA into ArcInfo also allows an interface with other external models (such as exposure, bio-availability and food web models). The ERA consists of a problem formulation, data collection and model selection, generation of GIS-maps, estimation of ecological risks and finally, an evaluation of results.

Problem formulation

According to Kooistra (2001), the first step of the ERA encompasses an explicit statement of an ecological entity and its associated functions that has to be maintained (Figure 1). For the problem formulation information is required concerning the current and possible future status of the floodplain under investigation. This includes land use, pollution status in the upper and deeper soil layer of the floodplain, the potential ecological receptors (e.g. plant and animal species), flooding frequency and sedimentation patterns. Reported contaminant concentration levels are compared with national soil quality standards. Based on this comparison and several additional aspects such as bioaccumulation potential, priority contaminants for the ERA are defined. From the set of identified ecological receptors, end-point species, which are part of a particular food web, are selected. For the selection of end-point species several criteria are

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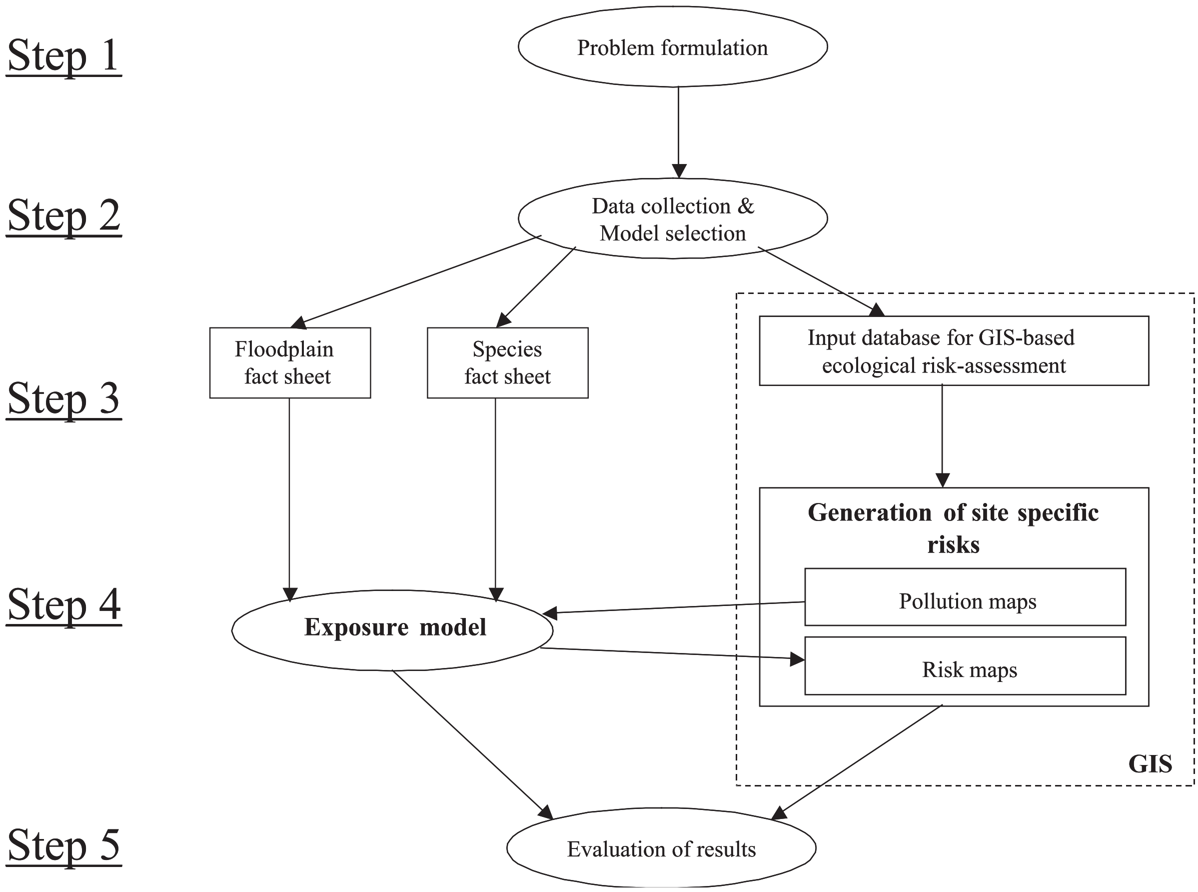

Figure 1. Generic procedure of the ecological risk assessment.

taken into account: 1) sensitivity to the identified priority contaminants; 2) compliance with policy goals; 3) they have to be used in previous risk assessments (Hope, 1999). Management scenarios for the future status of the floodplain can be defined to assess ecological risks.

Data collection and model selection

The second step in of the ERA takes into account the data collection and the selection of an external exposure model. All the data are stored in an input database (Figures 1 and 2) and divided in five major groups: sedimentation, floodplain soil (deeper and upper soil layer), floodplain structure and data of focal species in fact sheets. Valuable data for the ecological risk assessment can be selected from the input database. These data consists of two types; autecological data concerning the focal species and structure and functioning of the food web and information describing the spatial variability of environmental factors in the floodplain. Monte Carlo simulation will be applied to take into account variability and uncertainty in input parameters.

Next to the collection of data, the most suitable exposure model has to be selected during this step. There are several exposure models (aquatic vs. semi-terrestrial), which can be taken into account. The choice of the model will mainly depend on the ecological receptors, including the end-point species and contaminants of concern. The application of state-of-the-art-knowledge has to be the goal.

Generation of GIS-maps (contaminant concentration and foraging area)

The development of a method to assign a concentration value for the target substance to every point of the floodplain is an important step for the incorporation of the exposure of riverine food webs (including focal species of river management). Under the assumption of continuity or graduation between sampling points, geostatistical techniques such as splines and kringing can be used to make these extrapolations (Burrough & McDonnell, 1998). In this ERA, GIS-maps are developed (habitat and foraging area of focal species and various layers of soil pollution), based on selected data from the input database. For the habitat mapping and the development of a specific food web, several overlay techniques and selections have to be made. Apart from that, the incorporation of a specific foraging area for focal species

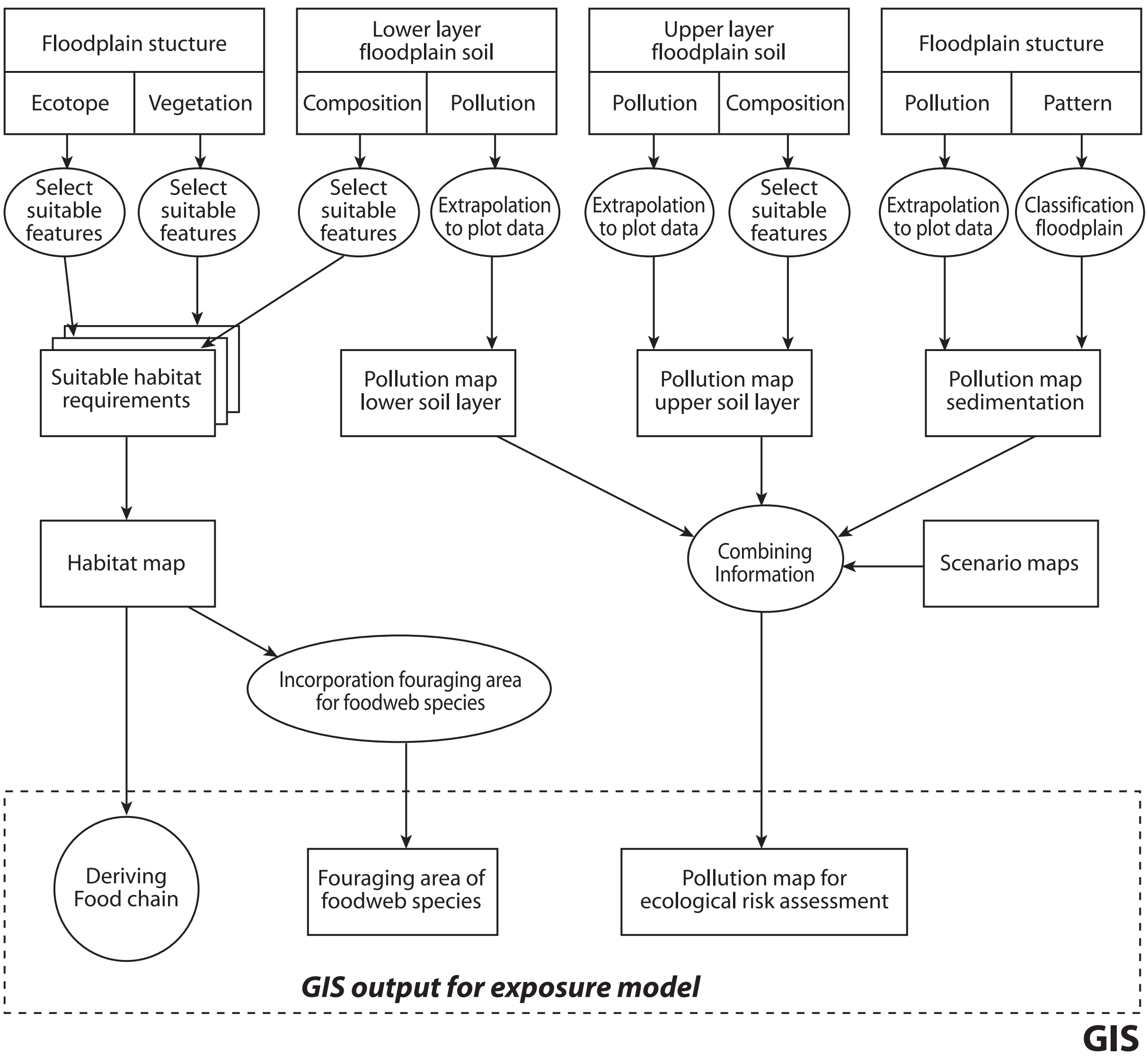

Figure 2. GIS-procedure for mapping sediment and soil pollution of and foraging behaviour of focal species in floodplains.

requires several complex GIS-techniques like watershed approach, overlay technique, Arc Tables and Arc Plot. In their search for food, animals move through a heterogeneously contaminated floodplain and are exposed to various pollutant concentrations. Thus, this is an important step for the estimation of accurate site-specific risks values. In short, weight values are added to specific components of a topography and vegetation map of the floodplain (Nolte *et al.*, 2001). According to these weight values and a maximum distance from nest locations a foraging area can be created. All maps will be put in a GIS-output database (Figure 2).

Estimation of ecological risks

The selected exposure model estimates the exposure induced by bio concentration and bioaccumulation for the selected species and end-point species. Risks are evaluated comparing the distribution for the potential exposure concentration (PEC) to appropriate toxic reference values (TRV), critical toxic levels for the end point species, resulting in a risk estimate. These values are part of the species fact sheet (Figure 1). Risks are calculated for the whole grid of potential foraging ranges in the floodplain. Using GIS, site-specific risk maps for the focal species are produced.

Evaluation of results

In this last step, the results of the ERA are evaluated (Figure 1). The site-specific risk maps are used to identify potential high-risk areas in the current floodplain situation. These results are compared with risk maps for the defined alternative management scenarios. Each scenario is evaluated regarding its effectiveness in reducing ecological risks. Comparison of the resulting site-specific risk maps allows the floodplain manager to choose the most efficient floodplain management alternative together with other floodplain priorities. Finally, an evaluation of the ERA-procedure is carried out. This also includes a description of the range of conditions over which the conclusions can be drawn and the associated uncertainty in the conclusions. Information of environmental monitoring programmes in the floodplain can be used to confirm model predictions and guide modifications.

Future research

Future research will be focused on several levels. First, several modules of the GIS-based ERA are taken into account. This concerns risk estimation on the population level, the impact of bioavailability due to priority contaminants and the use of food web models. The projects of Wijnhoven *et al.* (2003) and Thonon (2003) that takes in to account flooding ecology of small mammals and sedimentation patterns in floodplains respectively can contribute in the ERA-procedure. Subsequently, the ERA will be applied to various river floodplains (including uncertainty analysis). After that, the incorporation of temporal components (such as flood-pulse, sedimentation, ecotope distribution and bio-accumulation in the ERA is taken into account. Finally, the impact of changes in sedimentation processes on ecological transformation will be estimated.

