Book of Abstracts

NCR-days 2014
October 2-3
University of Twente, Enschede

D.C.M. Augustijn and J.J. Warmink (eds.)
NCR-PUBLICATION 38-2014

NCR is a corporation of the universities of Delft, Nijmegen, Twente, Utrecht and Wageningen, UNESCO-IHE, Alterra, Deltares and Rijkswaterstaat-WVL
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NWO
Netherlands Organisation for Scientific Research

IGS
INSTITUTE FOR INNOVATION AND GOVERNANCE STUDIES
NCR-Days 2014

The Netherlands Centre for River Studies (NCR), established on October 8th 1998, is a collaboration of nine Dutch research institutes with the goal to enhance cooperation in the field of river-related research. One of the NCR activities is to organize the NCR-days, an annual conference organized in rotation by the institute members. The edition of 2014 is organized in Enschede by the University of Twente.

At the end of 2013, a consortium build around the NCR members was granted a large research programme called RiverCare funded within the so called Perspectief Programme of the Dutch Science and Technology Foundation (STW) and supported by many public and private partners. RiverCare is an ambitious research programme that aims at a better understanding of the fundamental processes that drive ecomorphological changes in rivers, predict the intermediate and long-term developments and develop best practices to reduce the maintenance costs and increase the benefits of interventions. The programme consists of 20 research positions and will boost river research in the Netherlands over the next 5 years in which NCR can also play a prominent role.

Since RiverCare is still in the start-up phase, results will only become available over the next years. During these NCR-days a brief overview of the intentions of RiverCare will be given. As keynote speakers we have invited some international renowned researchers on themes that form a central place in RiverCare. So will Prof. Geoffrey Petts from the University of Westminster discuss the challenges in ecohydraulics for regulated rivers, Prof. Ton Breure from Radboud University and National Institute for Public Health and the Environment (RIVM) will elaborate on ecosystem services in environmental management and Dr. Igor Mayer from the Delft University of Technology will explain what the role of serious gaming could be in river management. In addition, Prof. Paul Bates from the University of Bristol will review the modelling of flood inundation, another important aspect in river research. The 21 oral presentations and 11 posters at these NCR-days are a sample of the current research on river related topics. We hope it will be an educating and inspiring programme.

Finally we would like to thank Koen Berends, secretary of the NCR programme committee, and Anke Wigger, secretary of the Marine and Fluvial System group at the University of Twente, for their immense support during the organisation of these NCR days. Also the financial support of the Netherlands Organisation for Scientific Research (NWO) and the Institute for Innovation and Governance Studies (IGS) at the University of Twente are greatly acknowledged.

Denie Augustijn
Jord Warmink
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*Presented by A. Vargas-Luna*
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1 – Keynotes
Ecohydraulics for river regulation: Past experiences and future challenges

G.E. Petts
University of Westminster, 309 Regent Street London W1B 2HW, United Kingdom, g.petts@westminster.ac.uk

Introduction

Ecohydraulics emerged during the second half of the 20th Century as quantitative data became available on gauged flows and from biological monitoring to demonstrate the impacts of dams and abstractions. Since the 1st international symposium combining the science of hydraulics with aquatic biological research, requiring the input of hydrological data, held in Trondheim in 1994 (Saltveit, 1996), Ecohydraulics has matured as a multi-disciplinary science. This paper reviews past experiences and examines the scientific bridges that must be built to address persistent challenges if Ecohydraulics is to contribute to a fundamental advancement in sustainable river management.

Ecohydraulics: the paradigm

The Eco-Hydraulics Committee of the ASCE defines the subject area as ‘the study of the fluid mechanics of natural and engineered systems to improve our understanding of such systems, and hence our ability to predict reliably and ameliorate the impact of human intervention in the environment.’ For most within the community, a slightly broader definition applies, focussing on the ‘dynamics of physical processes driving aquatic ecosystems and the modification of habitats’. Furthermore, in practice, advances in understanding the biological responses of organisms to habitat dynamics or change is often a secondary objective, except in the case of biota that function as ‘ecosystem engineers’.

Ecohydraulics: the impact

The literature suggests that the scale of international research clustered around the theme of Ecohydraulics has been impressive, and that this clustering of hitherto diverse activities has had benefits in advancing our understanding the interplay between flow, channel morphology and habitat across a range of spatial scales. These advances may be grouped into ten key themes:

1. Turbulence theory
2. Channel – floodplain interactions
3. Hyporheic flow
4. Winter ice in rivers - channel dynamics and biochemical processes
5. Sediment dynamics
6. 3D hydraulic modelling
7. Vegetation as ecosystem engineers
8. Upscaling from flume to river network
9. Morphological dynamics
10. Fish behaviour to environmental stimuli

The transfer and application of this new multi-disciplinary understanding has developed management practice in five prominent areas: environmental flows, impacts of power-peak regimes, design of naturalistic channel morphologies and particularly importantly the sustainability of pools in gravel-bed rivers; barrier removal and fish passage facilities.

Notwithstanding these contributions, tensions persist between the physical and biological sciences, between the contrasting temporal and spatial scales of the experimental hydraulic domain of flume studies and the empirical studies of river sectors, and between academics and practitioners. Discovery of the evidence for links between flow and biota is still the enduring challenge. Foci on hydraulic habitat, species with short life-cycles, and behavioural responses to hydraulic conditions have contributed to academic advances but difficulties remain in elucidating functional relationships at the important population and community scales. The latter difficulties have illuminated the possible significance of reach-scale hydraulic diversity, especially at tributary confluences, and river network-scale hydrological diversity within large catchments in determining the resilience of biological populations to extreme flows.

Much attention has focused on migratory species such as Atlantic Salmon (Salmo salar). Considerable efforts have been made to reverse the population declines of Atlantic salmon of the past 120 years. However, major investments in flow regulation and habitat re-engineering schemes have yet to yield demonstrable benefits for river fisheries. This has shifted attention away from river catchments to focus on estuarine and ocean phases of the salmon life cycle as primary drivers of population dynamics. It has also focussed attention on the scales of uncertainty associated with global climate change.

Particularly with regard to low flows, river regulation below dams, and management of diversions and abstractions a fundamental challenge has been our ability to measure discharge with the temporal and spatial precision required under management and legal...
frameworks. In England, this has constrained the application of the science of environmental flows over more than 50 years.

**Ecohydraulics: the future**

In the face of future hydrological changes with increased flooding and longer duration droughts, *Ecohydraulics* has a key role to play in evaluating management options that must balance the protection of infrastructure and water resource systems on the one hand and environmental protection on the other. River scientists must be more confident in promoting what new research has achieved and the successes from management, regulation and restoration schemes. Dwelling on the academic and what we don’t know – the notorious ‘research gap’ - has at best confused those responsible for policy and practice!

Advances in the integration of hydraulic and hydrological approaches provide new opportunities, but the past can no longer be used as a benchmark for the future. Non-stationarity of natural systems is the new paradigm! Much depends on our abilities to upscale our developing knowledge in both space and time. Major challenges include the need to develop models capable of projecting scenarios of habitat development over timescales of channel response to changing flow regimes and management solutions that allow channels to evolve in naturalistic ways as flow regimes change over multi-decadal timescales.

**References**


**Related recent publications**


Ecosystem services in environmental management

A.M. Breure
Radboud University, Institute of Water and Wetland Research, Heyendaalseweg 135, 6525 AJ Nijmegen; RIVM, Postbus 1, 3720 BA Bilthoven, the Netherlands, ton.breure@science.ru.nl or ton.breure@rivm.nl

Introduction
In 2050, about 80 percent of the world population will be living in urban areas, many of them in lowland areas close to rivers and shores. To solve consequent major challenges with regard to a healthy and safe living environment in a sustainable way, environmental management moves from quality protection towards sustainable use of natural capital and ecosystem services (ES). Therefore, we should become aware of the services nature delivers in order to utilize them in the development of our society.

Natural Capital and Ecosystem Services
Natural capital comprises the naturally occurring living and non-living components of the Earth, together constituting the biophysical environment, which may provide benefits to humanity, such as water and food, mineral and energy resources, timber and other biotic resources and land to occupy. Natural Capital comprises three components (Figure 1):
- Abiotic stocks, non-renewable and depletable assets (e.g. fossil fuels minerals, gravel salt etc.);
- Abiotic flows, renewable and non-depletable assets linked to geophysical cycles (solar, wind, hydro, geothermal);
- Ecosystems and their services, renewable and depletable.

An ecosystem is a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit. Examples are terrestrial ecosystems (e.g., forests and wetlands) and marine ecosystems. Interactions exist between different ecosystems at local and global levels.

ES are the contributions of ecosystems to man and society, which may be valued in economic terms but not necessarily. ES are provided by the combined action of living organisms (biota), and abiotic processes. They are highly specific for any ecosystem, because each ecosystem is unique. According to international conventions, ES may be divided into three groups:
- provisioning services (e.g. provision of timber, (drinking) water, fish, food);
- regulating services (e.g. purification of soil and water, atmospheric composition and climate regulation, pest and disease control, flood mitigation);
- Cultural services (such as the enjoyment provided to visitors to a national park).

Generally, provisioning services are related to the material benefits (food, timber) of environmental assets, whereas the other types of ES are related to the non-material benefits (public health, well-being) of environmental assets. (Maes et al. 2013, UN 2014).

Use of river systems
River floodplains have historically been favoured sites for human habitation because of the provisioning of goods and services. Originally, rivers provided water for domestic and agricultural use, fish, fertile soils and possibilities for transport and waste disposal.

As rivers posed also risks of flooding, resulting in losses of life and properties, river
systems have been changed over the centuries, e.g. by construction of dikes. Simultaneously forests on floodplains were cut to provide wood for fuel and building material, and land for agriculture. Later on changes were made to improve navigation and for energy production. The use of rivers to get rid of industrial and municipal wastes and surpluses (agricultural chemicals) caused a decline in water quality that was maximal during the 1960s and 1970s. During the following decades installation of wastewater treatment plants resulted in a drastic reduction of many pollutants (Lorenz 1999). Now the pollution has been reduced, the natural river system should be restored with floodplain forests and meandering side channels increasing water storage capacity improving fishing and recreational water, bird populations, recovering biodiversity, natural attenuation and pest control.

Quantification of ecosystem services
Quantification of ES is important to raise the awareness of the value of ES for our society. To estimate optimal development or management strategies of our living environment, we need an adequate understanding of the value of the various ES for different stakeholders and the dependence of our society on our natural ecosystems (Villa et al. 2014). The perspective of ES to assess human – natural system interactions considers:

- Biophysical processes of service provision;
- The economic outcome of service uptake by society;
- Social implications of service demand, utility and equitable distribution.

There is no general framework to assess and value ES so far. The following aspects of quantification and valuation ought to be taken into account: Maintenance of focus on the coupled human – natural system
A transfer of benefits from nature to society characterizes ES. For description of such services, the location of the beneficiaries and the scale of influence of the natural system on them have to be determined on a case-by-case basis.

Provisioning of appropriate quantitative information
Quantification of ES ought to be able to extend the temporal dynamics of the system and be able to capture thresholds and tipping points that are crucial for security of the service.

Explicitly address both potential and actual values
Analysis of services should provide information on potential benefits as well as actually used benefits, to see whether other types of ecosystem use might be more beneficial.

Address trade-offs in dynamic, scale aware perspectives
Trade-offs, either between different ES, or between different social groups in need of them, are strongly affected by system dynamics, and may change radically with varying spatial and temporal scales. E.g. deforestation for agriculture leads to trade-offs between food provision on the short term and increase of run-off and erosion on the longer term, eventually influencing flood risk and water supply.

Leave the definition of value to the decision maker / stakeholder
Valuation of ES is highly context dependent. Stakeholders may have different interests in specific services in an area at a specific time. Many services are hard to value economically. Therefore, the most optimal valuation of ES results from negotiation between the stakeholders having interest in ES in an area.

Why ecosystem services in Rivercare
The aim of research on ES is to raise awareness and develop tools to, for quantification and valuation of ES for different stakeholders.

The concept of ES in river management is a powerful tool for evaluating strategies for management of natural resources and sustainable societal behaviour.

References
Villa, F, Voigt, B, Erickson, JD (2014) New perspectives in ecosystem services science as instruments to understand environmental securities. Philosophical Transactions of the Royal Society B 369: 20120286
Modelling flood inundation from street to global scales

P.D. Bates
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Introduction
The last decade has seen astonishing advances in our ability to model flood inundation with the development of highly efficient algorithms for simulating shallow water flows that are capable of making use of new high performance computing tools. At the same huge leaps in our ability to collect data to parameterize and validate these models have started to make possible exciting new applications for such schemes. These have pushed the boundaries of hydraulic modelling away from traditional reach scale studies to high-resolution (~1m) simulations of whole cities at one end of the scale and global scale applications at ~1km resolution at the other. This paper will review the developments that have made this possible and present some examples studies showing the capability of what we can now do.

New algorithms and computer architectures
Over the last 5 years a variety of highly efficient numerical solutions for the various forms of the shallow water equations have been developed (e.g. Bates et al., 2010). Of these a consensus is emerging that for sub-critical flows the local inertial formulation of the shallow water equations (i.e. a formulation which ignores convective acceleration) is sufficient to capture wave propagation (de Almeida and Bates, 2013), whilst for super-critical flows the full shallow water equations are required (Neal et al., 2012). For both full and local inertial forms new numerical solutions have been proposed which are both compute time and memory efficient, although the local inertial formulation can be solved with approximately an order of magnitude fewer numerical operations and is hence to be preferred when not contra-indicated.

At the same time authors have also begun to explore how such codes can interface with new high performance computing architectures including General Purpose Graphics Processing Units (GPGPUs), shared and distributed parallel processing and high throughput computing systems (e.g. Neal et al., 2009).

The combination of these developments now makes possible dynamic model simulations over grids of $10^7$ or even $10^8$ cells, or massive ensemble simulations consisting of tens of thousands of model realisations.

New data sources
High-resolution models are meaningless unless the data are available to parameterize, calibrate and validate them. Fortunately, the increasingly widespread availability of airborne laser scanning terrain data (LiDAR) for local studies and bespoke versions of the global Shuttle Radar Topography Mission data set (e.g. Yamazaki et al., 2012) are now available to support modelling. In addition, a variety of novel hydraulic observations from remote and proximate sensors are also available and have been used to explore calibration and validation issues (see for example Jung et al., 2012). They over-arching idea here is the comparison of uncertain data to uncertain models within an appropriate statistical framework (see for example Mason et al., 2009).

New applications
Finally, new data and new models have allowed a whole range of new applications for hydraulic models. At one end of the scale, global hydrodynamic models are now available, and the scales at which hydrodynamic and climate/numerical weather prediction models can operate have, in effect, converged. Global models are currently at ~25km resolution (Yamazaki et al., 2013), but work is underway that will see the first 1km global hydraulic model within the next 6 months.

At the other end of the scale LiDAR data, and even vehicle-mounted terrestrial LiDAR with point spacing of a few centimeters is starting to allow a new generation city wide hydraulic models (see Figure 1) that can resolve individual buildings (see for example Neal et al., 2009).

This paper reviews this range of applications and suggests ways in which such developments will transform the field of hydraulic modelling over the next few years.

References
1 – Keynotes


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*Figure 1. Simulation of flooding in the Greenwich peninsula, London, UK at 5m spatial resolution using the LISFLOOD-FP flood inundation model.*
Serious games for river management: A frame reflective discourse analysis

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Introduction
The growing interest in the utilization of games for society, business and politics, commonly referred to as serious games entails a growing need to understand the effects of what we are doing and promoting. This is necessary out of professional and scientific curiosity as well as responsibility and accountability. An emerging discipline that advocates the use of games for learning or to repair a ‘broken reality’ (McGonigal, 2011) has a responsibility to critically reflect on the short- and long-term value and structural consequences of the tools they are developing, promoting and using; especially when vulnerable groups in society are involved, such as children, patients or immigrants. Furthermore, users (sponsors, clients, educators, players) are becoming more exposed to, and familiar with, SG. They have the right to know what they are actually buying, using or playing, what the games are for and what the effects or consequences of the application of games are. Moreover, when institutional stakeholders – policymakers of many kinds – start to promote SG as a vehicle for economic competitiveness, as contributing to some of the grand challenges (for example, safety and security), for social cohesion, empowerment or creating jobs, for science even (see references and examples below), then a critical, scientific and professional reflection on the economic, social and political benefits and limitations of SG is duly required.

Framing
Recently, we have come to use framing theory (Goffman, 1974) and frame-reflective discourse analysis (Rein & Schön, 1996; Schön & Rein, 1994) to shed some light on the games. Framing is the act of attributing meaning to events and phenomena; a way of creating order out of chaos by providing a critical analysis of the multiple, often conflicting, ways in which we perceive and discuss, in our case, the utility of games. Frame-analysis is a way of dissecting how an issue is defined and problematized and the effect that it has on the broader discussion of the issue. For our purposes, we define two ‘drivers’ with which to construct four frames on the utility of games (see Table 1).

1. Whether the world as we know it is more likely to be real (ontological realism) or constructed (ontological idealism): If the world is real, we are more likely to be able to observe it, measure it and come as close as possible to understanding it as it really is. If it is grounded in our ideas (mind), we can only explore and try to understand our relationship to the world as we think it is, expanding our understanding through interaction with others who may think differently (phenomenology).

2. How we consider change in the world (and in ‘ourselves’ within it): If we assume that the subject (‘I’/‘we’) can exercise some degree of control in changing its environment, we acknowledge ‘interventionism’. We then assume that we can ‘decide’ to act on (build, construct, repair, steer) parts of the world in which we live as we see fit. If we assume that actual change is less the creation of one or several individuals than it is the emergent result of various intentional and unintentional forces within a system, we accept a type of ‘evolutionism’ or ‘determinism’. The system is assumed to influence subjects to a much greater extent than subjects can influence the system.