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Incorporating spatial variability of exposure in ecological risk assessment of polluted floodplains using a combined GIS-Monte Carlo approach

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Abstract

This paper presents a procedure that incorporates spatial components of exposure of focal species (e.g. the Little owl *Athene noctua* Scop.) to soil pollution in ecological risk assessment of river floodplains. By linking a geographical information system (GIS) with a probabilistic exposure model, spatial aspects of exposure are taken into account. The resulting site-specific risk maps identify potential high-risk areas that can help floodplain managers to make decisions on the planning of floodplain reconstruction. In this study a risk is defined as the probability that PEC/TRV >1 (predicted exposure concentration and toxicity reference value in mg/kg fresh weight/day). The approach will be illustrated with results from a case study in the Afferdensche and Deestsche Waarden floodplain along the river Waal in the Netherlands.

Introduction

The coming decades, large-scale reconstruction measures are planned in the landscape of the Dutch river floodplains. Until now an evaluation of ecotoxicological risks for terrestrial receptors in

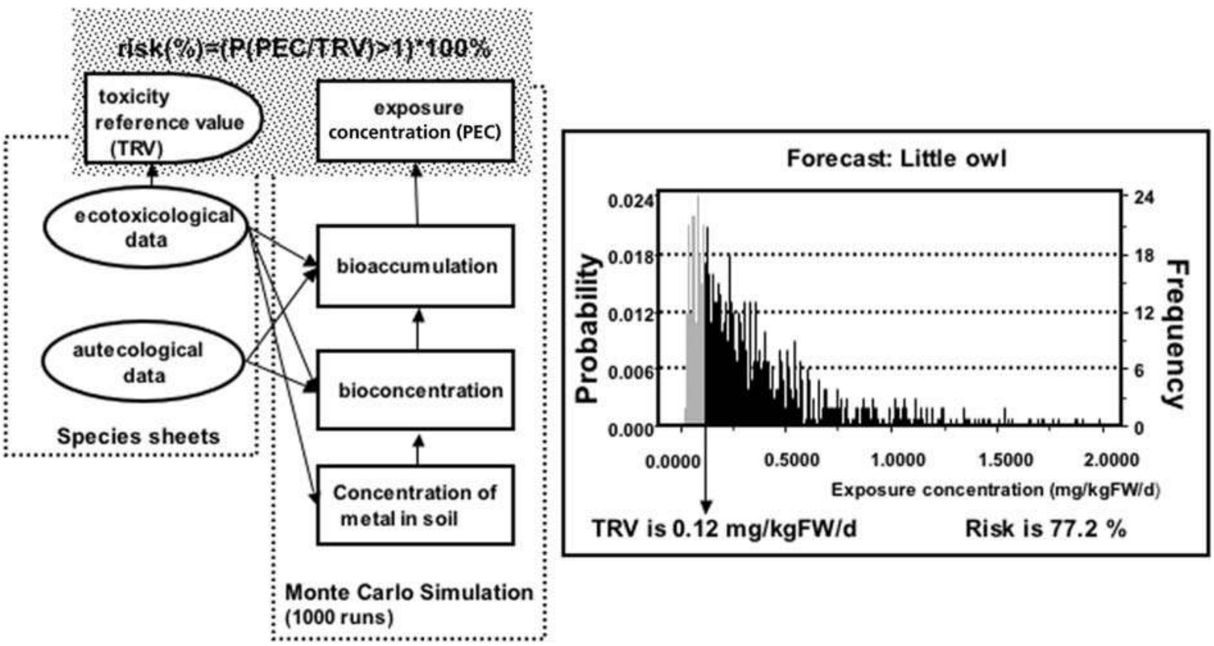

Figure 1. Model for site-specific ecotoxicological risk estimations of a focal species (e.g. exposure of the Little owl (Athene noctua Scop.) to cadmium pollution in floodplain soil) using Monte Carlo sampling (for detailed description see Kooistra *et al.*, 2001) and an example of the model output (frequency chart of the predicted exposure concentration of cadmium in mg/kg fresh weight/day) for the floodplain Afferdensche and Deestsche Waarden along the river Waal in the Netherlands. The toxicity reference value (TRV) for cadmium is 0,12 mg / kg fresh weight / day (From Leuven & Poudevigne, 2002).

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the current and future floodplain situation is not included in the planning of the future floodplain landscape and thus, no evaluation can be made if an improved or optimal situation for nature is planned.

River floodplains are heterogeneous systems. For a proper ecological risk assessment spatial variability of exposure to soil pollution has to be taken into account. Several studies have already shown that geographical information systems (GIS) are a useful tool to include spatial components in ecological risk assessment (Kooistra *et al.*, 2001; Leuven & Poudevigne, 2002; Linkov *et al.*, 2002). GIS can be used to include spatial aspects like variability of contaminants, animal movement and current and future distribution of habitat in floodplains. Next to spatial aspects also a flexible approach for ecological risk assessment is required. Available (ecological) data is often limited, and thus insight in sensitivity and uncertainty is necessary to define the most critical processes and to identify important parameters to characterise in future data acquisition. A probabilistic approach using Monte Carlo simulation was adopted to investigate these aspects.

A procedure for ecological risk assessment of river floodplains

Recently, a procedure has been developed that incorporates spatial variability of floodplain pollution into ecological risk assessment of focal species by linking a GIS with models that estimate exposure for a typical food web of a floodplain (Kooistra *et al.*, 2001). The procedure uses readily available site-specific data and is applicable to a wide range of locations and floodplain management scenarios. The procedure is a combination of generally applied steps and some novel ones that are all part of the GIS module.

Step 1 gives an explicit statement of assessment endpoints and associated functions or qualities that have to be maintained or protected. This step results in the definition of a conceptual model in the form of a food web that identifies the endpoint species, exposure routes, and sources.

Step 2 focuses on data collection, selection and processing. Several types of data are required for ecological risk assessment: autecological data concerning the end-point species (e.g., diet and food intake rate of focal species), ecotoxicological information (e.g., bioaccumulation factors and

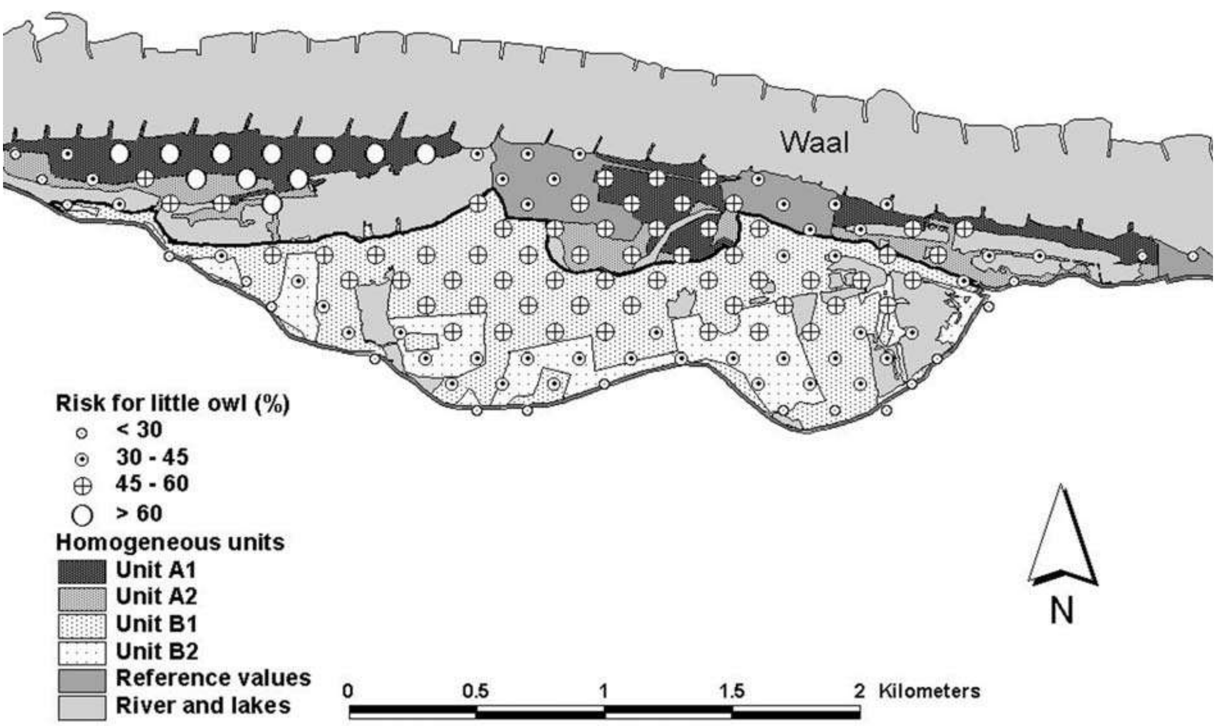

Figure 2. Site specific Cd exposure risk (calculated as probability that PEC/TRV >1) for the Little owl (Athene noctua Scop.) for a foraging range of 200 m in the Afferdensche and Deestsche Waarden floodplain along the river Waal in the Netherlands (Unit A: High flood frequency – outside summer dike; unit B: Low flood-frequency – inside summer dike; A1/B1: relatively low soils; A2/B2: relatively high soils; PEC: predicted exposure concentration in mg / kg wet weight day; TRV: toxicity reference value).

toxicity reference values), and information describing the spatial and temporal variability of environmental factors in the floodplain (e.g., topologic surfaces, geologic features, soil types, groundwater tables, vegetation, point data on soil pollution).

Step 3 quantifies the spatial variability of pollutants by overlaying in GIS appropriate topographic and soil maps and the application of state-of-the art knowledge on focal species, resulting in the definition of homogeneous habitat patches and pollution concentration maps.

Step 4 uses GIS to include spatial and temporal components of the exposed organisms of the food web. In their search for food, animals move through the heterogeneous contaminated floodplain and are exposed to different levels of contamination. Currently, a simple home range model is used to model this behaviour but also more complex models are available that take into account species interaction and prey density. This step results in a set of area-weighted contamination concentration distributions for different foraging ranges in the evaluated floodplain that are used as input for the exposure model.

Step 5 gives an estimate of the exposure for the different components of the food web. A probabilistic model (Figure 1) calculates the exposure using the area-weighted concentrations in homogeneous habitat patches and species-specific regression coefficients for bioconcentration and accumulation of pollutants. The input parameters for the model are defined as probability distribution functions (PDF). Through the application of the Monte Carlo simulation technique, the model takes into account intraspecies variability in age, weight, consumption and uptake patterns, and also pollutant variability within each homogeneous habitat patch. This step results in a geo-referenced set of predicted exposure concentration (PEC) distributions that can be presented in a map.

Step 6 calculates the risk estimates by comparison of the distribution for the PEC with a critical toxic level (toxicity reference value; TRV). The probability chart in figure 1 shows a risk-level of 77.2 % for the Little owl. The geo-referenced set of risk estimates is used to construct site-specific risk maps for the evaluated floodplain (Figure 2).

Step 7 evaluates the results of the ecological risk assessment. The site-specific risk maps are used to identify potential high-risk areas in the current situation, while also risks for alternative management scenarios can be presented. Comparison of the resulting maps allows the floodplain manager to choose the most efficient floodplain management alternative.

Conclusions and future research

The presented procedure illustrates the use of spatial modelling in the risk analysis of contaminated floodplains. Site-specific risk maps allow the delineation of the high-risk areas and based on this information floodplain managers can make decisions that take into account both sanitation costs and environmental benefit. The modular structure of the presented procedure is an important advantage. It allows easy integration of advanced knowledge through the inclusion of state-of-the-art models, while specific needs of floodplain managers also can be taken into account. Future research will focus on the integration of spatial models on habitat use and foraging behaviour of endpoint species, while also risks for future planning scenarios will be evaluated (Nolte *et al.*, 2003; Wijnhoven *et al.*, 2003). In addition, the probabilistic treatment of the model parameters, coupled with sensitivity analyses, should provide the basic parameters that are important for making sound environmental decisions.

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Monitoring and modelling of heavy metal contamination in embanked floodplains of the Dutch Rhine -Meuse river system

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Introduction

Over the last century large amounts of heavy metals have accumulated in the floodplains of the Rhine - Meuse river system. To enable decision making with regard to policies for river floodplains, the Dutch Institute for Inland Water Management and Waste Water Treatment (RIZA) needs to be able to determine the actual risk of heavy metal pollution in floodplain soils. As a part of their BIOCHEM research programme, this project aims to build an advanced soil chemical module, which can predict the chemical speciation of heavy metals in these soils and generate the input for an ecotoxicological module (www.riza.nl/projecten/biochem/fr_biochem.html).
In order to link heavy metal contamination with uptake in plants and organisms, knowledge about the distribution of metals over different binding forms (speciation) is essential. For more than two decades speciation calculations are successfully used to describe metal toxicity in natural water systems. In contrast, the availability of heavy metals in terrestrial soil systems is controlled by adsorption processes, since they determine to a large extent which fraction of the total metal content is present in the water phase. Moreover, in recent years we are becoming aware that dissolved organic carbon (DOC) is essential for the understanding of metal speciation in pore water.
To apply speciation models to soil systems accurate sorption models are necessary. In the last years, large progress is booked on modelling the metal adsorption to organic matter and iron oxides.
In this study we integrate speciation calculations with advanced sorption modelling to describe the speciation of heavy metals in river floodplain soils. This approach enables us to elucidate the influence of redox processes on metal speciation, and we can obtain a detailed description of metal availability within a soil profile and the influence of seasonal flooding on soil systems. We compare model calculations with extensive pore water sampling, focussing on the elements Cd, Cu, Zn and Pb.

Materials and methods

To generate the necessary input parameters for our model we sampled more than 140 soil cores in the Dutch floodplains along the rivers Rhine, Waal, IJssel and Meuse. The selected locations cover the whole range of contamination levels and are equally distributed over all river branches. Furthermore, we took care to include a variety of different land use forms from remote natural areas to intensively used grasslands.
The sampled cores were split into sections of 20 cm length each and analysed for the total amount of metals, organic matter content, clay fraction and pH.
On a subset of 46 of these locations we sampled pore water in-situ using Rhizon" sampling devices that were inserted horizontally at 15 cm and 45 cm depth during spring, summer and autumn. The application of Rhizon" sampling devices in-situ avoids the problem of soil heterogeneity and artefact by centrifugation. The elemental composition, DOC, inorganic carbon, SO_4, NO_3, Cl and pH of the pore water samples were measured.
To compare the measured and calculated mobile fractions of heavy metals with the actual plant uptake by different plant species, we collected 126 plant samples on different locations. Shoots were sampled and carefully cleaned with demineralised water prior to drying. Plant material was digested with HNO_3/HF/H_2O_2 and

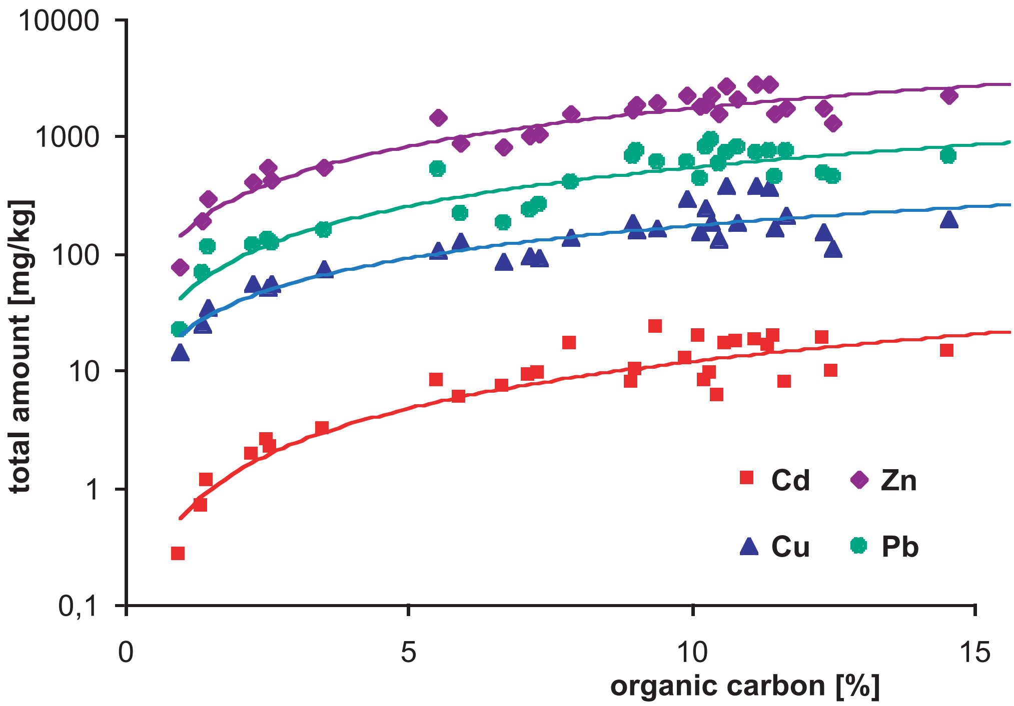

Figure 1. Total amount of Cd, Cu, Zn and Pb related to total organic carbon.

analysed for heavy metal concentration.
Speciation calculations are done with ECOSAT (Keizer and Van Riemsdijk, 1994). The NICA-DONNAN model (Milne, 2000) is used to describe sorption on organic matter and the CD-MUSIC model (Hiemstra & Van Riemsdijk, 1996) for sorption on iron(hydr)oxides.

Results and discussion

From analysis results we extract a generalised chemical description of the floodplain soil properties for modelling. The most striking feature is the strong correlation between organic matter content and heavy metal contamination (Figure 1). As a consequence, the pore water concentrations of metals associated with organic matter, e.g. Cu, Zn or Cd increases only slightly with increasing contamination of sediments.

Figure 2 shows metal concentrations of pore water samples. For a better visualisation the concentrations of Cd, Cu, Zn and Pb in pore water are normalised for 20 mg/l of DOC. The open symbols are pore water samples extracted from saturated soil layers. The lines represent the uncalibrated predictions of our model calculations. The model calculations predict the behaviour of Cd, Zn and Cu well. The samples from the saturated layers are not in equilibrium with the soil system resulting in lower metal concentrations. For high total amounts of Zn the pore water concentrations are underestimated, probably because of the lower redox potential in this organic matter rich soils. At the moment our model is not taking this effect into account. Pb is overestimated for all soils. Although often assumed in literature, we state that Pb is not predominantly bound to organic matter. Our

Table 1. Average uptake of Cd, Zn and Cu by different groups of plants.

	Average			Log sd		
	Cd [mg/kg]	Zn [mg/kg]	Cu [mg/kg]	Cd [mg/kg]	Zn [mg/kg]	Co [mg/kg]
Monocotyls	0.11	39	5.5	0.40	0.25	0.24
Woody dicotyls	2.36	207	6.0	0.45	0.20	0.22
Rhizobium forming dicotyls	0.07	36	8.5	0.35	0.17	0.15
Other dicotyls	0.49	62	8.8	0.35	0.15	0.29

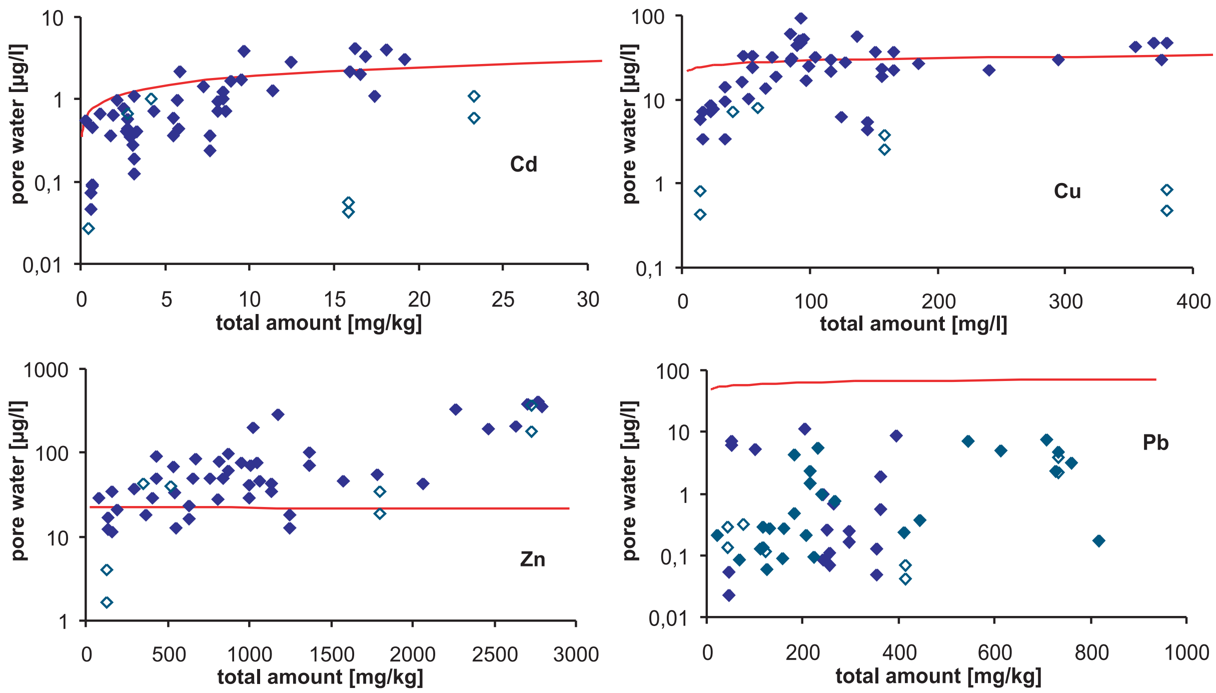

Figure 2. Predicted and measured porewater concentration of Cd, Cu, Zn and Pb. The open symbols are samples taken from saturated layers. Measured values are normalized for 20mg/l DOC.

results show evidence for Pb binding on iron oxides. However, the exact binding mechanism is yet not unravelled.

We divide the 26 sampled plant species in four groups according to their uptake behaviour (Table 1). The uptake of Pb was too low to be distinguished clearly from the contamination of plant material with soil particles (<0.1% of Pb concentration in soil). The metal uptake by plants depends only weakly on the total amount of heavy metals in soil: even without considering the large differences of total soil metal content (up to a factor of 20) we found the difference in uptake between the samples to be less then a factor two for Cu and Zn and less then a factor three for Cd. The concentrations of metals in pore water explain the results better. Which fraction of pore water metals describes the uptake best we will evaluate later.

Conclusions

The availability of metals is strongly affected by the correlation between contamination and organic matter. Given the large heterogeneity of field samples, it will be hard to distinguish contaminated and "clean" locations by only considering their pore water composition.

With speciation and adsorption modelling we were able to predict this trend for Cd, Cu and Zn. However, the ligand responsible for the binding of the largest fraction of Pb in soil is yet not identified.

The results of plant sampling are consistent with the results of model calculations and pore water analyses.

Although data analysis and modelling are still going on, we can conclude that speciation modelling is a useful tool for understanding and evaluating the risk of metal contaminated soils.

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Impact of flooding on small mammals along the river Waal (The Netherlands)

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Introduction

Small mammals (voles, shrews and mice) are often regarded as key species in the food chain of floodplains, as they form the major food items of various top predators. They are therefore often included in ecological risk assessments. At present, few data are available on the occurrence, distribution and migration behaviour of small mammals in periodically flooded areas. Data on the flooding ecology of small mammals will be required for the following purposes:

- Environmental impact assessment of floodplain reconstruction measures (e.g. flood defence measures such as lowering floodplains and removing levees; De Nooij *et al.*, 2001);
- Incorporation of spatial and temporal components of exposure to soil and sediment pollution in ecotoxicological risk assessment (Kooistra *et al.*, 2003; Nolte *et al.*, 2003);
- Evaluation of the role of small mammals in ecological transformation of polluted sediment and floodplain soils (e.g. the role of bioturbators in the purifying capacity of floodplains; Wijnhoven, 2001).