Table 1 Four frames

<table>
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<tr>
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<th>Interventionism</th>
<th>Evolutionism - Determinism</th>
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<tr>
<td>Realism Empiricism</td>
<td>I. SG = Tool,</td>
<td>II. SG = Creative</td>
</tr>
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<td>therapy, drug</td>
<td>innovation</td>
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<tr>
<td>Idealism Phenomenology</td>
<td>III. SG = Persuasion</td>
<td>IV. SG = Self-organization</td>
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</table>

Each frame has its own ontological assumptions, specifically concerning gaming itself and concerning gaming’s objectives. We discuss these frames in the sections below:

I. SG as a tool
This frame reflects the majority and most frequently cited examples of SG used for a wide
range of purposes (e.g. therapy, education, health, decision-making, and training). Through this frame, we see a ‘thing’ that can be measured, indexed and taxonomized. In other words, we see a ‘tool’ that might or might not work (Caluwe, Hofstede, & Peters, 2008). The language in this frame is pervaded by words such as ‘effectiveness’, ‘efficacy’, ‘randomized controlled trials’ (RCTs) and ‘evidence-based’. The tool itself is measured in terms of ‘metrics’ and its effects in terms of ‘analytics’. Especially within the context of health, it is treated as a new type of therapy, the effectiveness of which must be assessed in clinical trials (Fernández-Aranda et al., 2012). Research revolves around the question of whether the game offers a more effective tool for learning, education, health and training. Proponents do their best to prove and understand how it works. Opponents might argue that this serious game-play does not work, that there is inconclusive evidence or even that it has countervailing effects, such as addiction (see Table 3).

In the domain of river management, there are several of such tools. The virtual training simulator called Levee Patroller is a most successful one that has thoroughly been evaluated and assessed on its learning efficacy among levee inspectors (Hartevelt, Guimarães, Mayer, & Bidarra, 2009; Hartevelt, 2011, 2012). The game consists of a virtual environment that simulates a range of serious situations relating to dikes. The players can walk around without restrictions and decide for themselves which are the important places that need checking. Not only when water levels are high, but also during dry periods. Both extremes can lead to problems with dikes and involve the risk of a dike failure. Dike inspectors learn what to focus on during dike inspections. They also learn how to report observations and about the procedures required so that the right steps can be taken without delay. (Deltares, n.d.)

II. SG as creative innovation
In this frame we see SG as a part of evolutionary change, and as an especially significant factor in the competitive race among nations, regions, companies and even individuals. The argument in this frame is that the phenomenon of digital games is built upon means of persuasion and rhetoric (Bogost, 2007). Games are seen as a powerful new means of communication, and an even more powerful means of persuasion and rhetoric (Bogost, 2007). This new means can be used to sell products or services (e.g. adver games, many forms of gamification, games for branding), as well as to effect change in social behaviour (e.g., bullying prevention) or political ideas. Examples of such SG are numerous. Some, such as September 12 (Frasca, 2007), are well known and have made a mark on the debate about SG. Many others (e.g., Play As Julian Assange In WikiLeaks: The Video Game, Redmond Pie, n.d.) are known only within small communities. The vast majority offer simple, non-engageing game-play, although their procedural rhetoric remains very clear and strong (Bogost, 2007). The development of relatively complicated games such as America’s Army (America’s Army, n.d.; Nieborg, 2004)
and **Economia** (*Economia* game, n.d.) has been driven by a few large institutions and companies. Some persuasive games are supported at high political level as an example of how games can change society for the better (*“Games that Can Change the World | The White House,”* n.d.; USDA, n.d.). The case of *PING* (*Poverty Is Not A Game* (*PING*), n.d.) contains much of the rhetoric of intervention for social change (i.e., making children aware of poverty).

There are a few of such SG around the topic of integrated water management. FloodSim is an accessible online policy simulation that helps raise public awareness of issues around flood policy and provides feedback to insurers and policy makers about public attitudes towards different flood protection options. FloodSim puts the player in control of flood policy in the UK for three years. Players decide how much money to spend on flood defences, where to build houses and how to keep the public informed. But as in real life, money is limited. The player must weigh up flood risks in different regions against the potential impact on the local economy and population. The game brings to life the complexity of the issue and the trade-offs that policy-makers are grappling with in real life. (PlayGen, n.d.)

**IV. SG as complex systems**

Through this frame, we see games as part of an evolution in society and cultures at large. Adherents argue that we are witnessing the *ludification* (Raessens, 2006) of cultures, due to the growing pervasiveness of digital games, especially amongst the younger generation. Ludification (or gamification) affects the ways in which people organize and interact in everyday life (e.g., in social, political and cultural life, or at work). For many, this cultural change might be subtle, slow and unnoticed. It might also become submerged in self-organizing communities on the web (combinations of social media and gamification) or in our efforts to gamify science as in the examples of Quantum Moves (*ScienceatHome*, n.d.), Eyewire (*MIT*, n.d.) and Floracaching (*Biotracker*, n.d.; *Forster*, 2013). A marked difference with persuasive games, is that in games for self-organization, players are already persuaded to spend a significant amount of their time to give something back, to science, safety, nature, public space or otherwise. The sum of all individual players’ actions has emergent effects at the system level. We see examples where games are used to mobilize collective intelligence (wisdom of the crowd) such as in the case of finding the missing Malaysia Airlines flight 370 (*Nimmons*, 2014). It can also be used to encourage public participation (*EngagingCities*, 2011; *San Francisco Department of Emergency Management / CosmiCube Inc*, n.d.), or self-organization at the work-floor (*RANJ*, n.d.). One of the best examples of SG as self-organization is *Foldit* (*Cooper* et al., 2010). Critics might argue that ludification and gamification could potentially create a new divide based upon access or lack of access to, and literacy in, digital games. A wide range of ethical and socio-political questions arise with regard to the use of games for self-organization (e.g., in the workplace).

In the field of water management there are a few examples. *Aqua Republica* is a DHI and UNEP-DHI project that focuses on the development and promotion of a not-for-profit serious game in collaboration with a number of partners. The aim of the project is to promote sustainable water resources management by sharing knowledge, to raising awareness and building capacity in some of the most critical issues in water resources management through serious gaming, where participants can experience making decisions in managing a catchment in an interactive and engaging way, and in doing so learn about the connectivity and importance of water resources, as well as the need for careful management. The Delta Viewer uses data and knowledge about safety, liveability, ecology and economic development. The player can see how all these different factors are connected, and finds out that safety issues are indeed related to the availability of fresh water, nature, urban (re)development, shipping and raw material extraction (*Tygron*, n.d.).

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2 – Presentations day 1
RiverCare: towards self-sustaining multifunctional rivers


Introduction
Rivers are inherently dynamic water systems involving complex interactions among hydrodynamics, morphology and ecology. In many deltas around the world lowland rivers are intensively managed to meet objectives like safety, navigation, hydropower and water supply. With the increasing pressure of growing population and climate change it will become even more challenging to reach or maintain these objectives. In the meantime there is a growing awareness that rivers are natural systems and that, rather than further regulation works, the dynamic natural processes should be better utilized (or restored) to reach the multifunctional objectives. Currently many integrated river management projects are initiated all over the world, in large rivers as well as streams. Examples of large scale projects in the Netherlands are ‘Room for the River’ (Rhine), the ‘Maaswerken’ (Meuse), the Deltaprogramme and projects originating from the European Water Framework Directive (WFD). These projects include innovative measures executed never before on this scale. Although estimates have been made on the effects of these measures for many of the individual projects, the overall effects on the various management objectives remain uncertain. For all stakeholders with vested interests in the river system it is important to know how the system evolves at intermediate and longer time scales (10 to 50 years) and what the consequences will be for the various river functions. If the total, integrated response of the system can be predicted, the system may be managed in a more effective way, making optimum use of natural processes. In this way, maintenance costs may be reduced, the system remains more natural and more self-sustaining and ecosystem services can be safeguarded or even enhanced. The unprecedented extent of the current interventions, together with comprehensive in-situ monitoring now offers an excellent opportunity to gain extensive knowledge about their intermediate and long-term impacts.

Scientific challenges
To obtain the objectives mentioned above, interdisciplinary research is necessary related to the following key-aspects:

River morphodynamics: Many human interventions currently taken in rivers and streams, such as longitudinal training dams, construction of side cannels, removal of bank protection, remeandering of streams, dredging and nourishment and floodplain rehabilitation, initiate morphological changes that may ultimately hamper various river functions. Since most of these measures have not, or not at the current scale, been implemented before, it is unknown from experience what the morphologic evolution will be and how this will impact river functions. Therefore, knowledge of the morphologic effects of these interventions is crucial for a cost-effective management.

River ecology: Ecological processes will also be affected by these interventions. To understand and predict the ecological response, knowledge of biotic and abiotic processes needs to be integrated. The current scientific understanding of the dynamic interactions and feedback mechanisms between these processes is still limited, especially at the quantitative level and when it comes to establishing predictive models. There is also a need for a generic classification system of ecosystem units that is interpretable.
by and useful for stakeholders with various interests.

**Ecosystem services**: An integrated way to evaluate the societal impact of human interventions in river systems is by quantifying ecosystem services. River systems provide valuable ecosystem services such as safety, navigability, biodiversity, climate buffering and spatial quality. Suitable approaches, indicators and standards need to be developed in order to quantify these ecosystem services and evaluate the societal impact of human interventions.

**Uncertainty**: Management decisions rely on predictions of future developments in the river system. These predictions usually involve large uncertainties which tend to be overestimated, thus forcing managers to conservative choices. Quantifying and where possible reducing the uncertainties in the prediction of future developments will help managers to take more robust and cost-efficient measures.

**River governance**: Implementing measures in river systems involves many stakeholders with varying perspectives and perceptions. A better understanding of these frames and the way stakeholders interact may open ways to a new and innovative governance model for river management.

**Communication and valorisation**: For valorisation the challenge is how to translate specialist knowledge to practical relevant and usable information. Models, tools and guidelines should be developed that can be used effectively by end users in national or international contexts. This requires close cooperation between scientists, stakeholders and end users in developing these products.

**RiverCare**

The NCR partners have taken the initiative for a multidisciplinary research programme called RiverCare that has been granted in the ‘Perspectief-programma’ of the Technology Foundation (STW) of The Netherlands Organisation of Scientific Research, NWO. In RiverCare the NCR partners (5 universities, Rijkswaterstaat, Deltares and Alterra) and other public and private parties (STOWA, RIVM, Province of Gelderland, Arcadis, Bureau Waardenburg, Royal HaskoningDHV, Witteveen+Bos, HKV, Tygon, T-Xchange, LievenseCSO) collaborate to address the scientific challenges and get a better understanding of the fundamental processes that drive ecomorphological changes, predict the intermediate and long-term developments, make uncertainties explicit and develop best practices to reduce the maintenance costs and increase the benefits of interventions. The projects currently carried out in the Netherlands provide a unique opportunity to achieve these objectives. The findings should lead to a 'Virtual River', an interactive design tool that integrates all the collected knowledge and can be applied worldwide for lowland rivers.

RiverCare will run from 2014 until 2019. The programme consists of 8 projects each consisting of 2 or 3 research positions, adding to a total of 20 (15 PhD and 5 postdocs). Figure 1 shows the coherence between the projects.

![Figure 1. Structure of RiverCare consisting of eight projects.](image-url)
Distinct patterns of interactions between vegetation and river morphology

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Introduction
In a dynamically meandering river vegetation interacts with flow and sediment. The pattern of vegetation on the floodplain is determined by hydro-morphological tolerances which in turn are determined by species specific traits (Gurnell et al. 2012). Processes at different scales (ecological, hydrological and morphological) interact and create a patchy, young vegetation pattern on the point bar close to the channel and older, denser vegetation higher on the floodplain (Corenbilt et al. 2007). Modelling these processes at the right scales gives insight in the interaction between vegetation and morphodynamics and contributes to the design and long-term prediction of ecological rehabilitation measures. But advances in modelling have until recently only been one-way traffic either looking at the effect of vegetation on morphodynamics (Murray & Paola 2003) or the other way around (Ahn et al. 2007). The few models that do explicitly incorporate the interaction between vegetation and morphodynamics have until now represented vegetation as rigid cylinders causing hydraulic resistance that do not change over time (Perucca et al. 2007; Nicholas 2013; Crosato & Saleh 2011).

Here we present a dynamic vegetation model coupled to a morphodynamic model. Vegetation can colonize, grow, die and interact with the flow. We investigate the hypothesis that dynamic vegetation creates more realistic patterns in vegetation and fluvial morphology than the ‘old fashioned’ static vegetation. We compare a reference scenario without vegetation to a scenario with static vegetation and an innovative dynamic vegetation scenario.

Method
General model set-up and scenarios
We coupled the morphodynamic model Delft3D to a new dynamic vegetation model (Fig. 1). The morphodynamic model was designed to represent average morphodynamic characteristics of the Allier river in France. The vegetation model interacted with the morphodynamic model through hydraulic resistance at user-defined ecological time steps. The total simulation time was 150 years, enough to simulate at least one life cycle of riparian trees.

Three scenarios were tested: 1) No Vegetation, which is the control run of the morphodynamic model without vegetation, 2) Static Vegetation, where vegetation colonized each year in cells that were dry at average discharge but did not grow or die, and 3) Dynamic Vegetation, where vegetation colonized, grew and died. The vegetation types are loosely based on riparian tree Salicaceae species.

Vegetation processes
The vegetation model includes three classes of vegetation processes: colonization, growth and mortality. Colonization takes place depending on the timing of seed dispersal and the water levels during that period. The location for colonization is on bare substrate between the highest and lowest water levels during the annual dispersal period. The location for colonization is on bare substrate between the highest and lowest water levels during the annual dispersal period. Growth of vegetation is calculated with a logarithmic growth function. When the vegetation survives, its age increases each subsequent year until the maximum age is reached. Depending on the life stage which is related to age, the characteristics of the vegetation are different. Mortality of vegetation depends on days of subsequent flooding, days of subsequent desiccation, high flow velocities, scour and burial. Total mortality is calculated at the end of each year.
Results
Figure 2A shows the bed level results for all scenarios after 150 years. Results show that the scenario with dynamic vegetation has a decreased lateral migration of meander bends and maintains its active meandering behaviour as opposed to the scenarios without vegetation and with static vegetation. In these latter scenarios there is first an increased lateral migration followed by several meander cut-offs. Figure 2B shows the vegetation settlement of the static and dynamic vegetation scenarios. Dynamic vegetation creates a patchy vegetation pattern whereas static vegetation creates more densely vegetated floodplains. Comparing model results of vegetation age and vegetation pattern with aerial photos of the Allier shows that dynamic vegetation creates realistic morphological features and vegetation patterns (Fig. 3).

Conclusions
The three scenarios show distinct differences in fluvial morphology. We show that inclusion of dynamic vegetation processes in morphodynamic models creates more realistic vegetation patterns and river morphology than static vegetation. Also dynamic vegetation maintains its active meandering behaviour as opposed to the static vegetation and no vegetation scenarios.

References
Laboratory investigation on the hydrodynamic characterization of artificial grass

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Introduction
The morphological evolution of river systems is strongly influenced by the presence of vegetation (Hickin, 1984). On vegetated beds, velocity fields are spatially heterogeneous at different scales according to vegetation density and hydraulic conditions (Nepf, 2012). Plants affect velocity profiles that deviate from those commonly found in non-vegetated flows (Yager and Schmeeckle, 2013), changing the local sediment transport rates and morphology. To simulate the effects of vegetation on hydrodynamics and sediment transport, plants are treated as rigid cylinders characterized by diameter, height, density and drag coefficient (Baptist, 2005). Given the vast variety of plant shapes and considering that plants may be flexible, it is important to define the key parameters that characterize plants in model (Vargas-Luna et al., 2014a).

In this work artificial grass is characterized in a laboratory setup considering emergent and submerged conditions, three different plant densities, and two sediment samples. The Baptist (2005) model was applied to estimate the global flow resistance because it has shown good agreement with observations (Vargas-Luna et al., 2014b). The plants considered in this work will be used in subsequent laboratory experiments to analyse the effects of vegetation on river bank accretion.

Experiments
Both submerged and emergent conditions were tested under flow discharges between 0.2 l/s and 40.5 l/s by using two bed materials: gravel (hydraulically rough) and sand (hydraulically smooth), in a 0.40 m wide and 15 m long flume at Delft University of Technology. The bed particles were glued to metallic plates on the bottom of the flume, empowering hydraulic roughness, but preventing sediment transport. In addition to the non-vegetated conditions, sparse (31 plants/m²), transitional (112 plants/m²) and dense (422 plants/m²) staggered plant configurations were tested (see Fig. 1).

A downstream weir was used to ensure uniform flow conditions, maintaining the same discharges for all of the vegetation configurations. Flow discharges and water depths were measured (see Table 1 for the gravel bed), as well as vertical velocity profiles for the submerged conditions. Sidewall corrections were included by applying the method of Vanoni and Brooks (1957).

Preliminary results
For non-vegetated flows, comparisons between the measured velocity profiles and the ones derived by using the "universal" logarithmic velocity distribution (Nikuradse, 1933), see Eq. 1, allowed estimating the effective surface roughness height of the bed, $K_s$, depending on the hydraulic conditions (see Fig. 2). For hydraulically rough surfaces, velocity profiles are defined as:

$$\frac{u(y)}{U^*} = \frac{1}{\kappa} \ln \left( \frac{y}{K_s} \right) + 8.5$$

By considering linear superposition of the bed-shear stress and the drag exerted by vegetation, the drag coefficients for the tested plants under several flow conditions were calculated.
Table 1. Experimental results for the gravel bed

<table>
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<td>0.08</td>
<td>10.4</td>
<td>2.5</td>
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Figure 2. Measured and estimated vertical flow velocities for the non-vegetated gravel bed (Q=19.7 l/s and S=0.001 m/m)

Conclusions

The same effects of the selected vegetation were obtained in this laboratory investigation independently of the bed roughness, confirming the applicability of the bed shear stress linear partitioning. Due to the presence of vegetation the near-bed velocity decreases, increasing the global flow resistance and diminishing the bed-shear stress.

Drag coefficients obtained in this experimental work will allow to estimate the effect of the presence of vegetation on large-scale laboratory experiments.

References


Stability of the Merwedes and the effect of the removal of ancient tree trunks

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Introduction
Recently tree trunks have been identified in one of the branches of the Dutch Rhine-Meuse estuary, the Nieuwe Merwede. It is not clear what bed level changes will occur if for maintenance reasons the tree trunks will be removed. To investigate this, not only knowledge about the flow velocities, bed composition and erosion processes are relevant, but also the history of the area as reflected in river bed and the composition of the subsoil. The Rhine-Meuse estuary is characterized by a heterogeneous substratum in which poorly erodible peat and clay layers alternate with highly erodible sand layers (Sloff et al., 2013). If thin layers of clay or peat erode and sand patches are incised, large scours grow that form a potential risk for the stability of nearby structures like dikes and groynes.

This background formed the motivation to study the stability of both the Beneden and Nieuwe Merwede and estimate the risk of damaging or incising the current river bed. For this a multidisciplinary approach was used, in which geology, river morphology and expertise on dike stability and erosion processes in clay and peat were combined.

Project area and history
The Beneden and Nieuwe Merwede connect the Rhine river (via de Boven Merwede) to the Rhine-Meuse Delta. The Beneden Merwede is an old branch, while the Nieuwe Merwede has been constructed between 1850 and 1885 with the first steam-dredging machines available (Lintsen, 1992). The digging traces are still visible in the peat layer of the river bed, as revealed by the multi-beam measurements in Figure 1. Also other historic traces are visible in the river bed, like old meandering creeks and straight lines, which can most likely be attributed to old ditches in the polder from before the Sint Elizabeth Flood of 1421.

Other marks from history are the tree trunks found in the river bed of the Nieuwe Merwede. In spring 2011 the contractor removed 32 tree trunks. Judged by their size these are probably oaks or beeches, which have been conserved in the peat for maybe even thousands of years.

Subsurface structure
The method for the reconstruction of the subsurface structure has been comparable to previous studies on the Lek, Spui, Oude Maas and Noord (Sloff et al., 2011, Stouthamer et al., 2011). The primary data were the borings from the Dino-database (TNO). Among other data also multi-beam surveys and additional geological data like a map of the channel belts were used (Berendsen and Stouthamer, 2001; Cohen et al., 2012). Channel belts are subsurface sand bodies which have been formed by river deposits. As rivers change their course, their deposits remain. Over thousands of years a complex structure of channel belts has originated.

Figure 2 gives an impression of the lithology of the substratum of parts of both Merwedes. In the Nieuwe Merwede lithology sand patches are visible which represent channel belts. At these locations the bed level is often deeper as the sand is surrounded by the poorly erodible clay and peat layers. This shows how the channel belt maps can help to understand the river morphology and how vice versa the exact locations of the channel belts can be optimized based on multi-beam surveys. The Nieuwe Merwede is furthermore largely characterized by thick layers of peat and clay.

As the Beneden Merwede is a much older river, its subsurface is largely composed of sand and contains generally thinner layers of peat and clay. The groynes in the upstream part of the Beneden Merwede cause scours in the river bed that often incise the Pleistocene sand.
General stability Merwedes
Biannual multi-beam surveys reveal that the sandy river bed of the Beneden Merwede is very active. Dunes migrate and scours near groynes breathe. The general erosion and sedimentation behaviour can be related to the river discharge. Over 10 scours eroded more than 1 meter in 3 years. One eroded nearly 5 meters in the winter of 2011. This sudden erosion is most likely caused by incising the Pleistocene sand, increasing the risk on riverbank instability.

The river bed of the Nieuwe Merwede is much less active, as it is mainly composed of clay and peat. Few scours located in sandy layers have deepened over time, of which one most likely also recently incised the Pleistocene sand. Two other may in the near future.

Effect of removing tree trunks
Erosion processes generally depend on the flow velocity and the water depth. Under the current circumstances it can be concluded that the erodibility of the peat layers in the Nieuwe Merwede is low, as historic traces are still visible in the bed topography. When peat or clay layers get damaged, the erodibility increases. The organic structure in the peat keeps it together and damaging this leads to bulk erosion. Also in clay bulk erosion may occur after damaging.

Multi-beam measurements from one year after the removal of the 32 tree trunks were compared to measurements from just before. No indication of progressive erosion could be found.

The chance that the removal of the remaining tree trunks will lead to progressive erosion under current circumstances is considered low. The trunks are located in the peat layer and despite the fact that the peat will show bulk erosion after removal, it is not sure that progressive erosion will occur, as this did not seem to happen for the 32 trunks removed. Even if the peat would continue to erode, these layers are always followed by a thick layer of poorly erodible clay (see Figure 2), which will slow down or even stop the erosion.

Conclusions
The subsoil structure of both Merwedes as well as their morphology, are very different. This can be explained by their genesis. The peat layers in the Nieuwe Merwede river bed furthermore contain historic traces from its construction in the 19th century and before.

The stability of both branches was judged based on the reconstructed subsoil lithology and the multi-beam surveys. In both branches scours have been observed which seem to have recently incised the Pleistocene sand. These form a potential risk for the nearby banks or dikes.

The chance on progressive erosion as a result of removing tree trunks is considered low for two reasons. First, the tree trunks are located in the peat layer, which is always succeeded by meters of poorly erodible clay. Second, no evidence of progressive erosion in the peat has been observed in the multi-beam data after the removal of 32 tree trunks.

Acknowledgements
This project was funded by Rijkswaterstaat. We would like to acknowledge Ary van Spijk and Arjan Sieben from Rijkswaterstaat for their valuable input and Walther van Kesteren and Jan Blinde from Deltares for the expertise on erosion processes in peat and clay and dike stability.

References
Turbulent sediment fluxes along migrating sand dunes

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Introduction
Dunes are the most common bed forms in lowland river channels consisting of sand and gravel, generated by divergences and convergences of sediment over the bed. They act as roughness to the flow leading to increasing water levels. To be able to model dune evolution and dune dimensions adequately, knowledge on flow and sediment transport processes are crucial. Despite the dominance of suspended load in sand bed rivers (Kostaschuk et al., 2009), it is often assumed that bed load is the dominant transport mechanism in generating and migrating dunes. Suspended load is then neglected in modelling dune morphology and evolution for flood management purposes (Jerolmack et al., 2005; Paarlberg et al., 2009). However, several theoretical as well as field studies have shown significant difference in dune mechanisms under bed load and suspended load dominant transport regimes (Best, 2005). Our aim in this study is to understand and quantify the sediment transport distribution along equilibrium sand dunes (Figure 1). In particular, we are interested in the contribution of turbulent sediment fluxes to the total sediment fluxes.

Flume experiments
For a better understanding of flow and sediment dynamics above dunes, to-date velocity and concentration measurements above mobile and immobile dune beds were collected using separate acoustic and or optical measuring systems (Nelson et al. 1993; Venditti and Bennett, 2000; Kostaschuk et al. 2004; McLean et al. 2008; Wren and Kuhnle, 2008), resulting in a limited investigation of sediment fluxes to large scale processes. In particular, turbulence processes e.g. turbulent bursts and turbulence generation in the dune flow separation zones, which are the most important mechanisms of sediment entrainment, could not be directly addressed for flow scales smaller than the separation distance between different instruments.
**Preliminary results**
Our measurements showed that, over the stoss side of the dune and in the bed load layer, the turbulent mean streamwise flux is negative and reaches up to 40% of the total mean streamwise flux. Over the lee side of the dune, where turbulent intensities are highest, the contribution of turbulent fluxes to the total fluxes is larger and reaches up to 50%.

**Future work & Acknowledgements**
Further research will focus on the quantification of bed and suspended load along dunes under different flow conditions. Other important direction for future research is linking the results of this study to complex numerical models that describe the turbulent flow and sediment concentration above dunes (e.g., Nabi et al., 2013).

This study is part of the project named ‘Bed-FormFlood’, supported by the Dutch Technology Foundation STW, the applied science division of NWO and the technology program of the Ministry of Economic Affairs. The ACVP development by CNRS-LEGI (D. Hurther) is funded by the European FP7 project Hydralab IV-Water Interface with Sediments (contract no. 261520).

**References**
Flow in a sharp river bend with a strong increase in cross-sectional area

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Introduction

Horizontal flow recirculation is often observed in sharp river bends, causing a complex three-dimensional flow structure with large implication for the morphological and planimetric development of meanders. Several field observations in small-scale systems show that sharp bends are often found in association with a strong increase in cross-sectional area, the deposition of outer bank benches and reattachment bars near the inner bank. Recent studies show that these bends can also occur in large scale systems. In this study, we present field measurements of a sharp bend in the Mahakam River, East Kalimantan, Indonesia. We analyse the data in combination with results from a computational model.

Method

The flow data were collected using a 1200 kHz acoustic Doppler current profiler (ADCP) mounted on a vessel looking downward into the flow. The vessel sailed a track along seven cross-sections each of which was navigated 16 times (Figure 1). During the survey the water level remained constant with an average discharge of about 1700 m³/s. Bed samples taken in the bend were mostly composed of fine sands. In the deep scour some samples were taken containing mostly clay. There was not enough material in these samples to perform a grain size analysis.

The collected ADCP data were processed with a method that allows to reduce the extent of the homogeneity assumption (Vermeulen et al. 2014b). This assumption is needed when combining the raw radial components of velocity collected by an ADCP. Conventional processing combines raw components that are collected at the same moment, but at a large distance. The method used in this study combines raw components collected in a predefined cell. This reduces the volume in which the flow is considered homogeneous from the distance between the beams to the size of a cell (Vermeulen et al. 2014b).

The flow in the sharp bend was simulated using a finite element model (Labeur & Wells 2007), which combines the upwinding possibilities of discontinuous Galerkin methods while preserving the low number of degrees of freedom typical of a continuous Galerkin approach (Labeur & Wells 2007). The model is three-dimensional and can handle non-hydrostatic pressure distribution. It has a moving surface boundary that allows solving the free water surface (Labeur & Wells 2009). Large eddy simulation was used as the turbulence closure scheme.

Results

Depth averaged flow

The depth averaged flow pattern is dominated by horizontal recirculation near the scour (Figure 1).
\[
\frac{\partial z_s}{\partial s} = -C_f Fr^2 + \alpha_s Fr^2 \frac{\partial}{\partial s} \left( \frac{u}{R} \right) n
\]  
(1)

The first term on the right hand side represents the longitudinal slope due to friction and the second term represents the longitudinal slope induced by curvature changes. Since the present bend features a dramatic increase in cross-sectional area we add a new term to Eq. 1 that accounts for this when approximating the water surface elevation:

\[
\frac{\partial z_s}{\partial s} = -C_f Fr^2 + \alpha_s Fr^2 \frac{\partial}{\partial s} \left( \frac{u}{R} \right) n + \frac{Fr^2}{u} \frac{\partial A}{\partial s}
\]  
(2)

The water surface predict by this equation is comparable to the water surface resulting from the numerical simulation (Figure 2).

Figure 2. Water surface elevation computed from Eq. 2

Three dimensional flow

The three dimensional flow is mainly characterized by strong downflow near the scour. Here the measured vertical flow reaches 12 cm/s. At the scour the pressure distribution computed by the model deviates from a hydrostatic pressure distribution (Figure 3). The magnitude of this deviation is in the order of pressure differences induced by water surface elevation.

Conclusions

In this study we analyse the flow patterns of a sharply curved bend in the Mahakam River. The bend is characterized by an increase in cross-sectional just before the bend apex, where the depth reaches three times the average depth. The increase in cross-sectional area is shown to play a crucial role in generating an adverse surface gradient, a necessary condition for the formation of flow recirculation.

A strong downflow develops near the scour that reaches 12 cm/s. This strong secondary flow distorts the vertical pressure distribution that is no longer hydrostatic. The vertical flow also advects longitudinal moment moving the core of the flow to the bed of the channel, which is expected to locally increase the bed shear stress. This increase in bed shear stress could be one of the mechanisms that helps maintaining the deep scours found along the lower parts of the Mahakam River (Vermeulen et al. 2014a).

References


Ellipticity in modelling mixed sediment river morphodynamics

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Introduction
Mathematical models are increasing in popularity for predicting morphodynamic changes in rivers. In such models, natural processes are represented through a set of equations. When dealing with more than one grain size, the morphodynamics of a river is mainly represented by the mass and momentum conservation principle for water (i.e. the Saint-Venant equations), the mass conservation equation for sediment (Exner, 1921), and the active layer equation for mass conservation per grain size (Hirano, 1971).

Rivers convey information about hydrodynamic and morphodynamic changes at various speeds in the upstream and downstream direction. The effect of a flood or a hump in the bed will take some time until it is felt downstream and upstream from the disturbance. This poses some requirement on the mathematical model which describes the propagation of waves along a river. Over short time scales, we require that these speeds are real and finite, namely that the model is hyperbolic.

A shortcoming of the Saint-Venant-Exner-Hirano model is that the characteristic speeds may become complex when the bed degrades into a finer substrate. This is called elliptic behaviour. An elliptic model requires boundary conditions also in time from future to past, thus being inadequate for morphodynamic predictions.

When solving an elliptic problem with a numerical scheme developed for morphodynamic predictions, these mathematical and conceptual drawbacks also pose a problem in the solution. As Figure 1 shows, non-physical oscillations can be found in the profiles (Ribberink, 1987; Sieben, 1997). These instabilities do not relate with numerical artefacts but to inadequacies of the underlying mathematical equations.

Ellipticity tool
We have implemented a tool that enables us to detect if the system of equations turns out to be elliptic. This tool is based on the matrix approach of Stecca et al. (2014). First, specific information at a node of the fluvial reach concerning one time step needs to be provided. This information consist of flow velocity, flow depth, friction coefficient, active layer thickness, and the volume fraction of each grain size at the active layer, as well at the interface between the active layer and the substrate. Second, the system matrix of Stecca et al. (2014) is built with this data. Thirdly, the eigenvalues of the matrix are computed.

In a hyperbolic problem, the eigenvalues of the system matrix yield the above mentioned celerities at which the information is transmitted along the domain. If one of the eigenvalues of the matrix has an imaginary part different than zero, the system of equations is locally elliptic.

Figure 1. Average bed elevation over time at x=20m in Ribberink's computations resembling E8-E9 experiment (Ribberink, 1987). p represents the volume fraction content of the fine size fraction in the substrate.

Methodology
The numerical model of Viparelli et al. (2014) is used to reproduce a degrading bed into a finer substrate under sediment feed conditions. The fluvial reach is of typical flume dimensions (2 m long and 0.4 m wide), and the feed rate is set to 280 g/min. Degradation is imposed by means of a fixed downstream hydraulic boundary condition that initially creates a depth shallower than the normal depth. Worded differently, an M2 backwater curve is imposed. This causes degradation until normal conditions are reached. The sediment fed upstream consists of 60% of a 1.0 mm size fraction, 30% of a 2.1 mm one, and 10% of a 3.9 mm size fraction. The parent material has the same grain size distribution as the fed sediment.

The results show oscillations and the ellipticity tool is applied in order to verify whether the origin of these instabilities is the ellipticity of the system of equations.
Results
Figure 2 shows an ellipticity map of the simulation. For every time step (y axes), a black dot is plotted at the streamwise coordinates (x axes) in which the system is elliptic. At the start, oscillations appear upstream during the formation of a mobile armor layer and this characteristic travels downstream until the active layer is coarse enough everywhere along the fluvial reach (t=15 min). The degradation then diminishes but it does not stop until normal flow conditions are achieved everywhere (t=30 min). Ellipticity is found also in this second period.

Figure 2. Ellipticity map. A black dot represent a time step and x-coordinate at which the equations are elliptic. The red ones are the ones also represented in Figure 3.

The situation of the fluvial reach at one particular time step (t=6 min) is plotted in Figure 3. Note how a peak in sediment transport is found at the same place as a sudden increase in velocity and decrease in friction coefficient, the latter of which is related to a characteristic grain size. The tool proves that at these instable nodes the system is elliptic. This particular time step is also plotted in red in Figure 2.

Conclusion & Future work
Our ellipticity tool provides a method to analyse whether oscillations found in a numerical simulation of a fluvial reach are due to ellipticity of the system of equations.

Further research will focus on a method for identifying ellipticity from the symptoms of model results and the application of this tool to several other models.

References

Figure 3. Fluvial reach variables after 6 minutes of simulation. Black dots in the x axes highlight the nodes in which the system is elliptic.
Natural and artificial constraints in braided rivers

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Introduction
Braided rivers are regarded as highly dynamic with large annual bed level changes, and large shifting of bars and channels. Large braided rivers are vital elements in many densely populated areas in the world, but also cause social problems with their morphodynamics, for example bank erosion and alteration of navigation channels. The morphodynamics are affected and reduced by both natural and artificial constrains, such as discharge regulation by upstream hydropower dams, and channel confinement by river training or rock outcrops. At the same time, interferences within the river channel, such as sand mining, bar protection works and small-scale dams, contribute to the complexity of the morphodynamics. This combination of natural complexity and artificial interferences makes it very difficult to control large braided rivers and to predict the effects of river training works in these rivers.

In this study, we investigated the morphodynamic effects of river measures and other human interferences in large braided rivers. We used numerical modelling to systematically make ‘datasets’ of braided rivers with different kinds and degrees of river measures and interferences.

Method
We used Delft3D with simple initial and boundary conditions, similar to Schuurman et al. (2013, 2014). The settings were based on a large sand-bed braided river that shares many properties of the Brahmaputra River. The hydrodynamics were solved in 3D, and we applied Engelund-Hansen for sediment transport. An overview of the model runs is given in Table 1.

<table>
<thead>
<tr>
<th>Run</th>
<th>Initial bars</th>
<th>Extra</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>No</td>
<td>Floodplain</td>
</tr>
<tr>
<td>3</td>
<td>No</td>
<td>Hydrograph</td>
</tr>
<tr>
<td>4</td>
<td>No</td>
<td>Floodplain + hydrograph</td>
</tr>
<tr>
<td>5</td>
<td>Yes</td>
<td>Sand mining</td>
</tr>
<tr>
<td>6</td>
<td>Yes</td>
<td>Bar protection</td>
</tr>
<tr>
<td>7</td>
<td>Yes</td>
<td>Branch closure</td>
</tr>
</tbody>
</table>

By default, a confined channel of 3.2 km width and constant discharge of 40,000 m³/s (which is around the dominant discharge of the Brahmaputra) were applied. In runs 1-4, we applied an initial flat bed, while initial droplet-shaped bars were applied in runs 5-8. The river measures of runs 6-8 are illustrated in Fig. 1.

Figure 1. River measures in initial bed of runs 5-8: A) branch closure; B) bar protection; C) bar removal by sand mining. Flow is from left to right.

Figure 2. Modelled bed level in Run 2 after 1 year (up) and Run 5 after 9 months with mid-channel bars and multiple channel branches. Flow is from left to right.

Examples of the resulting bed morphology are given in Fig. 2

Channel confinement
The difference in morphological parameters between Run 1 and Run 2 is relatively small (Fig. 3). This implies that, using a simple bank erosion rule, the effect of erodible floodplain on the scale of a couple of years is small in this river. In should be noted, however, that the river has no intention to meander, bank erosion rates are small and the confined channel has a uniform width.

Discharge regulation
The modelling showed that a realistic hydrograph gives more or less the same morphology as a constant dominant discharge. For example, the Braiding Index is similar after a couple of years, although the BI and active channel widths vary in runs 3 and 4 because of seasonal water level variation (Fig. 3). The bar heights in runs 3 and 4 after 3 years are similar to runs 1 and 2 after 1 year.
Sand mining
The simulations show that after removal of a complete sand bar, a new bar emerges at the empty spot (Fig. 4). The bar is shorter than the original bar, but the width is similar. Despite the formation of a new bar, the sand mining affected the morphodynamics downstream of the removed bar. The gap attracted flow, resulting in enhanced channelization. Upstream of the location, the sand mining had no significant effect on the morphology.