This paper describes the recolonization and distribution patterns of small mammals during a flooding cycle and discusses the implications of the results for ecotoxicological risk assessment. The goal of the present study was to show the significance of incorporating temporal and spatial data on small mammal distributions in environmental impact and ecotoxicological risk assessment.

Methods

Thirty-nine monitoring sites were selected within the Afferdensche en Deestsche Waarden floodplain (ADW), situated along the river Waal 20 km west of Nijmegen (the Netherlands). The sites covered various gradients of physical structure (vegetation and substrate), abiotic factors (flooding regime) and land use (e.g. agricultural meadows, cornfields and nature areas) (Figure 1). Distances to non-flooding locations were also mapped. Environmental factors, including vegetation structure, were monitored over the period March 2001- February 2002 (one flooding cycle). The distribution and recolonization patterns of small mammal populations were surveyed using live trapping. To distinguish environmental factors that are relevant to habitats or corridors used by various species, a redundancy analysis (RDA) was performed using monitoring data of all the locations in or within 50 metres of the non-flooded areas (data from March - June were excluded, as animal numbers were too low). RDA is a direct gradient analysis based on linear models with a short gradient length (tested using Detrended Correspondence Analysis; DCA) and is used to explain patterns in species data by environmental variables. After exclusion of the non-discriminating factors and the interrelated factors, 17 factors were left to be tested for their correlation with the most abundant species, in order to identify important habitats, corridors and barriers. Recolonization rate and population development along the most likely routes were evaluated.

Results

Seven small mammal species were observed in the ADW floodplain: common vole (Microtus arvalis), short-tailed field vole (M. agrestis), bank vole (Clethrionomys glareolus), common shrew (Sorex

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Figure 1. Aerial overview of the 'Afferdensche en Deestsche Waarden' floodplain and the monitoring sites.

araneus), white-toothed shrew (Crocidura russula), wood mouse (Apodemus sylvaticus) and harvest mouse (Micromys minutus). As common vole, bank vole and common shrew were most abundant during the year, their distributions were analysed in more detail.

Figure 2 shows the results of the RDA on the monitoring data. The habitat of the common vole appeared to be best explained by the environmental factors and was dominated by grassland with a high vegetation coverage, as often found in temporarily flooded areas. The two other species, however, were more restricted to the biotopes with rough vegetation at relatively dry places (i.e., not grasslands). The RDA shows the species-specificity of the environmental parameters. The most influential factors (Figure 2) were used to calculate the correlation with the distribution of the three species. Once again, the common vole occurred mainly in grasslands (agricultural grasslands or grass dominated rough) with high vegetation coverage, most commonly in the periodically flooded wet parts of the floodplain (Table 1). The distribution of the bank vole was correlated with mown vegetation, but also with rough vegetation and hedgerows without a specific management regime. Correlations for the common shrew were weaker, but the distribution of this species seems to be most related to the presence of moist roughness within the floodplain.

Figure 3 shows three examples of the recolonization process from non-flooded locations, to which the mammal populations were restricted to during flood periods (locations 1 and 2, Figure 1). The common vole inhabited location 1, while location 2 housed populations of bank voles and common shrews. The patterns shown in figure 3 were confirmed by observations in other parts of the floodplain. The numbers of common vole were low during and just after the inundation period, but increased during the summer, especially in areas surrounding the non-flooded location. In autumn, when densities were high, individuals started to migrate over larger distances, but they were seldom observed further than 250 m from non-flooded locations. Bank voles were almost never observed more than 50 m away from non-flooded areas, but their densities were already building up after the inundation period. Their total numbers remained relatively stable throughout the year, with a shift from the non-flooded parts to some lower parts of the floodplain in autumn. The densities of the common shrew were always low, but this species could be observed in the lower parts of the floodplain immediately after inundation. The most suitable habitat for the common shrew was not very common in the areas surrounding the non-flooded parts (50-250 m from non-flooded locations), but at the end of the year the species were observed in moist rough vegetation throughout the floodplain.

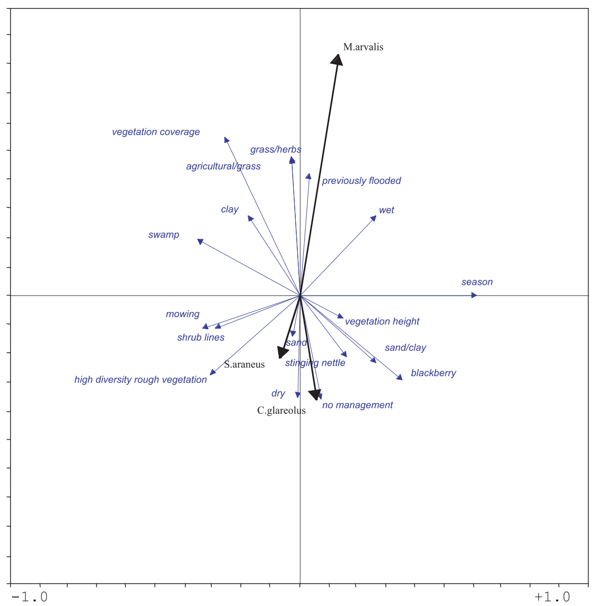

Figure 2. Redundancy analysis of monitoring data for 2001, collected from non-flooded areas and from the 0-50 m zone surrounding these areas. Only the three species discussed are shown. Data prior to June have been excluded.

Table 1: Main environmental parameters analysed, indicating the suitability of habitats for common small mammals in the 'Afferdensche en Deestsche Waarden' floodplain (data from 2001 monitoring).

Species	Environmental characteristic	Correlation coefficient (+)	Correlation coefficient (-)
Microtus arvalis	Vegetation coverage	0.43	
	Agricultural/grass	0.38	
	Grass/herbs	0.38	
	Previously flooded	0.37	
	Dry		-0.31
	Wet	0.28	
	No management		-0.28
	High-diversity rough vegetation		-0.25
Clethrionomys glareolus	Mowing	0.35	
	Shrub lines	0.33	
	No management	0.29	
	High-diversity rough vegetation	0.29	
	Grass/herbs		-0.27
Sorex araneus	Wet	0.23	
	High-diversity rough vegetation	0.21	

Discussion

The results show that the common vole is the most numerous species throughout the year in the ADW floodplain. This species lives in grasslands with a high coverage, and large parts of the floodplain form suitable habitats. Even the agricultural grasslands with their low vegetation can serve as a habitat when the other parts are densely populated. The best habitats for the common vole are not found in the non-flooded parts of the floodplain, as these places are dryer and often show less dense vegetation. The best habitats are grassland patches without a specific management regime, and grasslands with a less intense grazing or mowing regime (like the slopes of the dikes). Common voles are social animals living in relatively high densities. They are not very mobile and use small home ranges. Crowding of suitable places mainly regulates the recolonization process. In spite of the high reproduction rate, it takes some time before density stimulates dispersal, which makes them slow recolonizers. Figure 3 shows that the populations were still growing at the end of the year, but the annual flooding prevents this species from colonizing larger parts of the floodplain, especially the agricultural grasslands, in high numbers.

It was found that the distribution of the bank voles was related to mown vegetation, because of their preference for shrubs (like blackberry) and roughness (like stinging nettle), which are commonly found along mown patches in ADW. As the distances over which recolonization by bank voles occurred show, this species only forages on the mown areas of these rough patches, and does not move over larger distances (to suitable habitats in the middle of the floodplain). Bank voles benefit from protection by stinging nettles, but when these plants grow tall, their bare stems provide little shelter against predators, so that the bank voles migrate to other areas with a more diverse rough vegetation, as is shown by the shift from site A to site B (Figure 3).

Common shrews rapidly recolonize the floodplain, as they are very mobile and display a more territorial lifestyle than the voles, with a larger home range at low densities. They can be found throughout the floodplain but are irregularly distributed over the rougher vegetation in moist parts. The greater availability of food like earthworms, which survive the floods in large numbers (personal communication M.I. Zorn) and the lower predation pressure in the previously flooded parts probably also play a role in the rapid recolonization.

This means that throughout the year, numbers of small mammals are very low in larger parts of the floodplains; for instance, no small mammal activity was ever observed in the agricultural cornfields. This also means that floodplains (especially those with only a few or small non-flooding areas, and regular floods) are probably poor habitats for birds of prey, Mustelidae and larger carnivores feeding on small mammal species. Ecotoxicological risk assessment sometimes takes the heterogeneity of soil contamination into consideration. However, the present study shows that the small mammal populations are also heterogeneous in their spatial and temporal distribution, making the assessment more complex. Individuals living in non-flooded parts are probably exposed to much lower contaminant concentrations than those calculated from the mean concentrations for the total floodplain, which also means less exposure for the predators feeding on them. On the other hand, specimens living in wet spots with rough vegetation may prefer the same spots where sedimentation of polluted matter is greatest (Thonon, 2002). On the other hand, bioavailability of pollutants should also be taken into account. Incorporating spatial and temporal distribution patterns of small mammals in ecotoxicological risk assessment provides a much more balanced view of the risks of pollutants for these animals and their predators.

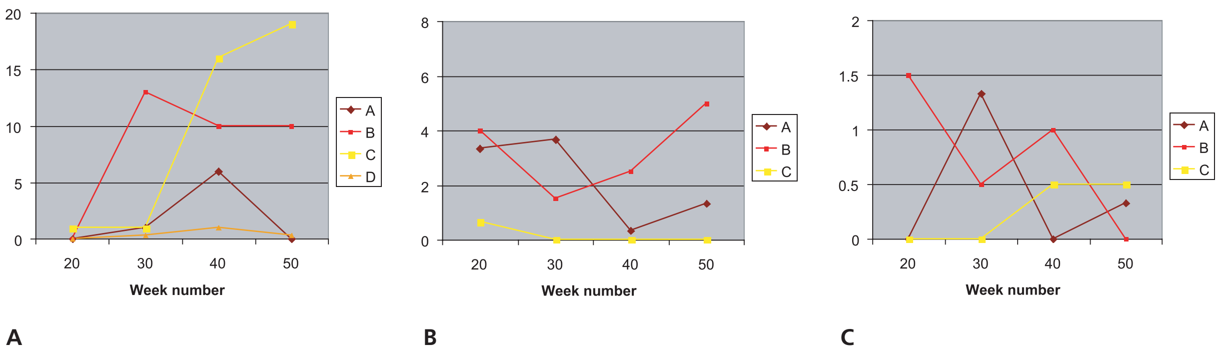

Figure 3. Population development of small mammals after flooding in the 'Afferdensche en Deestsche Waarden' floodplain, as indicated by the number of animals captured in live traps during the year 2001; a) Microtus arvalis at location 1; b) Clethrionomys glareolus at location 2; c) Sorex araneus at location 2. A = monitoring site in non-flooded area; B = monitoring site within 0-20 m from non-flooded area; C = monitoring site within 20-50 m from non-flooded area; D = monitoring site within 50-250 m from non-flooded area.

Conclusions

The results show that annual flooding has a major impact on densities, distribution and recolonization patterns of small mammals. Flooding may completely erase the populations of small mammals from the inundated parts of the floodplain. Recolonization occurs from non-flooded areas, such as dikes and small elevated sites in the floodplain. The recolonization rate varies per species and the process takes several months. This casts new light upon ecological risks of flood defence measures, exposure risks to soil pollution and ecological transformation of polluted floodplain soils. Until recently, little attention was paid to the migratory behaviour, occurrence and distribution patterns of various small mammal species in floodplains, which themselves are not homogeneously polluted. All these aspects are of great importance in predicting the exposure of small mammals to pollutants. Flooding also has a great impact on the population density of small mammals and thus on the feeding activities and exposure risk of top predators in the floodplain. Aspects of flooding ecology should therefore be incorporated in ecotoxicological risk assessments.

Acknowledgements

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Spatial variability in environmental risk of trace metals in floodplain lake sediment

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Introduction

River peak discharges have increased dramatically over the last years. This has caused a high frequency of inundations (e.g., 1993 and 1995). One proposed measure to prevent inundations is the development of side channels and lakes in floodplain areas. Sediment excavated should then be stored or re-used within the river system. Floodplain soils and sediments are however historically loaded with diffuse pollution. Sediment quality standards are often exceeded for trace metals. An important condition for restoration projects is therefore to get more insight in possible environmental risks posed by trace metals (fate and effects). In soils, metals can be bound to organic and mineral phases. In reduced sediments, metals can furthermore precipitate with sulphides. Metal-sulphide minerals have a low solubility, which leads to very low metal concentrations in pore waters if sufficient sulphide is present. Reactive sulphides are measured as acid volatile sulphides (AVS). The ratio or the difference of simultaneously extracted metals (SEM) and AVS is used to evaluate metal availability.

We studied spatial variability of metal availability and assessed trace metal effects on benthic ecosystems in floodplain lakes (Van Griethuysen *et al.*, 2002 and 2003a,b). We used different approaches to examine trace metal availability: total concentrations, clay or OC normalised concentrations, relations of SEM and AVS, and concentrations in aquatic worms (Oligochaeta). Two studies were conducted: spatial variation in a) one floodplain lake and b) a set of 10 lakes.

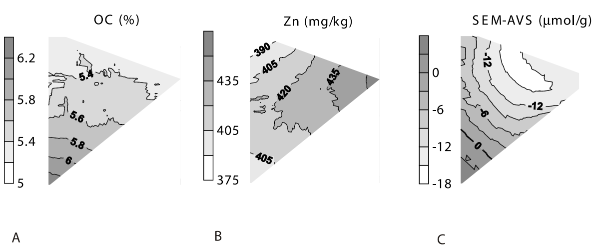

Figure 1. Spatial patterns of a) organic matter, b) total Zn concentrations and c) SEM-AVS in floodplain lake sediment.

Spatial variability within one floodplain lake

We selected a floodplain lake in the Afferdensche and Deestsche Waarden (river Waal). A total of 43 sediment samples were taken on a regular grid. Concentrations of sediment characteristics, major elements and total trace metals as well as SEM and AVS were analysed. Also, variables like water depth and redox potential were determined because they can be crucial for the understanding of geochemical processes influencing trace metal availability. Measured values were extrapolated using ordinary kriging to determine spatial patterns of variables in the lake.

Especially variables determined by chemical conditions like AVS were spatially variable. Sediment characteristics, total metal concentrations, and SEM-AVS levels show different patterns (Figure 1 a-c). Local chemical and hydrological conditions appear to determine variations in environmental availability of trace metals within this floodplain lake.

Spatial variability in ten floodplain lakes

Geochemical relations between metals and sediment characteristics in ten floodplain lakes along IJssel, Waal and Nederrijn were evaluated in a total of 40 samples. Relation of trace metals with community composition was tested in relation to other environmental variables (water, sediment and lake morphological characteristics) using a variance partitioning method.

Only few locations showed elevated risks

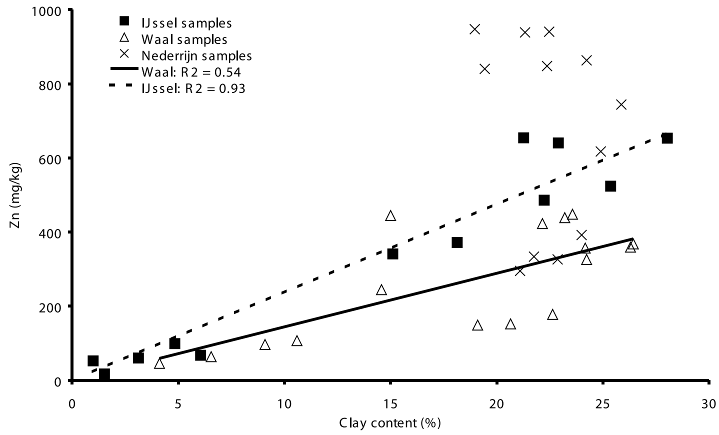

Figure 2. Relation of Zn with clay content in 10 floodplain lakes.

according to geochemical methods. The relation of trace metals with bulk variables organic carbon and clay differed among river branches (Figure 2). SEM-AVS critical levels were hardly ever exceeded. Trace metal concentrations in oligochaetes was positively related to sediment metal concentrations and negatively related to dissolved organic matter.

Around 62 % of the variation in species composition could be explained with a set of environmental variables (water, sediment and lake morphological characteristics). Explanation increased till 68 % when also trace metals were included in the analysis. Only SEM-AVS and SEM concentrations contributed significantly to the explanation. Extracted metals (SEM) contributed most, around 6 % of this variation. In this analysis, variables explained 50 %, and 10 % of the variation was shared between environmental variables and extracted metals. Figure 3 shows the ordination of benthic invertebrates by environmental variables and extracted trace metals.

Although trace metals generally appear to be well bound to floodplain lake sediment and only exceed environmental standards occasionally, an impact on benthic ecosystems is demonstrated. Temporal aspects and exposure routes other than those studied may be responsible for discrepancy between geochemical and biological observations.

Conclusions

Relations between sulphides (AVS) and extracted metals (SEM) gave a different spatial pattern of trace metal availability than total or normalised concentrations, which is important for priority settings in ecological risk assessment. SEM and SEM-AVS concentrations better explain benthic community structure than total or normalised concentrations. Our results show that metal sulphide formation appears to be important for the prediction of trace metal effects in floodplain lakes.

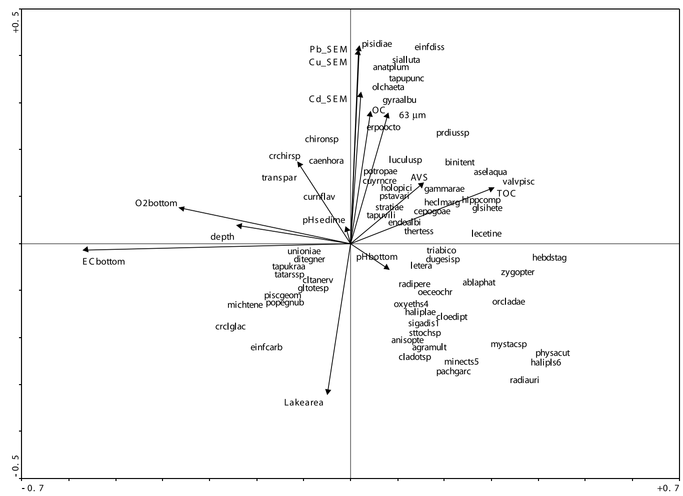

Figure 3. Ordination of benthic invertebrates with environmental variables and extracted metals. Variables are indicated with arrows and species with the abbreviation of their scientific name.

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Sediment contamination and production of benthic macroinvertebrates in river floodplain systems: Implications for nature restoration projects

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Introduction

Sediments in floodplain areas of the rivers Rhine and Meuse in The Netherlands are moderately polluted with trace metals, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). Several studies have shown that benthic macroinvertebrate community structure is negatively influenced even at low levels of contamination (Brils *et al.*, 1997; De Jonge *et al.*, 1999; Den Besten *et al.*, 1995; Reinhold-Dudok van Heel & Den Besten, 1999). According to Peeters *et al.* (2001), at least 14% of the variation in the macroinvertebrate community structure of the Rhine-Meuse Delta ecosystem could be explained by contaminants.

Effects of low contaminant levels on benthic productivity is, however, largely unknown. The present study, therefore, focuses on identifying and quantifying the effect of sediment-bond contaminants on the productivity of benthic macroinvertebrates. Productivity of benthic macroinvertebrates is important in assessing the carrying capacity for predators such as fish and waterfowl.

Material and methods

In spring 2001, 16 sites were selected along a clean-polluted gradient in creeks in the Biesbosch floodplain forest (De Lange et al., 2001). At these sites, samples were taken in April to characterise surface water (pH, O2, conductivity, nutrients, Chl-a); sediment (grain size distribution, organic matter content, CNP), sediment contamination (total and bioavailable trace metals, PAHs and PCBs), and benthic macroinvertebrate composition and biomass. Exclosures were placed at each site to exclude the effect of fish predation

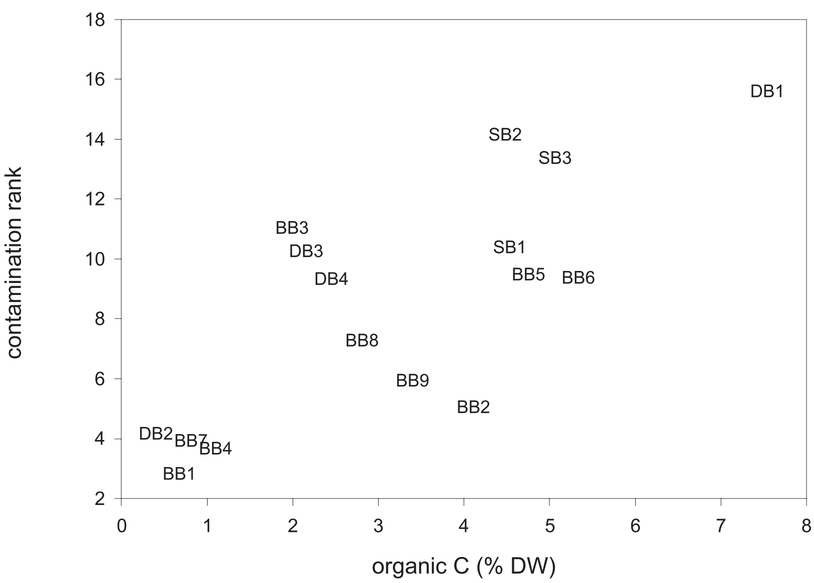

Figure 1. Average contamination rank versus organic C content of the sediment. Locations are indicated by their abbreviations:
SB = Sliedrechtse Biesbosch,
DB = Dordtsche Biesbosch,
BB = Brabantse Biesbosch.

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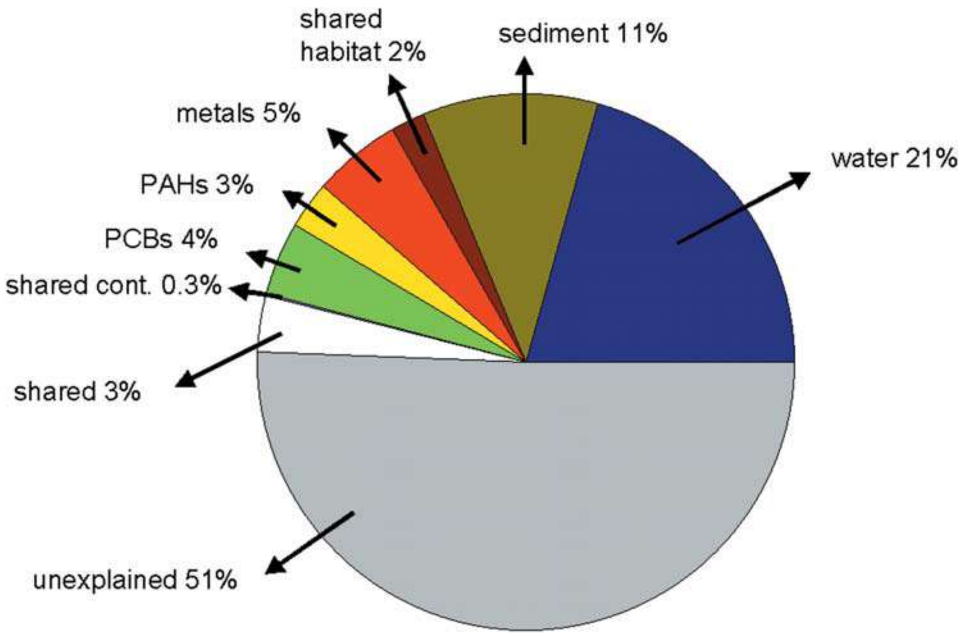

Figure 2. Variance partitioning.

on the productivity. Macroinvertebrate samples were taken again inside and outside the exclosures after four weeks. The macroinvertebrate data from these two sampling periods were used to estimate the macroinvertebrate production in the presence and absence of fish predation. Univariate and multivariate analyses were performed to analyse possible impact of contaminants on macroinvertebrate production.