Bar protection
Protection of a bar against erosion, thus fixation of the upstream bar edge, resulted in erosion of the downstream part of the bar (Fig. 5). This was caused by a lack of sediment supply from erosion at the upstream bar part. This shows that sediment used for bar migration and bar expansion is largely from the upstream bar part. Upstream of the bar, the morphology was hardly affected by the bar protection.

Branch closure
Closure of one of the branches by a dam, for example a hydropower dam, has a significant effect on the morphodynamics downstream of the bar (Fig. 5). Upstream of the bar, the effect is relatively small. As the dam was connected to erodible bars, major outflanking occurred on both sides of the dam. Furthermore, the simulation shows that the dam, originally in a branch, ended in the middle of a large bar/island, making the dam useless.

Conclusions
Our simulations indicate that discharge variation and non-erodible banks have relatively small effect on the morphology in a sand-bed braided river. However, interferences within the channel, for example dams, sand mining or other river training works, have a relatively large effect on the morphology downstream. Adjustments of flow directions and faster channelization cause the downstream propagation of the morphological effects. Upstream of the measure, the morphological effects are relatively small.

The simulations provide examples of how we can systematically test the effects of different measures and conditions in large braided rivers. They are supplementary to field and flume data.

References
Migration of banks along the Kapuas River, West Kalimantan, Indonesia

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Introduction

The Kapuas River (East Kalimantan, Indonesia) is the world’s longest river on an island, stretching over more than 1100 km in a relatively pristine region dominated by lowland forest and peatlands (Figure 1). The Kapuas River flows through different geological units and features complex hydrological links with the adjacent peat bogs and inland wetlands. This study aims to quantify bank migration in two main reaches with optical satellite images, relating these results with the surrounding vegetation cover and hydrological conditions.

Methods

The river bank lines are extracted from the Landsat images of 1973, 1990, 2000 and 2013. Change in delineation is used to identify erosive, aggrading and stable banks over these 40 years. Bank types are validated with an in-situ stream reconnaissance. Riverbanks were systematically described in the field and classified as erosive, aggrading and stable. Locations of point bars, embayments and bank protection were also described (Thorne, 1998; Van Berkum, 2012). The bank migration is furthermore compared with vegetation types using NDVI and flood occurrence. The NDVI gives a ratio between the green reflectance and the entire reflection. This is related to the vegetation classes, like trees, shrubs and grass. The reflectance of open water and water under vegetation is used to construct the flood occurrence using PULSAR images.

Results

The bank migration of the downstream area is predominantly in one bend (see Figure 2). The figure shows small changes along the banks of the river, these changes are most likely not bank migrations as such. These can be an effect of water level fluctuations due to tides and seasonal fluctuations in rainfall and river discharges.

In the past 40 years, bends were highly dynamic in the upstream area whereas in the downstream area migration was limited (see Figure 3). The Landsat-based classification agreed well with the classification from the stream reconnaissance.

Table 1 shows the difference in migration between up- and downstream area and of the entire Kapuas River from sea to 900 km upstream. Huisman (2014) and Hossain (2014) show that the difference between up- and downstream migration cannot be explained by the river gradient (see Figure 4). The river gradient of the dynamic area between A and B is comparable with the river gradient between D and E, which is stable.
Table 1. River migration of the Kapuas River from 1973 to 2013 (Huisman, 2014).

<table>
<thead>
<tr>
<th>Area</th>
<th>Validated river length (km)</th>
<th>Migration (m/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>105</td>
<td>1.8</td>
</tr>
<tr>
<td>Downstream</td>
<td>161</td>
<td>0.9</td>
</tr>
<tr>
<td>KapuasRiver</td>
<td>900</td>
<td>1.0</td>
</tr>
</tbody>
</table>

The NDVI values are higher near the river (see Figure 5), this indicates the presence of shrubs instead of tropical trees. The smaller vegetation type near the river bank can enhance the migration. River migration can also be enhanced by the high occurrence of flooding. This can also cause shrubs to grow near the river. (see Figure 6). Further research is necessary to understand the influence of vegetation type and flood occurrence on bank migration.

Figure 4. The river gradient from the upstream area from A to C and the downstream area from E to F. (Hossain, 2014)

The NDVI values are higher near the river (see Figure 5), this indicates the presence of shrubs instead of tropical trees. The smaller vegetation type near the river bank can enhance the migration. River migration can also be enhanced by the high occurrence of flooding. This can also cause shrubs to grow near the river. (see Figure 6). Further research is necessary to understand the influence of vegetation type and flood occurrence on bank migration.

Figure 5. NDVI values for the upstream area. (Hossain, 2014)

Figure 6. The occurrence of floods under vegetation in the upstream area (Hossain, 2014)

Conclusions
- The water level changes affect the river delineation.
- The indication of the banks from the satellite images agrees well with the classification of the stream reconnaissance.
- Over the past 40 years, the Kapuas River strongly migrated in the upstream area, while it was nearly frozen in the downstream area.
- The river gradient cannot explain the strong differences in bank migration between the upstream and downstream areas.
- Higher NDVI values and frequent floods are found in the upstream area of the Kapuas River.

Acknowledgements
This study is part of the SPIN joint research project, supported by Koninklijke Nederlandse Academie van Wetenschappen (KNAW).

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Effects of variable discharge on the river channel width variation

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Introduction

Many factors control the fluvial channel morphology (Leopold et al., 1995) such as flow regime, sediment supply and transport, as well as riparian vegetation (Baptist, 2005). Alluvial rivers are characterized by having wide ranges of discharges that are able to erode bed and banks, affecting the fluvial morphology in different ways (Lane et al., 1996). However, a constant discharge is used to represent the variable river flow in most applications. In morphodynamic studies, it might be unrealistic to assume that a single value of the discharge can reproduce the effects of the full river flow regime. Similarly, sediment is often characterized by its median diameter, while sediment gradation and sorting might have remarkable effects on river channel dynamics. This work is based on flume laboratory experiments in which the effects of flow variability as well as the effects of sediment gradation on channel dynamics are investigated. Constant and variable discharges with different high and low flow frequencies and intensities were considered. The results clearly show that there are differences in cross-sectional dynamics caused by formative discharges with respect to bankful discharges. Moreover, variable discharges have different effects from these two steady flows. In general, well sorted sediment results in relatively larger channels.

Materials and methods

Experiments were carried out in a small flume (2.20m x 1.25m) with erodible bed and banks. For all the tests, the flow conditions were maintained subcritical. Four sets of experiments were characterised by the same number of sand mixtures in the absence of vegetation. Samples 1 and 2 are well sorted and uniform while Samples 3 and 4 are poorly sorted and poorly graded (see Table 1).

<table>
<thead>
<tr>
<th>Sample</th>
<th>D₅₀ (mm)</th>
<th>stdv (Sample sizes)</th>
<th>Uniformity index (cu)</th>
<th>Sorting index (I)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.26</td>
<td>0.15</td>
<td>1.56</td>
<td>1.34</td>
</tr>
<tr>
<td>2</td>
<td>0.50</td>
<td>0.24</td>
<td>1.56</td>
<td>1.23</td>
</tr>
<tr>
<td>3</td>
<td>0.40</td>
<td>2.86</td>
<td>2.25</td>
<td>1.80</td>
</tr>
<tr>
<td>4</td>
<td>0.70</td>
<td>0.63</td>
<td>3.16</td>
<td>2.16</td>
</tr>
</tbody>
</table>

Table 1. Sediment properties

Each set of experiments started by allowing a formative constant flow, Qᵢ, of 0.093 l/s to form a channel from an initially excavated straight channel (3 cm wide and 2 cm deep). Once the equilibrium width, bₑ, is reached, the discharge is increased until it reaches the bankfull condition, Qᵥ. The channel is then allowed to adjust to the new constant discharge until it reaches a constant width, bₐ. In other tests, starting from the same equilibrium width, bₑ, different flow regimes were imposed for all the considered sediment samples. These regimes are characterised by having the same mean discharge, the bankfull discharge, but different high and low flow magnitudes and frequencies. Hydrographs 1 and 2 have a maximum discharge, Qₘₓ, of 1.5Qᵥ and a minimum discharge, Qₘᵦ, of 0.5Qᵥ, with frequencies of 10 and 20 minutes, respectively. Hydrograph 3 has the same magnitudes than the previous ones, but the durations of maximum and minimum discharge are 10 and 30 minutes, respectively. Hydrographs 4 and 5 have the same frequencies than hydrographs 1 and 2 (10 and 20 minutes, respectively), but the magnitudes of maximum and minimum discharges were closer to the average (1.2Qᵥ and 0.8Qᵥ, respectively). This experimental design implies that each sediment has its own bankfull discharge and corresponding regimes, see for instance in Fig. 1 the conditions for sample 4.

Results

Effect of sediment on channel planform

The production of braided rivers is relatively simple in the laboratory. However, meandering channels were mostly difficult to be produced without using cohesive materials for strengthening the floodplains. In Fig. 2 the combined effects of sediment sorting and grain sizes are shown. In general, poorly sorted sand results in smaller channels at equilibrium and coarser grain sizes showed higher stability of the channel banks. Our experimental finds show that the composition of a sediment mixture is essential for the creation of sinuous single-thread channels. Fine sand (Sample 1) resulted in ripples and scour holes in the channel bed, whereas poorly sorted sand (Sample 4), variable discharge and an initial perturbation, produced a sinuous single-thread channel. This comparison is shown in Fig. 3.
Effects of variable discharge

In Fig. 4 the channel-width variation in time for the considered hydrographs and samples is shown. According to our observations, bank erosion processes are very sensitive to flow variation and sequencing. At the laboratory scale; poorly sorted sand (samples 3 and 4) produced more stable banks regardless the median grain size (see Fig. 2 and Table 1). Additionally, both magnitude and duration of high flows have effects on channel formation. Moreover, high-flow duration exhibited higher influence than their magnitude.

References

Sediment supply from the German hinterland towards the Dutch Rhine delta: past and present

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Introduction
The transfer of sediment by rivers from the hinterland to coastal zones and oceans is a major pathway for material transfer on Earth (Walling, 2006). Although soil erosion rates are increasing globally due to land clearance for agriculture, the sediment transfer to the coastal zone often decreases due to the construction of dams (Syvitski, 2003), leading to erosion of coasts and deltaic river channels. Almost all studies of land-coast sediment fluxes focus on silt and clay sized particles, which are better preserved in the geological record and more easily measured in today’s rivers than coarser particles. As a result, little is known on the transfer of sand and gravel from the hinterland to river deltas and the sea, and the human impact thereon.

The objective of the present study was to determine the human impact on the fluxes of sand and gravel from the German hinterland towards the Dutch Rhine delta. This was done by combining quaternary-geologic data and field measurements of sediment transport with a thorough analysis of human impacts.

Methods
First, we estimated the transfer of sand and gravel to the Rhine delta during the Holocene using Quaternary-geologic data. Because the Rhine delta is known to have been a near-complete sediment trap for Rhine sediments during the Holocene (Beets and Van der Spek, 2000), the Holocene transfer of bed material towards the delta must equal the total Holocene accumulation of sand and gravel in the Rhine delta. After division by the duration of deposition (Gouw and Erkens, 2007), the average transfer of sand and gravel from the hinterland to the Rhine delta was found.

Second, we quantified the present-day fluxes of sand and gravel from the source of the Rhine in the Swiss Alps towards the onset of the Rhine delta near the German-Dutch Border by analysing thousands of bed-load and suspended-load measure-ments from the Period 1991-2010. In order to quantify the sources and sinks of this sediment, we carried out a sediment budget analysis incorporating the effects of upstream supply, bed level changes, tributaries, abrasion, floodplain deposition, dredging/supply and groyne field deposition.

Results
Glaciers, mass movements and soil erosion in the Alps carry vast loads of sand and gravel into the Rhine. These sediments are nearly completely trapped by Lake Constance, causing the Rhine downstream of Lake Constance to be almost void of sediments. In the following 335 km long river section up to the village of Iffezheim, the Rhine is impounded by dams. Although gravel is transported locally, there is no continuous transport of gravel through the impounded section. Sand fluxes are intercepted by the dams too, but during floods nevertheless 0.1 Mt/a of sand are able to pass the impounded section. Downstream of the last dam, 0.3 Mt/a gravel and sand are artificially fed to the river to reduce bed degradation. Over the next 530 km, up to the beginning of the Rhine delta, artificial gravel feeding and bed erosion represent the major sources of gravel and sand for the Rhine. At the same time, sand is lost to the floodplains, whereas gravel is deposited in river sections with a decreasing slope. Tributaries, abrasion and dredging represent minor sources and sinks of sediment.

The present transfer of sand and gravel from the German hinterland towards the Rhine delta equals 0.7 Mt/a ± 26%. This rate does not differ significantly from the pre-human Holocene rate of sediment transfer to the Rhine delta, which was found to be 0.9 Mt/a ± 20%. This notwithstanding, the character of the sediment supply towards the Rhine delta strongly changed over time. Presently, the sand and gravel load contains about 16% of gravel, whereas in the pre-human situation, gravel was almost absent. At the same time, the travel velocity of individual sand and gravel particles has strongly increased, from about 0.01 km/a to 7 km/a.

Discussion
The preceding section shows that the rate of transfer of bed-material (sand, gravel) from the hinterland to the Rhine delta did not change.
significantly over time, which is a remarkable conclusion, because the Rhine has been subject to strong human impact for more than 1,000 years. Many of the river training works that have been carried out (embankment, river straight-tening, river narrowing) as well as the intense dredging activities are known to have increased the bed shear stress of the river (Frings et al., 2009; Frings et al., 2014a,b), which might be expected to lead to an increased transfer of sediment to the Rhine delta. This did not occur, because the increased bed shear stress caused winnowing of sand from the river bed, leaving the coarser gravel grains behind. Together with the artificial feeding of gravel, this increased the bed grain size of the Rhine, leading to an increase in the critical bed-shear stress for incipient motion. Apparently, the increase of bed shear stress was counteracted by the increased critical shear stress, leaving the overall sediment transfer to the Dutch Rhine Delta about the same.

The fact that the sediment supply towards the Rhine delta presently contains much more gravel than in the pre-human situation must be ascribed to the aforementioned winnowing process.

The increase in travel velocity of individual sand and gravel particles is a consequence of the bank protection works of the 18th and 19th century. The natural Rhine River exhibited considerable lateral migration of meander bends, eroding bed material along concave meander banks and depositing sediment along adjacent downstream bars, resulting in lateral accretion of the convex point bars. Sand and gravel from upstream sources therefore were not simply transferred to the Rhine delta but were stored intermittently below floodplains. Because of the bank protection works, the process of intermittent sediment storage ceased, thereby strongly increasing the travel velocity of sand and gravel towards the delta.

Conclusions
Although human activity did not significantly change the overall rate of gravel and sand transfer from the German hinterland towards the Rhine delta, it strongly changed the character of the transfer: the travel velocity of the individual sand and gravel particles increased due to the prohibition of meander migration by bank protection, whereas the grain size of the sand and gravel load increased due to the effects of embankment, meander cut-offs, river narrowing, barrages and sediment mining.

References
3 – Presentations day 2
The calibration of a hydrodynamic model based on floodplain roughness

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Introduction
The hydrodynamic model of the Dutch Rhine River is currently calibrated by adjusting the main channel roughness. The roughness is calibrated between two water level measuring stations which can result in large discontinuities in the main channel roughness over the river. This makes the model unusable for morphological computations. Moreover, the calibration method results in unrealistic roughness values which causes an uncertainty in the design water levels. A different calibration method is proposed here. The floodplain roughness is adjusted during the calibration instead of the main channel roughness. This prevents large discontinuities in the main channel roughness and gives insight into the sensitivity of the calibration method when the model is used outside the calibrated range.

Method
The computation of the design water levels in the Rhine branches is done with a WAQUA-model. The WAQUA-model is used for 2D hydrodynamic calculations during flood conditions. The model is calibrated between two measuring stations and between those stations the main channel roughness is constant. The floodplain is divided in different ecotopes and each ecotope corresponds to a roughness value.

The model is calibrated using OpenDA (see www.openda.org). The model is calibrated using the peak of the 1995 flood (Becker, 2012); the same calibration conditions were used in this study. To be able to calibrate based on the floodplain roughness, an estimation of the main channel roughness has to be made. WAQUA uses the following formulation for the main channel roughness:

\[ k = Ah^{0.7}(1 - e^{-Bh^{0.3}}) \]

(1)

with \( A \) [\( m^{0.3} \)] is the main calibration parameter, \( B \) [\( m^{0.3} \)] is assumed to be 2.5 \( m^{0.3} \), \( k \) [\( m \)] is the roughness height and \( h \) [\( m \)] is the water depth.

Two experiments are set up which use different estimations for the main channel roughness:
1. The previously calibrated main channel roughness with a variation of ±20%.
2. Averaged calibration parameter in the main channel for each river branch with a variation of ±20%. The averaged \( A \) is calculated for each branch based on the roughness height predictor by Van Rijn (1984).

After calibration, each of these models was tested with design flood conditions in the Rhine. These conditions are discharges at Lobith of 13,000 \( m^3/s \), 16,000 \( m^3/s \) and 18,000 \( m^3/s \).

Results
The first experiment shows that the model is successfully calibrated using floodplain roughness with the same calibration quality as the calibration based on main channel roughness. The calibration quality of the second experiment is slightly lower. This is caused by the rough estimation of the main channel roughness in the second experiment. The calibration in the downstream part of the Nederrijn/Lek is difficult due to the relatively small floodplain. A second problem occurs between the upstream and downstream measuring stations of the barriers in the Nederrijn/Lek where the distance between the measuring stations is very small and the floodplain roughness does not have a large influence on the water level.

The calibrated models are used to calculate the water levels during design flood conditions. The results are described in the following two sections.

Exp. 1
Figs. 1 and 2 show the water level differences between the new and the old calibration methods. The figures show that locally the water level difference is in the order of 20 cm when the main channel roughness is varied between ±20%. From the results we can conclude that if the main channel roughness decreases, the average design water level increases because of the increase of the floodplain roughness. The largest variations occur upstream of Lobith and around the Pannerdensche Kop.

Exp. 2
The second experiment shows much more variation of the floodplain roughness and the water level difference due to the averaged
calibration parameter. Figs. 3 and 4 show the water level differences between experiment 2 and the original calibration. At some locations the water level difference is more than 30 cm. The largest differences are again at Lobith but also at the downstream part of each branch are the water level differences significant.

The large water level difference upstream of Lobith is most likely caused by the assumption that this area has the same value for the calibration parameter as the area downstream of Lobith.

**Conclusion**
The results show that it is possible to calibrate the Rhine branches with the floodplain roughness and that the accuracy of the calibration is similar. The calibration with an average calibration parameter over a branch shows a lower quality but is still acceptable.

The calibration method does have large influence on the water level for design flood calculations. From the results of the first experiment, it is concluded that the water level differences are on average in the order of 5 to 10 cm. The second experiment shows that it is possible to use this calibration method for the hydrodynamic calibration of morphodynamic models. Overall, the calibration method is promising and the method should be further investigated on the following points:

- A better estimation of the main channel roughness.
- A different calibration method for areas with relatively small floodplains.

**References**
Hydrodynamic modelling with unstructured grid using D-Flow-FM: case study Afferden-Deest

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Introduction
Accurate predictions of water levels play an important role in the management of flood safety. Nowadays, it has become common practice to use multi-dimensional numerical hydrodynamic models for such purposes. Currently, two model types are the standard tools in the Netherlands, namely WAQUA/TRIWAQ (Rijkswaterstaat, 2012) and Delft3D (Deltares, 2014). WAQUA and Delft3D are both based on a structured curvilinear grid, which can follow large-scale topographical changes and uses similar grid resolution throughout the entire computational domain. Drawbacks of the structured curvilinear grid approach are that elevation jumps in the river’s topography may lead to unrealistic staircase representations in the model, and the inner bends of meandering rivers gridlines may become focussed to unnecessarily small grid cells (Kernkamp et al., 2011). To improve on these issues, Deltares is developing the unstructured-grid-based hydrodynamic model Flexible Mesh (also referred to as “D-Flow-FM”). The unstructured grid approach enables the user to use a spatially variable grid resolution. By combining curvilinear grid cells with triangular grid cells, the modeller can increase grid resolution on the locations where, because of local topographical variations, it is most desired.

In this study, modelling results of Flexible Mesh and WAQUA are presented for a selected river reach near Afferden-Deest and benefits of local grid refinements in Flexible Mesh are demonstrated.

Comparison Flexible Mesh and WAQUA
Besides the advantage of allowing local grid refinements, Flexible Mesh allows the bed level of a grid cell to be diagonal, while in WAQUA the bed level in a grid cell is always horizontal. To compare model results of Flexible Mesh and WAQUA, a schematization of 50 km of the Waal river from the Pannerdense Kop is considered. The Waal schematization is modeled for the high discharge in 1995 (Fig. 1) and for a low discharge in 1994 (Fig. 2). The water levels appear to be higher in Flexible Mesh in the high discharge simulation. The difference between WAQUA and Flexible Mesh is largely caused by a difference in the treatment of energy losses at weirs. In the low discharge simulation, the modeled water levels in Flexible Mesh and WAQUA are closer, because in the low discharge simulation the water is mainly flowing through the main channel of the Waal, where less weirs are effecting the flow.

Grid Refinements
Next, the impact of local grid refinements of the Flexible Mesh model is investigated. The grid is refined at the side channel at Afferden-Deest along the Waal, located between Tiel and Nijmegen. This side-channel is of particular interest, because the scale of the side channel is relatively small compared to the scale of the main channel of the Waal and cannot be...
properly represented by the structured curvilinear grid in WAQUA.

The flexibility of the unstructured grid is used in Flexible Mesh to increase the grid resolution at location of the side channel. Fig. 3 shows the grid refinement at the side channel. Preliminary results show that the refined Flexible Mesh model gives significantly different water levels and a different discharge and flow pattern in the side channel at Afferden-Deest. Fig. 4 shows the discharge for the original grid and the refined grid, with especially large difference during peak discharge in the Waal (difference +30%). These and other results are discussed in the context of Room for the River design studies.

![Figure 3. Grid refinement of side channel Afferden-Deest.](image)

**Acknowledgements**

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**References**


![Figure 4. Discharge in side channel at Afferden and Deest for original and refined grid.](image)
Longitudinal training walls: optimization of channel geometry

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Introduction
Along the well-trained Waal River, Dutch authorities are considering substituting the old groynes with longitudinal training walls (Figure 1, Eerden, 2011). The goal is to obtain an improved navigation channel, while preserving the river conveyance capacity during floods, and improve the river bank natural value.

This intervention will create one or two side channels parallel to the main (navigation) channel and will possibly change the river flow distribution and morphology. Additional investigation is required to assess whether longitudinal training walls are indeed effective in achieving the goals and whether they may also produce some undesirable effects, with particular attention to the long-term developments. If undesirable effects are produced, then the geometrical characteristics of river channel and training walls should be optimized to mitigate impact and reduce maintenance costs.

Figure 1. Longitudinal training wall along the inner bank in the River Rhine at WalsumStapp. Source: Google map.

Goal of the study
The general goal of this study is to define guidelines to optimize the geometry of a river channel with longitudinal walls (Figure 2) to [1] improve navigation, [2] maintain the flood conveyance of the river, [3] improve the bank natural value, and [4] reduce maintenance costs.

The preliminary part of the study analyses the long-term effects of changing the location of the upstream end of a training wall (wall head) if the side channel has a fully open inflow and the initial riverbed topography presents alternate bars or point bars (as most rivers do). In this case, the position of the wall head (in a pool opposite to a bar, at a bar top etc.) might influence the discharge distribution between main and side channel.

Considering that the presence of a single training wall may create flow asymmetry which might lead to undesirable morphological changes, this part of the study includes also investigating the effects of having training walls along both sides of the river.

Approach
The preliminary part of the study includes numerical and experimental investigations, but this paper only describes the first results of the numerical tests.

Based on Crosato-Mosselman’s (2009) formula, a straight river channel with geometrical (width, depth, slope) and morphodynamic (flow and sediment) characteristics leading to the formation of steady alternate bars is obtained using the Delft3D code. This channel is inspired by the Wall River, but does not represent it.

After reaching an equilibrium bed configuration, long training walls are implemented starting at different locations with respect to a selected steady bar (Figure 3).
Preliminary results
The numerical tests show that with a single training wall along one side of the river, the river channel(s) may become unstable. If the training wall starts near the upstream head of the bar (position B in Figure 3), the side channel tends to silt up (Figure 4). Instead, if the training wall starts near the end of the bar (position F), the flow concentrates in the side channel, which then becomes deeper and deeper (Figure 5), whereas the main channel tends to silt up. If the training wall starts near the top of the bar (position D), the channels appear to have a dynamic balance.

The results also show that with training walls along both sides of the river one side channel will be eroded and the other one will silt up (Figures 6 and 7): flow concentration at one side of the river. Starting with a flat bed (all bars dredged before side wall construction) does not change the unstable character of the side channels.

Conclusions
The position of the training wall appears to play an important role for the morphological developments of main river channel and side channels. The results suggest that maintaining the parallel channels open will require either bed armouring or regular dredging. In natural rivers, due to discharge variations steady and point bars change their length, whereas migrating bars displace themselves also with a constant discharge, so controlling the development of bars near the upstream end of the training might become necessary to avoid blockage of the side channel inflow or (opposite case) flow concentration. A solution could be offered by controlling the water and sediment discharge distributions by means of well-designed structures.

This preliminary work will be followed by more numerical tests and an extensive experimental investigation to see whether similar long-term trends can be observed also in the laboratory.

References
Numerical modelling of bow thrusters at quay structures

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Introduction
Bow thrusters are of great help for the navigation at quay walls, but the high and turbulent velocities can result in a bed load exceeding the strength of the bed or bed protection. To be able to design a stable bed the velocities at the bed need to be accurately determined. In design practise the velocities generated by a propeller are determined with formulae based on a mix of the momentum theory and measurements. The application of the formulae is often limited to cases for which measurements have been carried out and do not allow a secure design for more complicated structures and the different velocity field of a bow thruster.

With the use of scale model measurements and the creation of a numerical CFD model in OpenFOAM an improvement to this approach is sought which can be applied to confined jets.

Design practise
Many different approaches have been developed for calculating the velocities by thrusters, but most use the same principles with a change in coefficients. One approach which is deemed to be giving good results by Van Doorn (2012) is the set of formulae referred to as the Dutch Approach (PIANC MarCom, 2013).

By a combination of Albertson’s momentum theory and Bernoulli’s principle the efflux velocities \( U_0 \) induced by the bow thruster are derived with Eq. (1) as a function of the rotation speed \( n \), diameter of the contracted water jet \( D_0 \) and the thrust coefficient \( K_t \) (Blaauw and Van de Kaa, 1978).

\[
U_0 = 1.60 \cdot n \cdot D_0 \cdot \sqrt{K_t}
\]  

(1)

In this same research the unconfined flow field is defined by Eq. (2) in axial direction \( x \) and in radial direction \( r \) to the axis of the propeller. In this formula the three coefficients are derived for the Dutch Approach as \( A = 2.8, a = 1 \) and \( b = 15.4 \).

\[
U(x,r) = A \cdot U_0 \cdot \left( \frac{D_0}{x} \right)^a \cdot \exp \left( -b \cdot \frac{r^2}{x^2} \right)
\]  

(2)

This formula can be rewritten to determine the maximum velocities on the slope, but this will only hold when assuming an unconfined jet. When taking the confinement by piles or by a slope into account, the formula needs to be amplified with a factor \( f \).

Scale model measurements
For the determining of this amplification factor a large number of scale model measurements were done by Van Doorn (2012) for ten different scenarios. The different scenarios were varied in geometry by changing the slope inclination, slope distance, roughness, water depth and pile alignment. The basic model setup used is shown in Fig. 1.

![Figure 1. Scale model setup used by Van Doorn (2012). Shown are the ship with thruster (marked red, diameter of 0.11 m) and a slope with piles.](image)

An amplification factor \( f \) of 1.1 to 1.5 was derived for the different scenarios but on further inspection this conclusion was not deemed to be valid due to a calculation error in the research of Van Doorn. For the corrected results no clear amplification factor to the analytical approach could be found as the data points are results were scattered.

However, the measurements can be used to calibrate a numerical model for a variety of geometries.

Actuator disc approach
In this numerical model the propeller is modelled by simplifying the propeller load to a local disc with forces with an axial and a tangential component (Fig. 2). In contrast to more detailed modelling options this gives good options for calibration at low computational costs.

![Figure 2. Simplification of the propeller to an actuator disc.](image)
The forces are variable over the radius of the propeller. For free propellers this force can be approximated by the Goldstein (1929) optimum which applies the vortex theory for a minimum loss of energy. The formulae were reduced by Hough and Ornday (1964) and Stern et al. (1988) to Eq. (3). It shows the force in axial ($f_x$) and tangential ($f_\theta$) direction for the dimensionless radial distance ($r^* = r/R$) with the hub radius ($R_h$), propeller radius ($R$) and constants $A_x$ and $A_\theta$, which are a function of the thrust and torque of the propeller.

$$f_x = A_x r^* \sqrt{1-r^*}$$

$$f_\theta = A_\theta \frac{r^* \sqrt{1-r^*}}{r^*(1-R_h/R)}$$

Equation (3)

Numerical model implementation

The open source CFD package OpenFOAM is used for the construction of this numerical model. An adjustment is done to locally include the force in the Navier Stokes equations as shown in Eq. (4) for a Newtonian fluid. In this equation the vector $F$ is the total body force consisting of both the axial and tangential forces in a Cartesian vector.

$$\frac{\partial U}{\partial t} + (U \cdot \nabla) U = \nabla (\nu \nabla U) - \frac{1}{\rho} \nabla p + F$$

Equation (4)

The turbulence is modelled using the Reynolds averaged Navier-Stokes (RANS) equations. The realisable $k$-epsilon model is applied as it has good results for swirling flows, flow separation and round jets.

Numerical model results

In the numerical model the calibration is done to the coefficients $A_x$ and $A_\theta$ resulting in an efflux as shown in Fig. 3. It shows that the velocity distribution of the measurement is well approached in both axial (x) and tangential (z) direction. As in radial direction (y) no velocities are expected, these measurements are most likely influenced by circulation.

Figure 3. Efflux velocities in x, y and z direction of measurements and numerical model at x/D=1 from the bow thruster.

Comparing the flow field generated by the bow thruster with both measurements as well as theory (Fig. 4) shows that the numerical has a lower diffusion than the measurements but have equal diffusion as formulated by Blaauw and Van de Kaa (Eq. 2).

Figure 4. Diffusion of the water jet over the distance (x) to the efflux of the bow thruster

When comparing the velocities at a slope (as shown in Fig. 1) to both theory and the scale model measurements. It shows an underestimation of the velocities at the toe for steeper slopes, which is caused by unexpected velocities in the wall boundary layer, as a result of the wall functions in OpenFOAM.

Conclusion

It is concluded that the modelling of a bow thruster as a simplified actuator disc in OpenFOAM gives an accurate model for an unconfined jet. When the water jet is confined the results are less accurate due to the inaccuracies in the wall boundary layer. For gentle slopes the model approximates the maximum velocities reasonably well. At piles the complex flow pattern is not well computed with the RANS model and requires a Large Eddy Simulation turbulence model. This approximates the measured velocities near the bed slope with an error up to 25% to the available measurements.

For further analysis and conclusions reference is made to De Jong (2014).

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Correlation impact in piping erosion for safety assessment of multi-functional flood defences

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Introduction

Adaptation to climate change is one of the main concerns for cities in deltaic areas. For a country such as the Netherlands where two thirds of the land are located under sea level, reliability of the flood defence system is a top priority. Flood defences are exposed to different deterioration processes (also known as failure mechanisms) which might compromise the water retaining capacity during a flood event. In the state of the art of safety assessment for flood defences, a failure mechanism known as “Piping erosion” is considered one of the most probable and uncertain threats for the Dutch dike system. This type of failure consists in the formation of longitudinal cavities in aquifers located underneath the foundation of flood defences. This type of failure is one of the challenges that planners and engineers must cope with when high reliable flood defence systems are conceived.

Multifunctional flood defences are one of the many solutions proposed for urban areas, where factors such as sea level rise, global warming and demographic explosion are the main concerns in future planning. In principle, the addition of extra functions and the strengthening of the existent flood defence system will signify an increase in the dimensions such as height and width (Fig 1.)

Correlation effect

Correlation effects in flood safety assessments have been studied in the past. However, they mostly considered the possible relationship between water related parameters (Diermanse and Geerse, 2012) or the effect of spatial autocorrelation (Length effect) of piping associated variables (Kanning, 2012). For safety assessment of piping failure mechanism of multifunctional flood defences, the possible correlation that might exist between grain size and hydraulic conductivity, might change the estimated failure probability by orders of magnitude. If that is the case, the investment required for such a large system can be unbearable for a government to finance.

Methodology

Using bivariate correlation models (fig. 2), different degrees of dependence where induced during a probabilistic Monte Carlo failure estimation for the piping failure mechanism. The revised Sellmeijer limit state equation was used (Sellmeijer, et al. 2011). This method was repeated for different flood defence widths. The method was tested in a hypothetical case study which preserves real order of magnitude values of the statistical parameters used for the safety assessment in the Netherlands. A global sensitivity analysis is performed in order to
estimate how much of the failure function variance is explained by the combined effect of the correlated variables.

The estimated cost of the required defence for different degrees of correlation given a fixed required failure probability is calculated in order to illustrate the error cost of neglecting the correlation effect.

**Results**

After assuming a bivariate model that represents the possible topology of the correlated variables it can be observed that the actual Dutch assumption of low degree of correlation can be quite conservative. Structures with required low failure probabilities such as multifunctional flood defences can be over dimensioned if correlation is not taken into account during the probabilistic assessment.

**Future work**

Further research will include the bivariate model selection and correlation degree estimation for a real case study.

**Acknowledgements**

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Public health and health in general are hugely influenced by the ecosystems humans live in (WHO, 2005). Relations between ecosystems of which humans are part of are manifold. The World Health Organization (WHO) relates ecosystems and human well-being in the millennium ecosystems assessment (see Fig. 1) and identifies three major types of health impacts: direct health impacts; ecosystem-mediated health impacts; and indirect, deferred and displaced health impacts. In many of these relations aquatic ecosystems are the nexus between environmental change and human health (Johnson and Paull, 2011).

The causes of direct health impacts are relatively well known, although for example the knowledge on the exposure to pollutants is very incomprehensive because the fate and transport of pollutants and pathogens are unknown and their effect on human health is often unstudied (Ferguson et al., 2003). The third group is less related to social and societal aspects in which water management plays a secondary role.

The second group, ecosystem mediated impacts, clearly shows the intricate relations between ecosystems and health. In scientific literature some of these relations can be found and are scattered across scientific disciplines. A few examples are given below:

- **Land cover change**: deforestation in the Amazon basin leads to decrease of shade and exposed standing waters with elevated temperatures promoting larval mosquito habitats. Combined with increased interaction with humans the malaria transmission and infection rates increased (Singer and de Castro, 2006).

- **Land cover change and water management**: Deforestation and the construction of dams and irrigation systems changed the freshwater snail population ecology: increased sunlight encourages vegetation growth which leads to changing water levels and flow rates. A new species of snail was found to be an effective host for pathogenic *Schistosoma* spp., leading to increase in transmission and infection rates (Myers and Patz, 2009).

- **Water quality change**: Fertilizer application upstream in a catchment in Belize lead to increased nutrient input in downstream wetlands. The vegetation composition of the marshes shifted form short, sparse vegetation to dense cattails-dominated vegetation. The mosquito population shifted towards Anopheles vestitipennis over A. albimanus, which is a more effective malaria vector (Myers and Patz, 2009).

- **Water quality management**: the release of pollutants and medicine (a form of pollutant) in the aquatic systems leads to ecosystem responses. One of the well-known developments is the increase in anti-biotic resistance in bacteria. Recently anti biotic resistant pathogens have been found in sewers in Berlin and in its urban rat population. The aquatic urban system is now a potential source for multiresistant infections (Guenther et al., 2012).

- **The intestinal microbiome** is found to be closely related to the susceptibility of humans to various diseases. The composition of the microbiome is partly influenced by the local environment in which humans live (the Human Microbiome Project Consortium, 2012). This leads to the hypothesis that the (aquatic) environment might have a larger influence with still unknown pathways on our well-being than previously thought.

References


Figure 1. Relations between Human pressures, environmental changes, ecosystem impairment and health impacts (WHO, Millennium assessment, 2005).
Environmentally friendly designs to improve the navigability of the Danube in Serbia

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Introduction
A consortium consisting of Witteveen+Bos (lead firm) together with DHI from Denmark and Energoprojekt from Serbia carried out the project “Preparation of documentation for River Training and Dredging Works on Critical Sectors of the Danube River in Serbia”. The project is 100% funded by the EU and the beneficiary is the Directorate for Inland Waterways Plovput.