Results and discussion

Sediment contaminant concentrations were standardized to standard sediment (10% organic matter and 25% lutum), locations were ranked for individual trace metals, sum PAHs and sum PCBs; resulting in an average contamination rank to place the locations in a sequence from clean to polluted. This contamination rank showed a strong correlation with organic C content of the sediment (Figure 1).

The macroinvertebrate community species composition was significantly affected by this sediment contamination. Direct ordination of the species community with org-C normalized bioavailable concentrations of contaminants, showed that all environmental variables explained 49.3% of the variation. Partitioning of variance showed that habitat characteristics explained 33.4%, and contaminants explained 12.7% (Figure 2).

Oligochaeta (worms) and Diptera (midge larvae) are the dominant groups in these benthic habitats. Production of these two groups during four weeks in Spring was not related with sediment contamination (Figure 3). Since contamination is strongly correlated with food availability (measured as sediment organic C content), it is possible that the large amount of food compensates for the adverse contamination effects for these two groups. Production of Ephemeroptera (mayflies), Heteroptera (bugs) and Crustacea (crustaceans) showed a negative trend with contamination rank.

Conclusions

Results show that 1) sediment-bound contaminants were strongly correlated with organic matter content of the sediment; 2) community structure was affected by sediment contamination; 3) production of worms and midge larvae were not affected by contamination,

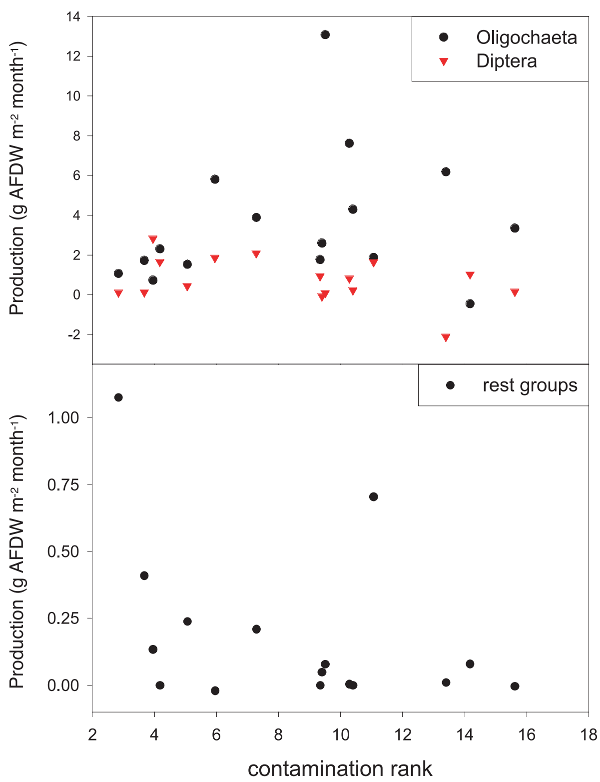

Figure 3. Production of Oligochaeta and Diptera (upper panel) and rest groups (lower panel) versus contamination rank of the sediment.

in contrast with production of mayflies, bugs and crustaceans that were negatively affected by contaminants; 4) both organic matter and contaminants determined production.

It may be concluded that due to the moderate levels of contamination the benthic macroinvertebrate community is low in species diversity but high in productivity. This moderate level of contaminants may therefore be problematic for nature rehabilitation projects along Dutch rivers. The organic matter content of the sediment is linked to high algal biomass in the surface water as result of eutrophication. Nature rehabilitation projects in floodplain areas should also consider nutrients in surface waters.

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Cyclic rejuvenation of floodplains

Remote sensing, floodplain vegetation and hydraulics

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Introduction

The river region is confronted with higher chances for extreme discharges. The recent flooding of 1993 and 1995 and future climatic change have lead to an increase of the design discharge. Floodplains of major rivers serve many goals, i.e. agriculture, recreation, mining, ecology and safety against flooding. From an ecologic point of view Dutch floodplains are part of the main ecologic structure leading to the intention of restoring floodplains to a more natural state. The implementation of the nature restoration is limited by transport and other economic needs. The main limitation though is set by safety standards for the surrounding protected areas. Discharge capacity and retention volume will continue to be a prerequisite for the lay out of future floodplains. Hydraulic models are used for the determination of water levels, given a certain discharge. Several problems arise while modelling floodplain flow: (1) Every five years, an assessment of floodplain friction is required. Friction is now based on ecotope maps based on aerial photography. The aerial photographs are manually interpreted, classified and re-classified by a certain friction value. This is a laborious, costly and time-consuming procedure. In the lumped units of classification, a lot of differences in vegetation structural characteristics is not accounted for. During calibration of the model, the friction is changed to make the modelled water levels fit the measured water levels. The resulting friction values will not be fully representative of local vegetation friction. (2) The formulas relating vegetation to structural characteristics to vegetation friction are not well tested, although it has been a subject of research for a several decades. The ability to use vegetation related friction as a physically based parameter would greatly improve hydraulic models.

Objectives of a recently started PhD study can be summarized as:

1 Determination of spatial distribution of vegetation structural characteristics (height and density) based on various types of remote sensing imagery.
2 Determination of friction for different vegetation types under field condition.

This paper describes the proposed activities for the coming years (Figure 1).

Spatial distribution of vegetation

A data mining approach will be used to extract vegetation structural characteristics from remote sensing data: Airborne data is combined with satellite data. Airborne data includes: lidar (light detection and ranging), (false-) colour infrared photo's and CASI images (Compact Airborne Spectrographic Imager). Quickbird or Ikonos satellites provide highly detailed satellite data. The spectral images combined with lidar image will be used in classification of the land cover. The advantage of satellite data is the high frequency of image acquisition.
Image processing and classification is the next step in delineating relevant floodplain vegetation classes. Several image-processing techniques exist:

- Filtering of lidar data using neighbourhood statistics or pattern recognition techniques. The central grid cell is assigned value based on the values of the surrounding cells. These filtered algorithms can be used as bands in subsequent classification.
- Wavelet decomposition. Wavelets are a promising tool to quantify patterns by allowing pattern identification at various spatial levels and directions (Epinat *et al.*, 2001).
- Different classification algorithms like nearest neighbour or maximum likelihood.

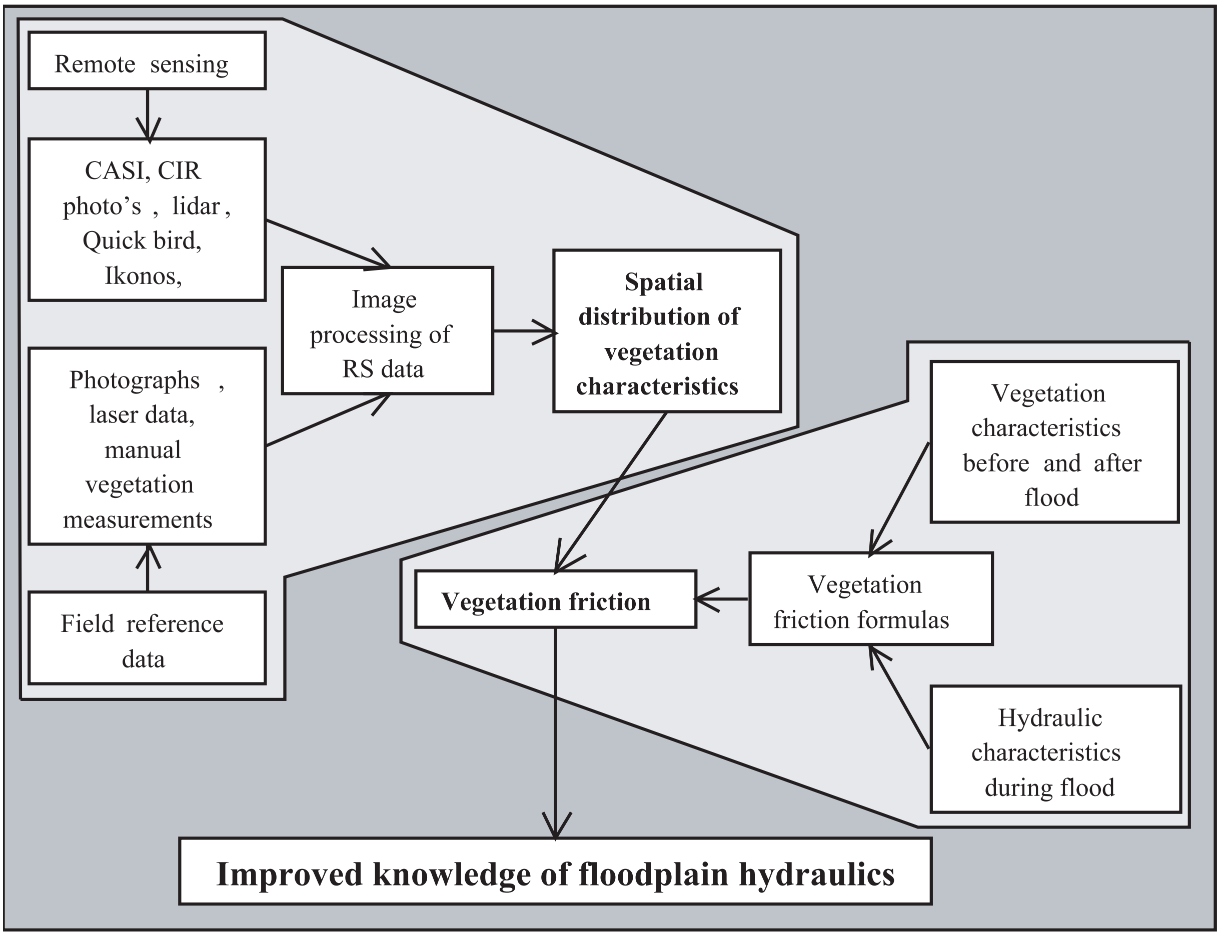

Figure 1. Research themes (in light polygons) and overall goal of the research.

Field reference data are required as calibration and validation for this process. Vegetation structural characteristics will be determined in the field by measuring height and density manually following Den Ouden (1993). This implies measuring vegetation height, number of stems and thickness of stems of various vegetation types. A stratified random sampling strategy will be used. Per stratum (vegetation class) at least 5 vegetation surveys should be done. The use of digital photos (Greame, 1991; Ritzen & Straatsma, 2001) is another possibility to determine vegetation density. Digital photos are made in the direction of the flow with a white background screen. The distance from the camera to the screen and the percentage of vegetation pixels determines the vegetation density. Another option to define vegetation height and density is to use a ground based laser range finder to scan the vegetation. No experience with this method is available to date.

A database will be build relating, vegetation types to spectral signatures from spectral images, histogram values from the lidar XYZ point cloud and physical flight parameters (i.e. flying height, footprint size and point density). Histogram values for specific vegetation types that are often used are D10 representing the ground surface and D90 representing the top of vegetation (Asselman, 2002; Neasset, 2002; Lefsky *et al.*, 1999). The combination of histogram parameters can be used to model vegetation density. The database will give insight in the vegetation types, which can be monitored using a combination of spectral and lidar data and the flight parameters needed for correct measurements of vegetation.
After classification two strategies can be followed: (1) Assigning vegetation heights and densities for each class, based on literature study and field data. This method will be used if no discrimination can be found in the lidar signal between different vegetation types. (2)

Algorithms can be developed to define vegetation height and density for each class from the lidar XYZ point cloud. Obviously the second option is preferable, because in that case actual remote sensing height measurements are used. The detectability of the top of the vegetation by laser pulses is restricting the possibilities of this method. Various methods exists for this objective like stepwise multiple regression, principle component analyses, partial least squares analyses, ridge regression or neural networks. The latter four options are particularly useful for highly correlated dataset.

Friction for different vegetation types

Vegetation friction describes the retardance of the water by vegetation elements. Three methods exist to derive friction factors from actual measurements (Van Rijn, 1994):

1 Roughness length determination from the vertical velocity profile. This profile has a logarithmic form. To define this profile properly, flow measurements should be made as close to the bottom as possible.

2 Using the Chézy equation, which relates flow velocity to friction, water surface slope and water depth. Water surface slope is a difficult parameter to measure, due to the spatial temporal changes.

3 Applying the Euler equation for non-uniform flow conditions. A large field data collection exercise is necessary.

Many tests relating vegetation characteristics to friction have been performed in the past. Both use the velocity profile method as the Chézy equation. But nearly all formulas are derived from flume experiments with low water depths and high water surface slopes. In this study, a field experiment will be conducted relating vegetation characteristics to flow properties under field conditions. In situ measurements will be made on vertical velocity profile, depth averaged flow velocity, water slope and water depth. Vegetation structure will be measured before and after the flood.

Field data will be collected to relate vegetation characteristics to flow properties. During floods data will be collected on flow velocities, water slope and depth. Before and after the flood, vegetation measurements will be made. Predictive functions of vegetation friction are further developed, based on field results.

Water slope is the most difficult parameter to measure. A novel technique is being developed after Biron *et al.* (2002). A float tracking tachymeter is used to measure the water surface slope. A circular set of reflectors is mounted on top of a floating buoy. These reflectors are automatically tracked by the tachymeter. Distance between the reflector and tachymeter is measured together with the horizontal and vertical angle to the reflectors. Final output is a XYZ-ASCII file in a local coordinate system. Other options include hydrostatic slope measurements using water hoses or capacitance wire. Flow velocity is measured easily with an acoustic doppler current profiler (ADCP), electromagnetic flow meter (EMF), or acoustic doppler velocimeter (ADV). Water depth can be measured using echo sounding.

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Assessing the benefits of floodplain rehabilitation along the lower river Rhine (The Netherlands)

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Introduction

Water quality of the river Rhine has improved significantly over the last three decades, but its river-floodplain landscapes are highly altered with a shortage of dynamic processes, characteristic landscape elements and biodiversity. During the last decade manifold floodplain rehabilitation projects have been planned or realised along the river Rhine in the Netherlands. Yardsticks for recovery are naturalness, biodiversity and spatial connectivity, but actually there is no clear end-point or reference to assess the rate of success. Constraints for rehabilitation projects are safety and shipping in the main channel. We present a subset of those projects that are situated along the largest free-flowing river branch, which has an open connection to the North Sea (Figure 1). We have tried to assess the benefits of these projects at two landscape levels: that of the project (1-10 km) and that of the river stretch (> 100 km) using five parameters (landscape mosaic, vegetation, macro-invertebrates, fish and birds).

Results

Generally the terrestrialised floodplains have been set back to more (semi-)aquatic habitats that are more frequently flooded (Table 1). Especially dynamic, shallow water habitats have been recreated. When management has been altered from farming to extensive grazing vegetation structure and species composition responded quickly. Rheophilic fish and macro-invertebrates profit immediately from re-opened or created secondary channels. The outcome is expressed in line with the EU Water Framework Directive (Table 2). The rehabilitation projects are promising with respect to effects on both the completeness compared to the target situation and the spatial connectivity. However, the overall status of the river is still moderate or even poor. As the results are comparable for ecotopes and the four groups of species studied, the conclusion is considered to be robust. This is in spite of the scarcity and incompleteness of the underlying data and the difficulties of interpreting them. For birds, the EU Bird and Habitat Directive and the WFD may not comply, since significant numbers of waterfowl forage on production grasslands in the floodplains and use man-made large deep sand-mining pits for resting. For these reasons those areas have been designated as protected areas.

Discussion and conclusion

Ecological rehabilitation is restricted by safety constraints. On the other hand, room for the river gives opportunities to combine safety and ecological rehabilitation. The results of the projects indicate that it is possible to restore several riverine habitats and to recover several biotic species within the constraints of safety. However, more effort is needed to restore other parts of the floodplain as well. Within

Table 1. Composition of the natural ecotopes (in ha) before (1990) and after (2000) rehabilitation measures and target values for the main branch of the river Rhine in the Netherlands (Van der Molen et al., 2002).

	1990	2000		Target
Shallow riverbed	390	443	11%	4020
Floodplain channels	560	605	66%	910
Bar/beach/bank	131	183	20%	920
River dune	132	146	31%	475
Hardwood forest	343	342	43%	790
Softwood forest	829	845	70%	1200
Marshland	543	522	46%	1140
Herbaceous floodplain	819	960	35%	2770
Natural pasture	1905	2439	73%	3340
TOTAL	5652	6485	42%	15565

% = 2000/Target

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1	**Gelderse Poort** - ± 2500 ha	• Development of high dynamic nature (partly realized) • Combined with existing natural and historical values
2	**Klompenwaard** - 97 ha	• Lowering of the embanked floodplain (started in 1999)
3	**Afferdense & Deestse waarden** - 300 ha	• Lowering of about 15% of the embanked floodplain • Creation of a secondary channel (however not yet connected) • Low grazing intensity (1996)
4	**Leeuwense waarden** - 40 ha	• Low grazing intensity (1994) • Lowering of a part of the embanked floodplain (1995/1996) • Creation of a secondary channel (1997)
5	**Wetland Passewaay** - 60 ha	• Connected floodplain channel (1996)
6	**Stiftsche Uiterwaarden** - 256 ha	• Lowering of 25% of the embanked floodplain (1995/1996) • Low grazing intensity (1998) • Creation of a secondary channel (plan)
7	**Heesseltsche Uiterwaard** - 283 ha	• Creation of a secondary channel (1994) • Low grazing intensity
8	**Oude Watertoren** - 7 ha	• Development of low dynamic nature (2001)
9	**Gamerensche Waard** - 128 ha	• Creation of secondary channels (1996-1999) • Low grazing intensity
10	**Breemwaard** -129 ha	• Lowering of a part of the embanked floodplain (1996) • Combined with strengthening of minor dykes to stimulate low dynamic nature • Low grazing intensity
11	**Het Gors**	• Deepening, extension (1.5 km) and reconnecting of a secondary channel (2000) • Low grazing intensity (2000)
12	**Polders Sliedrechtse Biesbosch** - 330 ha	• Lowering of a part of the embanked floodplain (1996-1998) • Re-creation of a channel system and connection with tidal system (planned for 2002)
13	**Riparian zones** (several locations)	• rehabilitation of riparian zones (in total 8.1 km, since 1986)
14	**Oude Maas** (several locations)	• Protection and redevelopment of riparian zones in tidal freshwater system
15	**Splitsingsdam** - 0.35 ha	• Construction of surface layer with shells and gravel for breeding habitatsterns (2000)

Figure 1. Rehabilitation projects along the major branch (Boven-Rijn, Waal, Merwede, Oude Maas, Nieuwe Waterweg) of the river Rhine (170 km from the Dutch-German border to the North Sea).

rehabilitation projects the landscape changed significantly, but the projects do not yet contribute significantly to the ecological recovery of the whole river stretch (Van der Molen *et al*., 2002).

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Table 2. Ecological assessment of the present state and the direction of development of the main branch of the river Rhine in the Netherlands (Van der Molen *et al*., 2002).

	Present ecological status	Direction of development: Biodiversity /Completeness	Direction of development: Spatial connectivity
Ecotopes	poor	positive	unchanged/positive
Flora	poor	positive	-
Macroinvertebrates	poor/moderate	positive	positive
Fish	poor/moderate	positive	very positive
Birds	moderate	unchanged	-

Flow resistance of dense vegetation

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Abstract

Traditional flow modelling in open channels uses time averaged turbulence models. These models are valid in clear fluid, but not if dense obstructions are present in the flow field. Newly developed flow models can describe open channel flow like flow in a porous medium. Flow in rivers, channels, estuaries and irrigation networks is often obstructed by vegetation, and coarse bedrock. A combination of Reynolds averaging for the turbulent flow and volume averaging was used in order to take into account the dense obstructions. The obstacle density can be modelled by a porosity term if structural parameters of the vegetation are taken into account. The theoretically derived model was used as an application to compute resistance factors for Manning's equation from the structural properties of the vegetation modelled as a porous medium.

Introduction

Flow in open channels and rivers is often obstructed by dense vegetation. Reed (Phragmites) can completely ``fill” an open channel and increase the flow resistance considerably. The objective of this article is to present a physically based flow resistance model for flow in densely vegetated open channels.
The requirements are that the model is easy to apply, extendable to different turbulence models and non-uniform flow. Here we will present a simple model for emergent vegetation with a reed like geometry.

Method

The Navier Stokes equations are spatio-temporal averaged (Pedras & de Lemos, 2001), and the porous medium resistance term is expressed as in (Hoffmann, 2002):

$$\rho\left[\frac{\partial}{\partial t}(\epsilon v) + \nabla\cdot(\epsilon\langle\bar{v}\bar{v}\rangle^i)\right] = -\nabla(\epsilon p) + \mu\nabla^2(\epsilon v) + \nabla\cdot(-\rho\epsilon\langle\overline{v'v'}\rangle^i) + \epsilon\rho\mathbf{g} - \frac{\rho C_D(1-\epsilon)v^2}{2d_s(\sqrt{\pi/4}-\sqrt{1-\epsilon})^2}$$

In order to express the drag term, the correlation of Taylor (1985) is used for CD:
log CD = - 0.125 log Re + 0.375.

To simplify the equation a representative unit cell is used for a prototype flow solution (Figure 1).

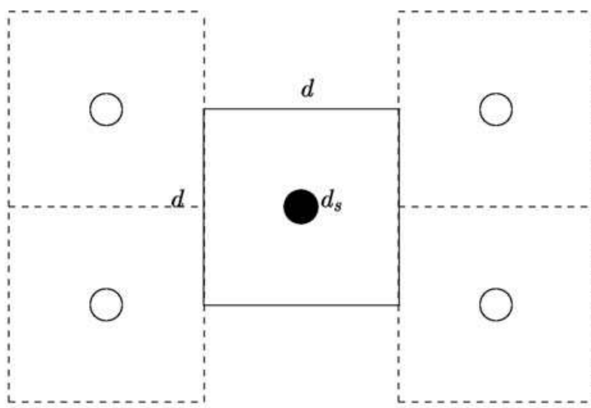

Figure 1. Representative unit cell for a prototype flow solution.

The following simplifications are used: steady state, uniform flow, hydrostatic pressure distribution, flow driven by bed slope, and plant resistance >> bottom resistance. This leads to the an equation which can be rewritten in a form similar to Mannings equation:

$$\mathbf{v} = \sqrt{\frac{2\mathbf{d_s}\epsilon\mathbf{g}\left(\sqrt{\pi/4}-\sqrt{1-\epsilon}\right)^2}{\mathbf{C_D}(1-\epsilon)\mathbf{R}^{4/3}}}\mathbf{R}^{2/3}\mathbf{S}^{1/2}$$

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with epsilon denoting the porosity, ds the diameter of the reed stems, S the slope and R the hydraulic radius. The advantages are: relative simple solution, direct incorporation of plant information, and resistance expressed in terms of plant parameters. The major drawback is that it is a (quasi) steady-state solution, valid only for water plants that are not submerged.

Conclusions

The theory predicts a simple flow equation for steady flow through water plants that are not submerged. Extension to non-uniform flow is possible, but a turbulence model is required. Prediction of the flow resistance for the engineering equation is possible from vegetation parameters.