The project consists of a Pre-Feasibility Study (Phase 1), Feasibility Study (Phase 2) and for six sectors the preparation of Main Designs and Tender Documentation (Phase 3). During the Pre-Feasibility Study 24 critical sectors were identified where the navigation fairway has insufficient depth or width or where the bend radius is too small. For each of these 24 critical sectors various environmentally friendly conceptual designs have been developed to comply with the Danube Commission recommendations in order to assure safe and swift navigation on the Danube.

For the six critical sectors located on Serbian territory main designs were prepared using a 2-D morphological model. The results of the 2-D morphological modelling are presented in this abstract.

Project stretch
The project stretch is located between the Hungarian Border (km 1,433) and Belgrade (km 1,170) as presented in Fig. 1. Two tributaries flow into the Danube: the Drava at km 1,383 and Tisa at km 1,215. The Danube is the border between Serbia and Croatia from km 1,433 - 1,295. The river flows entirely in Serbia downstream km 1,295 to Belgrade (km 1,170). The Danube in the project stretch is a meandering river with straight sections. Many bends have pointbars and significant side channels that cut through the floodplains. At the relatively wide straight sections the flow is divided into multiple flow paths leading to the formation of sand bars and islands which are often dynamic in nature. In both situations this may lead to a navigation fairway which is not wide or deep enough according to the Recommendations of the Danube Commission.

2-D Morphological modelling
Detailed designs were prepared for six critical sectors located in Serbia using a 2-D morphological model (MIKE 21C).

Model Setup
A curvilinear grid was established with 50 points in transverse direction and a longitudinal spacing varying from approximately 50 to 200 m, depending on resolution demand. The highest longitudinal resolution was applied in bends located in the critical sectors (20-25 m).

The model bathymetry was based on a single beam survey of river bed profiles that was conducted by the beneficiary. The interval between the profiles is 200 m outside of the critical sectors and 50 m at the critical sectors. A uniform grain size of 0.25 mm was specified which is based on river bed samples taken at various locations in the project stretch.

Model calibration
The calibration of the morphological model took place in two steps. First the hydrodynamic component was calibrated using measured water levels by adjusting the Manning value of the model. In the second step the morphological component was calibrated. The morphological model was calibrated using the water levels and bathymetrical changes observed during the period July 2011 - July 2012. After testing different sediment transport formulas it was found that the combination of the sediment transport models of Engelund-Fredsøe (bed-load formula) for bed-load and
Yang (total load formula) for suspended load performs best. Fig. 2 presents the observed and simulated bed elevation changes after calibration.

The sediment transport (ST) component was calibrated using existing sediment transport rates near Novi Sad (km 1,257.1). The washload was subtracted from the total load. Estimates of the washload range from 55% - 80% (Babic, 2007) which gives a lower and upper limit of the total sediment transport. The simulated and measured total sediment transport is presented in Fig. 2. It is observed that there is a good agreement between the measured and simulated sediment transport magnitude.

It can be concluded from Fig. 3 that in general the observed erosion and sedimentation pattern is simulated quite well by the calibrated model. It should be noted that perfect agreement cannot be expected in a morphological simulation - only the main bed features can be represented well.

**Morphological modelling results**

The calibrated 2-D morphological model was used to further develop the conceptual designs of the six critical sectors located in Serbia into main designs. The layout of the river training structures were tested, optimised and adverse morphological effects were mitigated. The morphological modelling resulted in design solutions that contain river training structures in combination with dredging at three of the six critical sectors while only dredging turned out to be the best solution for the other three critical sectors.

The following environmentally friendly structures were designed:

- A detached downstream facing groyne and a chevron were designed at the sector Futog to stabilise the navigation channel.
- Four sills were designed in the existing side channel at Cortanovci along the right bank to increase the resistance of this channel and thereby to divert more flow to the main channel. This decreases the unstable behaviour of the river bed.
- Two chevrons at the sector Preliv were designed to divert a part of the flow from the side channel towards the main channel. This will prevent the side channel from becoming dominant while providing some flow through the side channel.

The tender documents of the dredging and construction works are being finalised.

**Acknowledgements**

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**References**


Introducing a framework for the rapid assessment of river navigability and bathymetry

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Introduction
The economic viability and competitiveness of (sea) ports have an intimate relation with the quality of the inland waterway network that connects the ports to the hinterland. Rivers form the main arteries of this network, but their natural behaviour may create local navigability bottlenecks such as shoals and sharp bends. Traditionally, engineering interventions to maintain and improve river navigability involved relatively complex, time consuming studies. Recent advances however, have brought rapid assessments within reach.

We propose a framework to construct quantitative river information from global open-source data in local data-scarce environments, allowing the identification and assessment of navigability bottlenecks. The framework provides a common ground for transparent coupling of quantitative data with proven and experimental scientific methods.

Economic developments abroad lead to increased demand for navigability studies, though often available data on the river’s bathymetry and even planform are scarce at best. We aim primarily at such data-scarce cases.

We propose a framework to construct quantitative river information from global open-source data in local data-scarce environments, allowing the identification and assessment of navigability bottlenecks. The framework provides a common ground for transparent coupling of quantitative data with proven and experimental scientific methods.

Methods
The main challenge of the first stage assessment is to say as much about a river as possible with little information. Much information can be gathered from open sources like NASA’s SRTM and various mapping services. In this we follow the approach of e.g. Schellekens et al. (2014) who construct a hydrological model from open sources. However, for navigational studies as opposed to hydrological studies, we naturally require much more detail of the river’s topology. An important requirement is to acquire and check a polygon detailing the river banks, and from that to generate a centreline. Centreline assessment of a river network is nontrivial without resorting to bitmap approximations. We propose to use a medial axis approximation of the river centreline. We use an algorithm that exploits polygon connectivity based on the proposal by Vilaplana (1996). McAllister and Snoeyink (1997) give an insightful application of possible other approximation techniques especially aimed at rivers.

The bankfull discharge of the river is best gathered from local sources, but in absence of information the bankfull discharge can be approximated by using a global hydrological model as described by Winsemius et al. (2013). Likewise, the valley slope can be approximated from SRTM satellite data, but these data have large uncertainties and local knowledge is in these cases, as with other parameters as bed material, often superior input.

There is no clear-cut way to determine the bathymetry of a river from open sources. However given the river centreline and additional information like the bankfull width, discharge, curvature and hydraulic roughness one can estimate the bathymetry using equilibrium approximations. Currently a combination of Chézy and an axis-symmetric solution is used to predict the bed level. In the future we hope to improve this method by making use of insights from the Miandras model (Crosato, 2008) and recently developed theories by Ottevanger (2013) and Frascati and Lanzoni (2013).
Application
Since the aim of the framework is to use open sources for data-scarce environments, it is logical to follow suit for the framework itself. The framework’s programming language of choice is therefore the Open Source language Python and we intend to integrate with existing open source initiatives like GDAL for flexible coordinate transformation and management. Furthermore, we intend to use established Delft3D file formats for exchange of (geometrical) information, in so doing hitching on to already existing (visualization) tools and laying the foundations for extended numerical studies.

Use-cases
We have described the outlines of a framework for the rapid assessment of river navigability and bathymetry and briefly touched on methods applied within this framework. We applied these methods on two study cases that have exposed possible uses as well as needed future developments.
In the first case we synthesized the bathymetry of the Borcea branch of the Lower Danube (Romania), having obtained information on discharge and bed material from local authorities. Figure 1 shows the result of the intended application. The comparison of the computed bed level with both available scarce bed measurements and manually interpolated complete bathymetry show a reasonable reproduction of the average bed level and the location of shoals in river bends.
Secondly we have applied the model to the Brazo Mompos branch of the Río Magdalena (Colombia) to obtain cross-sections for a 1-dimensional hydraulic model. A verification of the results has not yet been performed, but application to this relatively narrow river branch already showed the need to account for (mildly) braiding systems.

Outlook
The framework is currently in an experimental stage and being actively developed, and as such we naturally see many aspects that should be added, improved or expanded upon. Still, we would give a few possible leads that we think have merit to incorporate.
Given the centreline of a river the determination of the channel curvature seems trivial, but given the strong sensitivity of the bathymetry to the curvature and its inverse, the radius of curvature, we’ve found that a straightforward determination is too crude an approximation. We intend to explore alternatives, including using a polynomial approximation of the river centreline.
We will furthermore the bed level prediction with newly developed theories, to properly account for sharp bends, strongly varying river width and bifurcations.
Finally, looking beyond the initial assessment, calculating the effects of mitigating measures like groynes probably still need numerical assistance. Exchangeability with the Open Source numerical modelling suite Delft3D would be a logical extension.

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Challenges in the design of the Virtual River serious game

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Introduction
River management of national and regional waterways has become a complex matter involving multiple disciplines and stakeholders. The decision-making processes in river management regard issues that have a broad, wide-spread, non-transparent and frequently politically sensitive impact on a large and diverse group of stakeholders. The decision-making processes are therefore multidisciplinary as well as multi-actor; it can only be addressed properly by integrating these disciplines and actively involving all end users.

As part of the RiverCare research programme, the project presented in this abstract focuses on communicating the results of the other RiverCare projects effectively to river managers and stakeholders by creating interactive and intuitive visualisations incorporated in a serious gaming environment: 'Virtual River'. Ritterfeld et al (2009) define a serious game as "any form of interactive computer-based game software for one or multiple players to be used on any platform and that has been developed with the intention to be more than entertainment". In this project, the serious game, combined with the visualisations, aims to empower stakeholders to make informed decisions in the realisation of self-sustaining multifunctional rivers by allowing a highly usable and accessible interaction with the models and data generated in the RiverCare projects. Ultimately, the serious game aims to provide stakeholders with an environment where they can safely test management strategies together.

Challenges
There are multiple challenges to overcome towards realising the serious game. This abstract focuses on two specific challenges regarding the design of the serious game:

a. How can the decision-making process in river management be best supported?
b. How detailed should the integrated knowledge be presented to the end users in the serious game?

The challenges regarding these questions are explained using case examples.

Decision-making process
As part of ‘Ruimte voor de Rivier’ (RvdR), the Overdiepse Polder, located between Waalwijk and Geertruidenberg, was considered as a temporary water storage in times of high water. After the inhabitants learned about this plan, they announced that they would do whatever necessary to obstruct it (Roth and Winnubst, 2010). Soon after, the deputy of the Noord-Brabant province met with the inhabitants. Concluding this meeting, inhabitants asked if they could make their own plan to combine living, agriculture and water storage in the Overdiepse Polder. To prevent a long period of uncertainty, the inhabitants preferred that if something had to be done that it was done quickly and on their terms and conditions. The inhabitants, supported by a farmers’ organisation and the province, came up with the plan of constructing nine terps with farms on the south side of the area. The plan was backed by the province and by the committee ‘Bezinningsgroep Water’. Ultimately, the plan of the inhabitants was continued and the Overdiepse Polder project received a frontrunner status within RvdR.

In the Overdiepse polder case, the inhabitants had an active role in the decision-making process and were part of the project organisation. This was only made possible by the constructive role of the province in mediating conflicts and impasses which helped to build trust between all parties. The case shows how the governance model of the decision-making process changed and, in this case, showed good results. Towards the serious game, this raises the question on how to support the decision-making process. Should the serious game be based on the current decision-making process or not? In other words, should the serious game support the current, actual use regarding the decision-making process or by for example lowering the timespan and costs of management decisions. Alternatively, the serious game could ‘intervene’ towards an ideal use situation; towards ‘better’ solutions and decisions. Better in this context could be decisions which are supported by all stakeholders or a decision-making process which is less problematic or perceived as more satisfying.
**Integrated knowledge**

In the case of Arnemuiden, a small town in the municipality of Middelburg, a redevelopment project was started to develop an adjacent rural area in which water was a key topic. Similar to the Overdiepse polder case, inhabitants and local stakeholders were against the project and successfully obstructed it (van Schie, 2010). To break the deadlock, the stakeholders were gathered in an advisory group, supported by external experts, in order to develop scenarios for the redevelopment of the area supported by all stakeholders and the government. The aim of this involvement was to ease the obstructive attitude of the local stakeholders. The advisory group developed four scenarios which were subsequently developed into two realistic scenarios.

After the advisory group presented the two final scenarios, the municipality stopped communicating about the project for a long time. When new visions and plans were finally presented, the advisory group was not mentioned and only a handful of their recommendations were included. According to van Schie (2010), the city council of Middelburg had included its own (limited) interpretation of the advice in these plans. The cause of neglecting this advice is explained by the traditional view of experts and municipal civil servants on the function of experts in the decision-making process; expert knowledge was assumed superior and the input of non-experts was therefore not considered valid to include in the decision-making process.

Towards the serious game, this example shows that the role of experts should be carefully considered in order to create as much support for the serious game as possible. This is highly dependent on the amount of knowledge integrated in the serious game. Integrating a high amount of knowledge in the serious game steers the serious game towards a simulation tool. Such a simulation game lowers the threshold for non-experts to participate, but may also lower the need for knowledge from experts. Question is if such an approach is acceptable towards the decision-making process. Alternatively, a lower amount of knowledge could be integrated and experts could play a role during the game sessions based on their knowledge. This way, the serious game becomes a facilitation tool.

**Future work**

The two challenges described in this abstract are far from the only challenges and only relate to the design of the serious game. Towards these challenges, it is likely that a balance will need to be found on how to support the decision-making process as well as the level of detail of integrated knowledge. Future work will therefore focus on finding a sweet spot in the axis system as shown in fig. 1. The next step towards achieving this will be to perform interviews and hold discussions with stakeholders to determine what end users want out of the Virtual River serious game.

**References**


![Figure 1. Decision-making versus knowledge challenge towards the serious game design](http://example.com/figure1.png)
The Delta Programme, a new risk-based flood management approach in the Netherlands

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The Delta Programme develops strategies that are aimed at protecting the Netherlands against flooding, while anticipating climate change. The programme was launched in 2010 and it is aimed at avoiding a disastrous flood, rather than responding to it after the event. This requires a multigovernmental approach, strategies dealing with uncertainty and adequate institutional arrangements to secure future flood-proof implementation.

The Delta Programme adopts a risk-based approach and will result in updated standards for flood protection, a policy framework regarding flood-proof urban (re)development and efforts to improve disaster management (see figure). The programme will include the necessary measures for the short term (maintenance and improvement of flood defences and "aging infrastructure"), framing these measures into the long-term perspective of socio-economic developments and climate change. The multifunctional design of these measures is stimulated, since this increases societal "added value" (regarding nature, recreation or urban development) and enhances the acceptance of the proposed measures.

Within the Delta Programme one of the largest challenges is dealing with uncertainties about the future climate, population, economy and society. The Delta Programme tries to tackle uncertainty by an adaptive way of planning i.e. maximizing flexibility, keeping options open and avoiding "lock in". The Delta Commissioner directs this multigovernmental process of policy development and implementation, monitors progress, reports to Parliament every year in September and takes the necessary steps when problems arise. From 2020 onwards, a Delta Fund of about 1 billion euros per year will provide stability in financial resources, reducing dependency on economic developments and securing continuous political attention. The new Delta Act forms the legal basis for the implementation of the programme, the responsibilities of the Commissioner and the Delta Fund.

The risk-based approach will examine the likelihood of a flood and the possible consequences of a flood.
4 – Poster presentations
Mapping bed-level evolution in laboratory flumes by means of structured light

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Introduction
Experimental work in river morphology has already become a key factor to assess and analyze physical and numerical models that describe bed-level evolution in channels (Paola et al., 2009). Different techniques could be used to measure bed topography in laboratories ranging from traditional to high-technology methods. In this work, the structured light methodology applied through a Camera-Projector 3D scanner is presented as an accurate and low-cost alternative for this purpose.

Methodology
The Camera-Projector 3D scanner, hereinafter CP-3D scanner, is a photogrammetric stereo system in which, instead of using two cameras with a parallax distance, a camera and a projection unit are used. Within the possible advantages of this system, can be mentioned the speed of data acquisition, flexibility of equipment’s displacement, low cost and high accuracy (Peng, 2007). The main potential of this system for mobile-bed flume laboratory applications lies on its ability of contactless shape measurements, allowing to reconstruct 3D models with no flow disturbance. An appropriate geometry configuration and calibration of the Camera-Projector set is required to obtain an accurate representation of the studied surface. Geometry configuration (see Fig. 1) consists on establishing the distance B between camera and projector, and the average distance Z between the surface and the CP-3D scanner. The selection of these parameters will also define the required depth resolution, dZ, of the 3D model (Khoshelham et al., 2012).

![Camera-Projector 3D scanner (CP-3D) set.](image)

General procedure of the structured light methodology is to project known light patterns of black and white fringes in different frequencies on the flume bed surface (see Fig. 2).

![Set of eleven black-white fringes projected patterns with increasing frequency.](image)

Then, a digital camera is used to take images of the surface with the projected patterns. As the surface presents 3D faces, the projected patterns will appear distorted in the acquired images. Therefore, it will be essential to find the positions of the patterns on the camera image, knowing their locations on the projected image of the projector. This is possible by defining an image coordinate system (x,y) that determines the position of the pixels. The ‘distortion’ of the pattern’s original positions in the camera image is analyzed to construct a 3D point cloud that represent the shape of the surface. Each pixel (x,y) in the camera image will define a 3D point in an (X,Y,Z) coordinate system with origin in the projection center of the beamer.

Devices Calibration
A fundamental step to perform image data processing and reconstructing 3D point clouds is to find the internal parameters (focal length, radial lens distortion, vertical principal point offset) and external parameters (rotation angles of the camera) of the camera-projector set. This action can be carried out by measuring some geometrical characteristics, using a ‘chessboard’ image projected on a flat surface and considering some control points.

An advantage of the CP-3D scanner is that once calibration is done, it is possible to take measurements over any surface without control...
points, and move the system to another position without a recalibration procedure.

**Data acquisition and elaboration process**

The core of the CP-3D scanner technique is to compute the exact position of each projected black and white fringe in the camera image by finding the correspondences between each camera pixel $(x,y)$ of the acquired image and the column of pixels of the projected image in the surface. Then, it is possible to assign a 3D space coordinate $(X,Y,Z)$ to each pixel $(x,y)$ of the image using the collinearity equations used in photogrammetry (Gorte et al., 2013). An algorithm of data processing was developed to reconstruct the point cloud from the acquired images. Some initial tests were performed with the same flat surface for calibration and recognized objects and surfaces in order to assess the effectiveness and resolution of the obtained point cloud and make the correspondent corrections.