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NCR: future activities

New educational activities of the NCR

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Introduction

The activities of the Netherlands Centre for River Studies (NCR) concern (1) achieving a river science potential of sufficient breadth and depth in the Netherlands, in order to meet societal requirements, both nationally and internationally, (2) establishing and reinforcing the position of Dutch scientific river research, and (3) enhancing education and scientific research at Dutch universities (Figure 1). Recently, the NCR developed a number of new educational activities for junior researchers (e.g. undergraduates and PhD students) and river managers. This paper focuses on the new NCR-activities, with special emphasis on Thematic and Institute Days.

NCR and educational activities

The educational activities of the NCR can be summarised by five categories:

1 Preparation of an overview of existing courses on the NCR-web-site (in progress);
2 Exchange of teaching staff and undergraduate and graduate students;
3 Development of new courses concerning river science and management (e.g. a course on dynamic river management for staff members of the Dutch Ministry of Transport, Public Works and Water Management);
4 Organisation of Thematic Days (TDs) aimed at young researchers;
5 Organisation of Institute Days (IDs) aimed at students looking for trainee positions or jobs after graduation.

Thematic Days

The Thematic Days are developed and organised by junior researchers of the universities participating in NCR (bottom-up activity). The major goals of these days are cross education, strengthening the NCR network and building a common ‘body of knowledge’. Each university yearly organises one Thematic Day (in total 3-4

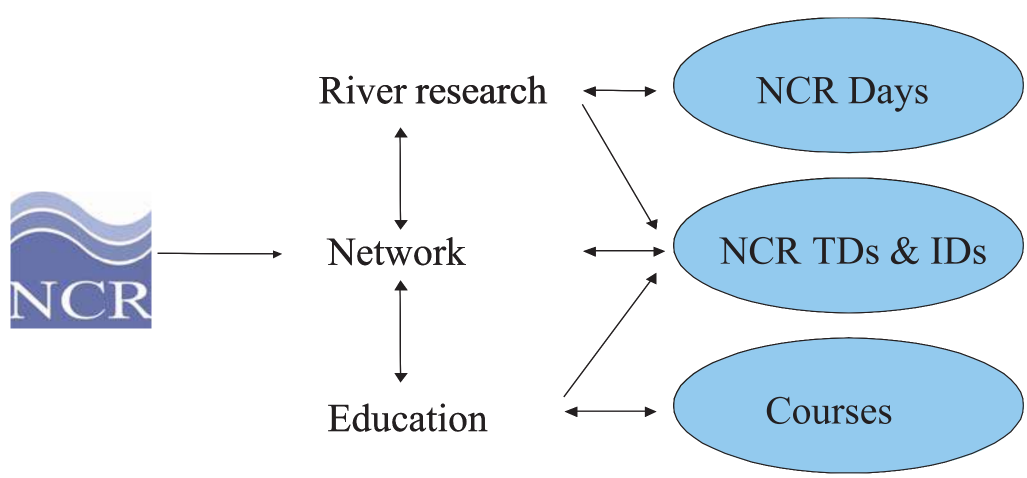

Figure 1. Coherence of NCR activities and the relations with various meetings and courses (NCR: Netherlands Centre for River Studies; TDs: Thematic Days; IDs: Institute Days).

days per year) concerning one of the disciplines of river science (e.g. hydrodynamics, morphology, ecology and systems theory). The education is focused on the specific approach of each discipline, enabling the participants to learn each other's theoretical concepts, methodologies and professional language. About 80% of each day will be focused on the contents of the specific theme; about 20% is aimed at integration of various disciplines.

The first Thematic Day was organised by the University of Nijmegen and concerned ecological concepts for river studies, the empirical approach of ecologists and biodiversity of riverine ecotopes. This day was a positive experience. There were 22 participants (Delft University of Technology: 5, University of Nijmegen: 8, Utrecht University: 6, University of Twente: 3). However, there was not enough time for discussion and exchange of ideas.

The second one concerned hydrodynamics of rivers and was held at Delft University of Technology on December 6th, 2002. The third one focused on bed morphology of large rivers on several time scales and was organised by the Department of Physical Geography of Utrecht University on May 2nd, 2003. Other proposed themes are complexity theory and environmental science of fluvial systems.

Institute Days

The Institute Days concern visits to the large technological institutes (WL | Delft Hydraulics, TNO-NITG, Alterra) and the governmental research institute (RIZA) participating in NCR. The NCR Programme Committee yearly organises these visits (top-down activity). The goal is to give undergraduates and PhD students an overview of (the contents of) the working field of these NCR-institutes, and to facilitate the recruitment of trainees and new staff. A number of participants of 20-30 each year is aimed at. So, within a time span of 4-6 years, each undergraduate and Phd student has the opportunity to participate in the Institute Days. Within a two-day programme, each institute organises a meeting of three hours that includes presentations of their research and

Figure 2. Teaching on fluvial dynamics, nature management strategies and vegetation structure of river dunes on location in the Millingerwaard (photo: M. Baptist).

consultancy activities, job possibilities and recruitment procedures. The visits also include a short tour of the institutes and talks with staff members. The first Institute Days programme was organised by the University of Nijmegen and attended by 23 participants (University of Nijmegen: 12; Utrecht University: 9; Delft University of Technology: 2). It received a very positive evaluation. However, there still is room for improvement: attention should be paid to timely announcement, all relevant aspects of traineeships / staff recruitment, a broader overview of institute activities, and more time for informal talks and discussion. In 2003 the Institute Days will be organised by the University of Twente (Dr. J.S. Ribberink).

Future activities

Based on the positive evaluation of the first Thematic and Institute Days, the NCR Programme Committee decided to continue and to facilitate these educational activities in the future. Young river researchers are invited to participate in these educational activities. Further information about the Thematic and Institute Days can be found at the young researchers page of the NCR-website (http://www.ncr-web.org/) or by contacting one of the authors.

NCR: future activities

Progress after IRMA-SPONGE

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Abstract

Recent floods have increased the request for improved flood risk management along the Rhine and Meuse Rivers, but not only along these rivers! In response the IRMA-SPONGE research programme was established, consisting of 13 research projects, in which over 30 organisations from 6 countries co-operated. The aim of IRMA-SPONGE was (Hooijer & Van Os, 2001): *"The development of methods and tools to assess the impact of flood risk reduction measures and of land-use and climate change scenarios, in order to support the spatial planning process for the Rhine and Meuse River Basins."*

General conclusions from this research programme emphasise the need for a shift from 'flood control' to 'flood risk management', and advocate a much greater role for spatial planning. We aim to address this need in the 6th Framework programme of the European Commission.

Figure 1. The IRMA-SPONGE umbrella project of the Netherlands Centre for River Studies (NCR) was funded by the Interregional Rhine-Meuse Activities (IRMA) programme of the European Union and included 13 innovative, mutually consistent and complementary projects in which more then 30 institutes from all countries in the Rhine-Meuse basins co-operated.

Introduction

The IRMA-SPONGE Umbrella Project was partly (36 %) funded by the European IRMA Programme, which stands for Interreg(ional) Rhine-Meuse Activities Programme. IRMA was established after the Rhine and Meuse flooded their banks in 1993 and 1995, as an international flood control partnership aiming to reduce the risk of flooding in the future (Figure 1). All EU countries in the catchment areas of the Rhine and Meuse (Belgium, France, Germany, Luxembourg and The Netherlands) participated in this project. Besides the EU Member States mentioned, Switzerland was also participating in various projects of IRMA-SPONGE.

IRMA-SPONGE was a cluster of 13 innovative, mutually consistent and complementary projects in which more then 30 institutes from all countries in the Rhine-Meuse basins co-operate (Figure 2). Netherlands Centre for River Studies (NCR) executed the IRMA-SPONGE management. An International Scientific Advisory Committee (ISAC) supported NCR in its task. The research addressed the following issues:

- Assessment of past and actual flood risks;
- Analysis of the impact of climate change on flood incidence and magnitude;
- Effects of land use change, flood control measures, and changed land use in flood prone areas in order to reduce the societal vulnerability; design and evaluation of comprehensive strategies for a sustainable flood risk management;
- Instruments required to achieve this, with emphasis on spatial planning.

NCR is a co-operation of the universities of Delft, Utrecht, Nijmegen, Twente and Wageningen, UNESCO-IHE Institute for Water Education, RIZA, ALTERRA, TNO-NITG and WL | Delft Hydraulics

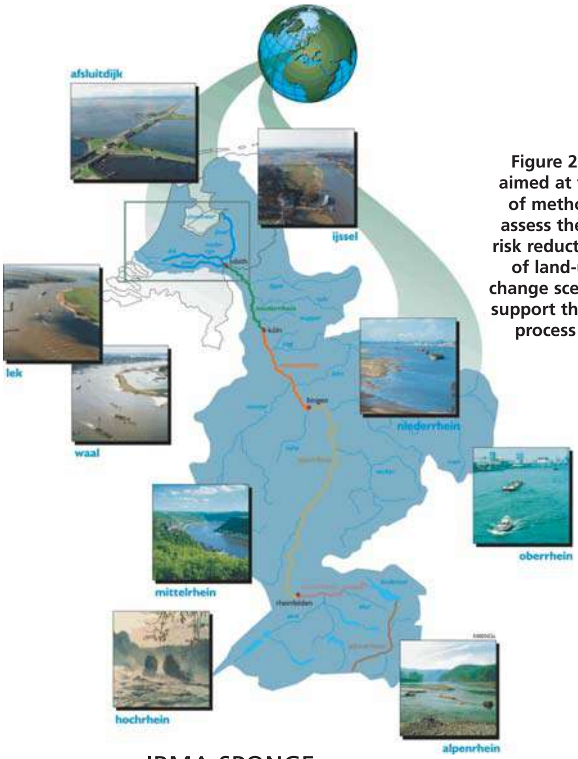

Figure 2. IRMA-SPONGE aimed at the development of methods and tools to assess the impact of flood risk reduction measures and of land-use and climate change scenarios, in order to support the spatial planning process for entire river basins.

IRMA-SPONGE was concluded in June 2002, and resulted in important recommendations to scientists and decision-makers (see the sections Results and Conclusions). We aim to follow up on these conclusions through an Integrated Project within the 6th Framework programme of the European Commission, called FloRiMaS (Flood Risk Management Strategies in European River Basins). FloRiMaS will continue on the firm basis laid by IRMA-SPONGE. A generic Flood Risk Management (FRM) strategy for European river basins will be developed, by:

1 Linking the recommendations of IRMA-SPONGE to those from similar programmes in other countries.
2 Expanding the scope of FloRiMaS to include more countries (in order to produce more generic results) and include other aspects of water resources management (WRM) into flood risk management strategies and design and evaluate an ecological network using river corridors, based on a participatory approach with local authorities and stakeholders.

More than 40 research centres from various countries all over Europe have already stated their commitment to FloRiMaS.

Main results

The main results of IRMA-SPONGE were (Hooijer & Van Os, 2002; Hooijer *et al.*, 2002; Van Os & Hooijer, 2002):

1 The effects of climate change on extreme river discharge far exceed the effects of deliberate land use changes in the river basin.
2 Retention and detention far upstream in the river basins cannot prevent extreme floods.
3 The most effective and sustainable reduction of flood risks is achieved by reducing the potential damage (vulnerability) in flood prone areas through adapted land use and dedicated spatial planning.
4 Flood risk management should not only aim at a reduction of flood risks but may also enhance the ecological quality of rivers and floodplains, and/or the quality of the living environment at large.

Additional conclusions

Apart from the main results mentioned above, some additional conclusions were drawn:

- Need for inclusion of social and economic sciences;
- Centralised programme management, a prerequisite to keep this type of research on track;
- Improved understanding amongst scientists; there is not necessarily a single ‘best’ flood risk management strategy: the perception of issues varies in space and changes in time, and these differences should be bridged, not covered up;
- Language differences can lead to differences in understanding: in some cases it was difficult to agree on translation of terms for region-specific concepts (e.g. certain measures) into or from Dutch, German or French; it was therefore recommended to ‘standardise’ terms and concepts at an early stage. The glossary added to the IRMA-SPONGE Final Report Summary aims to contribute to this.

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