**Effects of refraction**

Research on river morphology is mainly interested in analyzing submerged areas. Measurements have to be performed under the presence of water in order to keep the boundary and local conditions of the morphodynamic processes along time. As photogrammetry and the CP-3D scanner work with the projection and acquisition of light rays, the optic effects of having a two-media interface (air-water) have to be strongly considered for preserving the required accuracy levels. Experiments were performed in a laboratory flume with defined water levels for assessing the effects of refraction in the 3D point reconstruction of the bottom.

**Results**

Figure 3 shows the first results of the 3D point cloud reconstruction suggesting that the presence of the air-water interface affects measurements proportionally to the water depth. The resulting point cloud of the flume bed appears to lie above the original position. Assuming clear water, (i.e. a minimum level of transparency), and small levels of water depth it is possible to perform a correction procedure for the computed 3D point cloud (Butler et al., 2002), considering the angles of refraction and the refractive index between air and water.

3D point cloud reconstructions were also performed in a sand mobile-bed flume with an initial rectangular channel (Fig. 4). Initial results allow obtaining a high level resolution and accuracy reached due to the calibration procedure and geometry definition of the CP-3D scanner.

**Conclusions**

Corrections made for the obtained point clouds with flow by using the Butler et al. methodology show a good level of agreement with observations in a dry environment, enabling the application of this technique in the presence of water. Some limitations of the technique regarding the intensity of light in the environment should be considered. External light has to be limited in order to reach a good contrast between black and white fringe patterns. Future work will be focused on the study of the refraction effects on the mobile-bed flume in cases with spatially-variable water depths.

**References**


Introduction

One of the most important physical aspects that have to be taken into account in morphological predictions for river bends is the influence of spiral motion intensity on the direction of bed load transport. Mathematically, for the equilibrium solution in the fully developed region in a bend, if there is any, we can neglect the adaptation lengths of friction and spiral flow, and the non-linear behaviour of the bed, and we can find that the depth-averaged velocity coincides with the direction of bed load transport, still neglecting suspended load. Depending on the way we model the bed slope effect in a 2DH context, the equilibrium slope could then be determined by the value of the effect of the transverse bed slope on bed load direction that cancels out the effect of secondary flow (axi-symmetric solution, see Olesen, 1987).

Including suspended sediment transport and neglecting the spiral flow influence on it by straightforward depth averaging, one would assume that suspended sediment might affect the wave length and damping of the solution due to the non-linear behaviour of the river bed, but not the axi-symmetric solution. This assumption would be based on the hypothesis that suspended sediment transport would follow the direction of the water flow velocity field, and as a result there would be no transport component in the direction of the transverse slope. This is not the case. Suspended sediment transport does follow the direction of the actual water velocity (at least that is what we generally assume, except in the vertical where the grains 'slip' with their fall velocity), but not the direction of the Reynolds averaged velocity. Reason for the deviation is the diffusive transport of sediment, which causes a non-zero transport component in the direction normal to the depth averaged velocity. With high suspended sediment load in comparison with bed load, bars in the outer bend and pools in the inner bend can be modelled.

Including the influence of spiral flow intensity on suspended sediment transport, the resulting morphology in the axi-symmetric region will be steeper than in the case without this influence. This behaviour complies with physical observation (Talmon, 1992). Inclusion of the influence of spiral flow on suspended sediment transport is hence vital. Accounting for it by modifying the diffusion coefficient would require unrealistic negative values for this coefficient.

Mathematical description

The secondary flow in a river bend causes a deviation of the concentration field due to convection of concentration in an analogous way as it causes the convection of flow momentum. Moreover, if the fluxes of sediment transport are used for computing morphological changes, these have to be corrected due to the secondary flow influence. The corrections can be added to the equations in two ways; either by averaging in a similar way as Reynolds averaging diffusion or by expressing the 3D convection-diffusion equation in depth averaged quantities multiplied by similarity profiles and then depth averaging. For the sediment transport the first approach was chosen while for the convection-diffusion equation the latter.

The similarity profiles of sediment concentration and secondary flow can be used for closing the extra terms. In the present study, the linear approximation of the secondary flow as derived by Kalkwijk and Booij (1984) is used, along with a 0th order approximation as derived and named after Rouse for the concentration profile.

Numerical experiments

We included the influence of spiral motion in both the concentration field and the transport of suspended sediment in 2DH modelling using Delft-3D. Numerical simulations where run for modelling hypothetical bends where the results where compared with 3D modelling of the same simulations (hypothetical bend experiment). Moreover, the performance of the model was investigated with a real flume experiment with suspended sediment load (Talmon, 1992). The set-up of the simulations is shown in Table 1 (\(W\) is the width of the cross-section, \(R\) is the radius of curvature in the centreline, \(Q\) is the discharge, \(i\) the bed slope, \(h\) the equilibrium water depth, \(C\) the Chézy smoothness coefficient, and \(d_{50}\) the median sediment grain diameter. In the hypothetical bend experiment
we used the Engelund and Hansen (1967) formula when only bed load was modelled, whereas we used the Van Rijn (1984a, 1984b, 1984c) formula when modelling both suspended load and bed load.

Table 1. Simulations settings.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Flume experiment</th>
<th>Hypothetical bend experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>W [m]</td>
<td>0.5</td>
<td>100</td>
</tr>
<tr>
<td>R [m]</td>
<td>4.1</td>
<td>2000</td>
</tr>
<tr>
<td>Q [m³/s]</td>
<td>5.7 x 10⁻³</td>
<td>1020</td>
</tr>
<tr>
<td>i [-]</td>
<td>3.4 x 10⁻³</td>
<td>5 x 10⁻⁵</td>
</tr>
<tr>
<td>h [m]</td>
<td>0.048</td>
<td>10</td>
</tr>
<tr>
<td>C [μm/s]</td>
<td>18.6</td>
<td>50</td>
</tr>
<tr>
<td>d₅₀ [μm]</td>
<td>88</td>
<td>200</td>
</tr>
</tbody>
</table>

Fig 1 and Fig 2 show the results of the numerical experiments. The equilibrium water depths near the inner and outer bend region from the flume experiment measurements and the 3D simulation results are used as a basis for assessing the predicting capabilities of the 2DH simulations. In both figures the water depths are normalized with the calculated depth upstream of the bend.

Conclusions
The influence of spiral flow intensity on suspended sediment transport direction is vital for morphological computations in river bends when suspended load is dominant. Neglecting it leads to unrealistic predictions. A practical way out in such cases is that the effect of diffusive transport of suspended sediment on transverse bed slopes is neglected too.

References

Figure 1. Flume experiment.

Figure 2. Hypothetical bend experiment.
The influence of mixed-size sediment on the propagation of a sediment nourishment to prevent river bed degradation

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Introduction
River beds are sometimes protected from degradation by a nourishment of sediment material. With a nourishment, a volume of sediment is dumped and spread over a river reach by the flow. Knowledge on the propagation of the nourished sediment is paramount to obtain optimal efficiency in protecting the river bed. Smaller grains are moved more easily by the flow; a nourishment of finer sediment can cause the material to spread over a river reach larger than needed or causes the material to deposit too far downstream, outside the region of interest. On the other hand, when using coarser sediment, the stabilizing effects can remain too local.

This difference in behavior between finer and coarser material indicates that the different grain size fractions within the supplied sediment propagate with different speeds. This is illustrated by Fig. 1 which shows field data of the Iffezheim tracer case (Gölz et al., 2006). The figure shows the displacement in time of the centroid of the distribution of a sediment fraction. A spread of different sediment fractions can be observed: the finer fractions move with a higher celerity than the coarser fractions. In general, the propagation of different fractions can be seen as kinematic waves of grain size distribution of the river bed, known as sorting waves.

Flume and field data available in literature on the propagation of the waves of the grain-size distribution of the bed have been analyzed to obtain information on the sorting wave celerities. Laboratory experiments are conducted in a tilting flume of the Laboratory of Environmental Fluid Mechanics of Delft University of Technology, to obtain additional flume data. Field and flume data have been compared with analytical models (Ribberink, 1987; Stecca et al., submitted) and a numerical model (Stecca et al., 2014).

Field and laboratory data
We have analyzed two sets of laboratory data (Suzuki, 1976; Promny, 2003) of flume experiments on the transport of mixed-size sediment with measurements of the variation of the grain-size distribution of the bed in time. This gives us information on the measured sorting wave propagation. These data sets do not include information on the propagation of disturbances in bed elevation. A third set of laboratory data is obtained in a new flume test. Furthermore, field data of the transport of different fractions in the Rhine River near Iffezheim (Gölz et al., 2006) are analyzed.

Analytical model
By analyzing the mathematical system of governing differential equations which describe the morphodynamics of mixed-size sediment reaches (Saint-Venant equations together with Hirano’s (1971) active layer model), Ribberink (1987) and Stecca et al. (submitted) developed linearized approximations to the celerities of the Saint-Venant-Hirano model which describe bed perturbation and sorting wave celerities. We use these expressions to provide insight into the behavior of sorting waves by comparing these estimates to the laboratory and field data and numerical model results.

Numerical model
The system of governing equations, the Saint-Venant-Hirano model, is solved using a numerical model (Stecca et al., 2014). The results of the model are compared with the data from the laboratory experiments. This provides
insight in the accuracy of model predictions regarding sorting wave propagation. An example of the results from the numerical model for the laboratory experiment described in the next paragraph is shown in Fig. 2. In the lower panel it shows the mean grain diameter at a given moment in time as a function of the streamwise position.

**New laboratory experiment**

We have conducted two new laboratory experiments, to obtain additional flume data. One is an experiment with a bimodal sediment mixture in which at the upstream end an installed shoal consisting of only the coarser sediment fraction propagates downstream (Fig. 3). The bed consists of an evenly distributed coarser and finer fraction. The propagation of the coarser fraction (painted in a different color than the finer material) is measured with an image analysis technique (Orrú et al., 2014) by taking pictures of the bed surface and analyzing them with a computer algorithm to obtain the areal fraction content.

Prior to above experiment, an experiment with the same settings but with unisize sediment is performed to provide insight into the behavior of the shoal sediment, which is painted and tracked with the image analysis technique. By using such a set-up, we avoid any grain-size selective processes. This experiment can be seen as an even more fundamental test of Hirano’s mixed-size sediment conservation equation.

**Conclusions**

The Iffezheim field data (Fig. 1) clearly indicates faster propagation of finer sediment fractions than the coarser ones, i.e. a separation of sorting waves associated with sediment size fractions.

The results of this research will improve the understanding of the propagation of sediment nourishments in rivers and therefore will provide information on how to enhance numerical models to design more effective sediment augmentation measures.

**Acknowledgements**

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**References**


Morphological prediction of braided Congo River at Brazzaville

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Introduction

Congo River is one of the largest rivers in Africa. Natural border between Congo and the Democratic Republic of Congo, the river covers a surface of approximately 4 million km² and has a discharge of 44,000 m³/s on average (dry season: 36000 m³/s - flood season: 52,500 m³/s). Near the two capitals of Brazzaville (Congo) and Kinshasa (Democratic Republic of Congo) the river is divided into two parts, one large branch mostly used by ships to reach Kinshasa and one braided branch used to reach the port of Brazzaville. As a result of different politics between the two countries, commercial ships to Brazzaville can only join the port using the braided river way.

The term “braided river” is associated to the planform morphology of the river bed. It is composed of several channels crossing and separating around island. It forms a more or less developed channel network. This type of river is considered unstable because of the permanent changes of the network. The fast changes are associated with high rates of sediment transport and bank erosion. The port area of Brazzaville experienced sedimentation in recent years, implying difficulties for river navigation. My study focuses on the braided river and the port area.

Following previous studies on the Brahmaputra River in Bangladesh and guided by a few data and satellite images, some predictions of morphological changes of the Congo River can be made.

Observations from data and satellite images

Comparing the planform evolution over the last 5 years and focusing on the main channels, we can predict some basic river branch migration.

The images show that the morphological changes can be fast and complex, so that a long-term prediction does not make sense. Erosion and sedimentation areas can move every year, allowing island creation, branch abandonment and branch migration. Yearly rates of bank erosion or accretion can reach hundreds of meters, and consequently change the landscapes rapidly.

Probabilistic predictions methods

Based on the method and previous applications of Klaassen et al. (1993) for the river Brahmaputra in Bangladesh, a network model of the river can be made. It consists of representing all the main channels, of elaborating a probability tree of abandonment, and of calculating the erosion rates along banks of interest.

The predictions are made using geometrical data such as width, length, and the angles between upstream and downstream channels at bifurcations.

Table 1. Probability of Abandonment for Congo River case of study, established using probabilities of abandonment for each angle.

<table>
<thead>
<tr>
<th>Channel ≤ 20 km</th>
<th>Channel &gt; 20 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>θ ≤ 20°</td>
<td>P(A)=0</td>
</tr>
<tr>
<td>20° &lt; θ ≤ 108°</td>
<td>P(A)=(θ-20°)/11%</td>
</tr>
<tr>
<td>θ ≥ 108°</td>
<td>P(A)=100%</td>
</tr>
</tbody>
</table>

Using the probability of each branch, overall probabilities can be determined:

![Figure 1](image1)

**Figure 1.** Representation of a bifurcation, with a probability along the site of interest of P(A_site) = P(A2)P(A3)

![Figure 2](image2)

**Figure 2.** Representation of a bifurcation, with a probability along the site of interest of P(A_site) = P(A2) + P(A3) - P(A2)P(A3)
The next step consists of calculating the erosion factor using formulas of Hickin and Nanson (1984) (B=width; R=curvature radius):

\[ f\left(\frac{B}{R}\right) = 2.5 \frac{B}{R} \text{ for } \frac{B}{R} \leq 0.4 \]

\[ f\left(\frac{B}{R}\right) = \frac{2-2\frac{B}{R}}{3\frac{B}{R}} \text{ for } \frac{B}{R} > 0.4 \]

Combining them with probabilities and channel width, we obtain the erosion rates.

Table 2. Empirical formulas for bank erosion (m/\text{year}), associated to Hickin and Nanson erosion factor:

<table>
<thead>
<tr>
<th>Probability of exceedance (%)</th>
<th>Bank erosion rate in direction perpendicular to former channel (m/\text{year})</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>0.3 \cdot B \cdot f(B/R)</td>
</tr>
<tr>
<td>75</td>
<td>0.5 \cdot B \cdot f(B/R)</td>
</tr>
<tr>
<td>50</td>
<td>0.7 \cdot B \cdot f(B/R)</td>
</tr>
<tr>
<td>25</td>
<td>0.9 \cdot B \cdot f(B/R)</td>
</tr>
<tr>
<td>10</td>
<td>1.1 \cdot B \cdot f(B/R)</td>
</tr>
</tbody>
</table>

Correction factor: (100\%-P\{Abandon\})

(Appplied on previous results, to obtain not overvalue results.)

Results
Taking into consideration all the results of abandonment probabilities, elementary cases, observations and erosion rates, we can forecast the evolution of the river for the next 2-3 years (Figures 1 and 2).

Conclusion
This work gives a first approach, to understand the dynamics, sediment transport and the morphology of the braided Congo River. These methods of prediction could be used as a reference for more detailed numerical or physical modelling.

This study has been carried out in the framework of the project “Studies on hydraulic structures on the River Congo in Brazzaville”, carried out by BRL Ingénierie in association with Deltares and other partners.

References
Reintroduction of large woody debris in navigable rivers: a pilot study to stimulate biodiversity within safety constraints

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Introduction

River ecosystems in the Netherlands lost much of their specific values due to human impact. A major modification in these controlled river systems is the lack of large woody debris (LWD) in the main channel and tributaries. Since riparian forests have become rare and LWD is actively removed from the water, this natural structure is nowadays missing in our large rivers. Studies indicate that LWD is an important habitat structure for both fish and macro-invertebrates (Piégay & Gurnell 1997). LWD also enhances morphological differentiation of the river bed in free flowing rivers (Gurnell et al., 1995, Gerhard & Reich 2000). The reintroduction of LWD has proved to be a successful measure in many smaller river systems worldwide (e.g. Kail et al. 2007, Miller et al., 2010). In the larger rivers, with shipping as an important economic function however, LWD has never been applied. Therefore, Rijkswaterstaat started a pilot study to investigate the contribution of LWD in navigable rivers to better achieve the goals of the Water Framework Directive (WFD).

Pilot study

The pilot study was carried out at twelve locations in the river Nederrijn-Lek, a branch of the river Rhine. This stretch of river is impounded and therefore any possible maximum effect of LWD will be reduced, but it was selected for safety reasons. In order to investigate the steering parameters of LWD, we selected study sites that differed in water depth, stream dynamics and exposure (main channel vs. side waters).

A primary condition in these experiments is that the trees that were used as LWD stay in position, even during high flood periods. LWD drifting in the fairway can lead to dangerous situations which must be prevented. Determining the appropriate fixing method is therefore an important part of this pilot study. A total of six trees (length ~15 metres), including branches and roots, were placed just under the water surface near the banks of the river in the main channel, a side channel and a fishway. The trees were attached to steel beams by strong steel chains. Another six trees were placed at different depths in deep erosion pits that occur near the groynes close to the main channel. Based on multibeam data, sites were selected that were deep enough under all circumstances and at sufficient distance from the navigation channel (Fig. 2). These trees were attached to two large concrete slabs of over 2,000 kg (Fig. 3).

Figure 1. Six trees are placed in shallow zones along the river.

Figure 2. Multibeam data help to find the safe pilot location on the spot. The white line indicates the intended tree location. The rectangle indicates the position of the ship. Blue = deep, red = shallow
Ecological effects
The main goal of reintroducing LWD into the river system was to enhance ecological diversity, especially for fish and macro-invertebrates. Accordingly, monitoring concentrated on these taxa. Fish surveys based on fyke nets and electrofishing complemented with underwater video surveys, provided insights into the presence of fish in the LWD habitats. Preliminary results from the shallow locations in groyne fields showed large concentrations of juvenile fish, especially near branches and roots (Fig. 4). LDW at the pilot locations appears to be attractive for roach, perch, pike-perch, eel, bleak, nose carp and several gobid species.

For complete macro-invertebrate sampling, one entire tree was lifted from the fishway after four months and showered (Fig 5). A total of ca. 100,000 individuals was collected. The stem section appears to contain the largest densities: over 10 times more than on the stones from the fishway bed (Fig. 6). Also the branches and to a lesser extent roots contained higher densities than the stones. At least 12 chironomid species were found that have never or rarely been found in the river Rhine. The most abundant species were common though and not specific to streams. Complete monitoring results of fish and macro-invertebrates will be available in late 2014.

Future
If future monitoring results confirm that LWD contributes to biodiversity in navigable rivers and the fixation methods prove to be adequate, the measure will be exported to faster flowing parts of rivers. In those circumstances, we expect even more interesting results, with LWD not only providing habitat structure, but also generating habitat diversity by enhancing and changing morphodynamic processes such as erosion and sedimentation. In this way the river system can be interlaced with small hot spots of high ecological diversity, in co-existence with shipping and flood-defence structures.

References
Design water levels based on a probabilistic approach of hydrograph shape

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Introduction
The River Meuse is a typical rain fed river. Therefore flood waves in the River Meuse show large variations in hydrograph shape. Some have a short duration and narrow peak, but other waves have a much broader peak. These differences affect the downstream water levels as a result of wave damping and storage effects (Gerretsen, 2009).

For the design of flood defences along the River Meuse design water levels are needed, which are based on hydrodynamic simulations. Current practise is that these simulations are carried out using one design hydrograph at the gauging station Borgharen. Water level and discharge records of about 100 years are used to determine the peak discharge (frequency analysis) and the shape (average shape) of this design hydrograph.

This paper compares the current method to alternative methods for determining design water levels.

Method
In the analysis, we used - instead of 100 years of measured data - a dataset with discharge simulations from the GRADE project (De Wit and Buishand, 2007). These discharges are generated using rainfall resampling, a hydrological model and a hydraulic model. The GRADE dataset represents 50,000 years, and allows more advanced analyses compared to the 100 year measured dataset at Borgharen.

We compare five different methods for determining design water levels:
1. simulation of the complete GRADE dataset
2. the standard hydrograph
3. a vertically averaged hydrograph
4. an explicit probabilistic method
5. an implicit probabilistic method

In method 1, all GRADE hydrographs with a peak discharge Qp exceeding 1750 m³/s were simulated with the one-dimensional SOBEK-Meuse model. The results of method 1 serve as reference for the other methods. The standard hydrograph was constructed according to the method of Klopstra and Vrisou van Eck (1999). The vertically averaged hydrograph was constructed according to the method of Ogink (2012). These two design hydrographs were both constructed for peak discharges of 2600, 3280, 3800, 4000, 4200, 4400 and 4600 m³/s at Borgharen.

In the two probabilistic methods 4 and 5, an essential part is to find a relation between downstream maximum water levels and hydrograph characteristics at Borgharen. The peak discharge Qp and peak curvature C2 were found to be good predictors of the maximum water levels at location x (Hmax,x), or

\[ H_{\text{max},x} = f(Q_p, C_2) \]  (1)

C2 is an approximation of the second derivative of Q around the peak:

\[ C_2 = \frac{Q(T - 2) + Q(T + 2) - 2 \cdot Q_p}{4^2 \cdot Q_p} \approx \frac{\partial^2 Q}{\partial t^2} \cdot \frac{1}{Q_p} \]

where:

T (days) is the time of the flood peak

Other shape variables like the duration or peak volume are also suitable, but using C2 simplifies some parts of the analysis. Eq. (1) can be based on a small set of 25 hydrographs and corresponding SOBEK simulations.

Method 4 is a modification of the approach of Geerse (2013), where the exceedance probability is expressed as Eq. (3). Qp,crit is the peak discharge that leads to Hmax,x, given C2. Qp,crit is found with Eq. (1). Qp and C2 can be considered independent, in which case Eq. (3) can be simplified to Eq. (4).

\[ P(H_{\text{max},x} > h) = \int_{q_p}^{\infty} \int_{c_2}^{\infty} f(q_p, c_2) dq_p dc_2 \]  (3)

\[ P(H_{\text{max},x} > h) = \int_{c_2}^{\infty} \int_{q_p}^{\infty} f(q_p, c_2) dq_p dc_2 \]  (4)

Unlike method 4, method 5 does not use probability distribution functions for the shape variables, but uses Eq. (1) to estimate the local water levels corresponding to all GRADE hydrographs. In this way, the probabilities are implicitly taken into account. Subsequently, the estimated water levels are used to construct the local water level frequency line.
Results
In the methods 2 and 3, using design hydrographs, a return period is assigned to each hydrograph, based on a generalized Pareto distribution. The same distribution was used for method 4. Table 1 gives the distributions that were used in method 4 to model the two shape variables. In the methods 4 and 5, a polynomial function was used for Eq. (1), which proved to give a good fit ($R^2$ close to 1) when 25 hydrographs are used.

Fig. 1 shows the results of the five different methods for location Mook, 150 km downstream of Borgharen. At the other studied locations the results show a similar pattern.

Table 1. Probability distributions of $Q_p$ and $C_2$

<table>
<thead>
<tr>
<th></th>
<th>Peak discharge $Q_p$</th>
<th>Peak curvature $C_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Generalized Pareto</td>
<td>Weibull</td>
</tr>
<tr>
<td>Scale</td>
<td>462.98</td>
<td>$a = 21.055$</td>
</tr>
<tr>
<td>Shape</td>
<td>-0.0806</td>
<td>$b = 3.432$</td>
</tr>
<tr>
<td>Location</td>
<td>1750</td>
<td>-</td>
</tr>
</tbody>
</table>

Conclusions
The results show that the current method (2) seems to systematically overestimate the flood water levels. These findings confirm results of Gerretsen (2009) and Geerse (2013). Differences vary between 0 and 45 cm, and increase for larger return periods and in downstream direction. Such consistent overestimation implies that in specific cases, river dikes may be safer than previously thought.

Alternative methods (3,4,5) give results closer to the reference method 1 in which 50,000 simulations are used. An advantage of method 3 is that it also uses a single design hydrograph. Method 4 is more complex since it needs 25 simulations and a probabilistic analysis, but does not yield significantly better results than method 3. Although method 5 also needs 25 simulations, it gives an even better result and uses less assumptions.

The results show that probabilistic methods using 2-dimensional hydrodynamic simulations may be feasible, also when assessing the effect of measures in the river.

The probabilistic methods may be even improved by a better understanding of the relation between $H_{\text{max,x}}$ and the shape variables, and by a better representation of the tails of the probability distribution functions.

Acknowledgements
The MSc Thesis research on which this paper is based, is supported by TU Delft, HKV Consultants and Rijkswaterstaat.

References

Figure 1. Water level return periods at Mook based on the five different methods.
River dune predictions: Comparison between a parameterized dune model and a cellular automaton dune model

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Introduction
River dunes are of great importance for the determination of water levels, especially during flood events. They have a large influence on the hydraulic roughness and thereby on water levels. In addition, dune formation could affect the navigability of rivers and propagation of dunes could uncover pipelines or other constructions beneath the river bed. That is why many have tried and are still trying to model dimensions and propagation of dunes under various conditions (e.g. Van Rijn, 1984; Nabi et al., 2013).

Because fast calculations are essential during an upcoming flood event, there is a need for fast model predictions. The focus of this research is on a parameterized dune model (Paarlberg et al., 2009) and the cellular automaton dune model (CA model) HR Wallingford is experimenting with (Knaapen et al., 2013). Both models are relatively fast in their calculations they do however, have a fundamentally different approach to predict river dunes. This research reveals the performance of these two models tested under various conditions.

The objective of this research is to compare the performance of the cellular automaton dune model and the parameterized dune model for the prediction of dune dimensions, migration rates and sediment transport in equilibrium state, under flume conditions, similar to low-land river situations like the River Rhine (the Netherlands).

Adjusting the CA model
The initial CA model is based on stochastic rules; there is no link between sediment transport and flow characteristics within the model. Therefore we adapted the CA model before comparing it with the parameterized dune model. We added a length scale by linking the model parameters to a distance instead of a number of cells and assuming a fixed domain. In this way parameters and the domain itself are defined in meters and no longer in number of cells. The moved sediment within the model is determined by counting the number of slabs and the distance travelled. The amount of moved sediment is used to add a time scale to the model by relating it to the sediment transport according to Meyer-Peter and Müller (1948). Additionally we linked model parameters of the CA model to the characteristics of the experimental data. We used the formula of Cheng and Chiew (1998) to relate flow characteristics with the pickup probability of the CA model (Eq. 1).

\[ P = 1 - 0.5 \left( 1 - \exp \left( -\frac{0.46}{\theta C_L} - 2.2 \right)^2 \right) \]

where \( P \) is the pickup probability, \( \theta \) is the Shields parameter and \( C_L \) denotes a constant that is assumed to be 0.25. Sekine and Kikkawa (1992) proposed a relation between the shear and settling velocity and the step length of saltating grains. We used their formula to relate flow characteristics with the step length of the CA model (Eq. 2).

\[ \lambda = \alpha_2 \left( \frac{u_s}{v_s} \right)^3 \left[ 1 - \frac{(u_s C_L)}{(v_s C_L)} \right] \]

where \( \lambda \) is the dimensionless step length, \( \alpha_2 \) is a constant with value 3.0*10\(^3\), \( u_s \) is the shear velocity [m s\(^{-1}\)], \( v_s \) denotes the settling velocity of the sediment [m s\(^{-1}\)] and \( u_c \) is the critical shear velocity [m s\(^{-1}\)]. The dimensionless step length is related to the step length in [m] in the following way:

\[ \Lambda = \frac{\lambda}{\sigma} \]

where \( \Lambda \) is the step length in [m] and \( \sigma \) the grain size in [m]. The adjustments led to new input parameters for the model; these are the step length, pickup probability, shadow distance and sediment transport.
Comparison of the model performances
We tested the performance of the parameterized dune model and the CA model using sixteen flume experiments to determine their predictive value for prediction of dune dimensions and migration rates. Both models show problems for predicting migration rates. The parameterized dune model overestimates the observed migration rates about three times, while predictions of the CA model are about three times smaller than the observed migration rates in general. Results of predicted dune heights are presented in Fig. 2. On average, predictions of dune dimensions are lower than observed for both models. With a root-mean-square error of the dune height and length of 0.036 m and 0.82 m for the CA model against 0.044 m and 0.77 m for the parameterized dune model predictions are comparable.

A part of the midsection of the CA model is plotted against the predicted dune profile of the parameterized dune model for one of the experiments. Results are presented in Fig. 1 to show the differences in dune profiles. The skew shape of the dune profile predicted by the parameterized dune model is not clearly represented in the profile of the CA model. Runs with longer simulation times have shown that the predicted dune shape in the CA model becomes more asymmetric like the dunes predicted by the parameterized dune model. This indicates that longer run times are required to simulate equilibrium dunes as predicted by the parameterized dune model and observed in the field.

Conclusions and recommendations
In this study a non-dimensional CA model is made dimensional. The CA model is tested for the first time in the way as presented here, by adding time and length scales to the model. There is no other research to compare results with. Results seem promising and show predictions that are reasonable; however in general the predictions are slightly underestimated.

The model has potential and recommended improvements are:

a. Linking the shear velocity to flow characteristics to improve the relation of the CA model with the flow characteristics.
b. Adding an equilibrium state, to overcome the infinite growth and merging of dunes until a single dune covers the domain.

References

Figure 1. Predicted dune profiles. Red line represents the parameterized dune model, blue line the CA model, flow direction from left to right.

Figure 2. Observed dune heights versus predicted values parameterized dune model (left) and CA model (right).
Future Deltas: a new Utrecht University research focus area

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Focus area: Future Deltas

Every four years, Utrecht University defines new research focus areas to stimulate interdisciplinary research, that should act as nuclei for broad (inter)national collaborations. Future Deltas was recently established as a new focus area (period: 2014-2017) to bring together expertise on the functioning of delta systems.

Future Deltas aims to understand and predict how deltas under pressure of massive urbanization, land-use and climate change, sea level rise and subsidence will change in the future and how societies can successfully deal with this. To be able to predict and anticipate to the impacts of these changes in future deltas, it is crucial to have insight and profound understanding of the functioning of both natural and societal aspects of delta systems. This enables us to answer questions like: how does river embankment influence floodplain development and coastal sedimentation? What is the impact of deep and shallow groundwater extraction due to expanding cities on subsidence and saltwater intrusion? Who is responsible for causes of negative impacts, how are mitigation strategies organized, how and at what level are decisions on delta management taken?

Integrated approach

To address the challenges deltas world-wide face and to facilitate integrated sustainable and resilient management, an integrated approach combining mechanistic knowledge of natural system functioning, comprising interacting physical, chemical, and biological processes, with specialized knowledge on spatial planning, land and water governance and legislative frameworks is required. Such an integrated approach has been lacking to date and forms an interdisciplinary challenge that will be engaged within Future Deltas (Fig. 1).

Research themes

In Future Deltas we initially focus on two interrelated themes: ‘Living in sinking deltas - pressures and competing claims’ and ‘Ecosystem services in changing deltas’. Both themes include physical, chemical, biological, socio-economic, institutional and legal processes and their interactions.
ecosystem services. On the longer term, we envisage a broadening of the focus area by the inclusion of additional themes that address new emerging priorities.

Theme 1: Living in sinking deltas: pressures and competing claims

Although land subsidence poses a far more immediate and severe problem than for instance climate-change-induced sea level rise, the processes and consequences of land subsidence have yet to receive the full and integrated scientific and public awareness. Delta subsidence causes a range of problems, including flooding, salt water intrusion, fresh water scarcity, damage to buildings and infrastructure, loss of cultivated land, wetlands and biodiversity, degradation of fishing areas, and rapid shoreline retreat. Combined with a future sea level rise, submerging of deltaic areas is projected to increase by 50% by the end of the 21st century. Within this theme will be worked on 1) understanding current and predicting future subsidence, 2) impact assessment of land subsidence, and 3) restoration or mitigation of delta subsidence and their effects, to tackle the grand challenge of submerging deltas.

Theme 2: Ecosystem services in changing deltas

Mankind relies heavily on deltas and associated water bodies and wetlands for the delivery of essential ecosystem services, including primary production and agriculture, environmental filtering and water quality improvement, flood abatement, coastal protection and safety, nature and biodiversity conservation, and critical interactions with the atmosphere and climate through greenhouse gas reduction and carbon sequestration. It is imperative that provisioning of delta services be included in future planning and governance schemes that integrate ecosystem services into the discussion of land use rights and the governance of limited resources. The knowledge generated within this theme will facilitate adaptation decisions for nature management, biodiversity restoration, water resources management, sustainable agriculture, urban planning, and area developments yielding safer and more resilient delta systems for the future. Within this theme will be worked on 1) integrating the physical, biological and chemical processes that dictate the provision of delta services and developing new governance and regulatory arrangements, 2) understanding the impacts of changing delta hydrology and land use on nutrient and sediment source-sink functions, biodiversity and ecosystem resilience, and 3) examining interactions and tradeoffs between different planning and management strategies.

Organisation and further information

Future Deltas is a close cooperation between the faculties Geosciences (GEO), Science (BETA) and Law, Economics and Governance (REBO) of Utrecht University. The focus area is led by a steering committee, consisting of the following members: dr. E. Stouthamer (project leader), prof. dr. H. Middelkoop, dr. M. van der Vegt, prof. dr. E.B. Zoomers, prof. dr. P.P.J. Driessen (all GEO), prof. mr. dr. H.F.M.W. van Rijswick, mr. dr. F. Groothuijse (REBO), dr. M.B. Soons (BETA).

Organisations that are interested in our integrated approach are cordially invited to join the Future Deltas research programme. Further information on Future Deltas can be obtained from Esther Stouthamer (e.stouthamer@uu.nl).
Establishing sediment budgets in three ‘Room for the River’ areas in the Biesbosch inland delta

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Introduction

Many Deltas in the world cope with drowning and loss of delta land by sediment starvation and accelerated soil subsidence, because of embankment of channels and drainage of land. The urgency of the problem is enhanced by sea level rise (Syvitski et al., 2009). Loss of delta land is a problem, since most deltas are densely populated and seen as valuable because of their ideal location for a harbours, agriculture, aquaculture, or tourism (Kirwan and Megonial, 2013). Moreover, deltas encompass vast wetland areas of great ecological value Delta restoration by re-introduction of natural processes and sedimentation is considered as a mitigation measure, but it is difficult to implement, since natural processes are often in conflict with current activities in the delta. Furthermore, several deltas are subject to sediment starvation, because of a decrease in sediment delivery from upstream. For these delta’s it is uncertain whether delta restoration will be effective. Effective delta restoration can be achieved when more understanding of the mechanisms of delta aggradation and their controls is obtained.

The Biesbosch, an inland delta in the south-west of the Netherlands, is currently drowning, because of sea level rise and soil subsidence. However, as a result of for the Room for the River (RfR) projects, re-introduction of water and sediment is established in former polder areas. This means that natural processes are re-introduced in a human controlled situation, which makes the Biesbosch the ideal trial area to study the effectiveness of delta restoration.

Research questions

The research questions of the PhD project are:
1. What is the effect of the RfR measures on the hydrodynamics and morphodynamics of the former polder areas in the Biesbosch?
2. What are the factors and mechanisms of influence on the sediment budget of the Biesbosch delta system
3. Is it possible to influence these factors to optimize the amount of sedimentation
4. Are the current rates of sedimentation enough to compensate the prospected rate of sea level rise and soil subsidence.

Approach

Fig. 1 shows a map of the Biesbosch in which red circles indicate the RfR areas. Areas 1 to 3 represent ‘Natuur ontwikkelingsgebied Noordwaard’, ‘Zuiderklip’, and ‘Tongplaat’ respectively, where all RfR measures have been implemented. The fourth area is the ‘Grote Noordwaard’, where the implementation of the RfR measures will be finished at the end of 2015.

Figure 1. The four RfR areas in the Biesbosch with their main flow pathways.

Water and sediment budgets

Fieldwork will be conducted in the first three RfR areas. Eight permanent measurement locations have been established at the entrance and exit of each area. At each location, water level, flow velocity and suspended sediment concentration (SSC) are monitored by a pressure sensor, H-ADCP and Seapoint Turbity Meter (STM) respectively. Several field campaigns will be carried out to collect manual water samples collected near these locations are used to determine the SSC, which is needed to calibrate the STM measurements. Furthermore vertical gradients in the velocities and SSCs are measured during different conditions of river discharge and vegetation coverage. In this way water and sediment budgets can be calculated for each area.
Patterns in sedimentation and erosion
Understanding of the mechanisms of delta aggradation and their controls will be obtained by measuring the changes in height of the flats and channels and mapping the thickness and composition of the freshly deposited sediment layers. To determine short-term erosion or sedimentation, lateral gradients in SSC and flow velocity will be measured across the study areas. A decrease in SSC over the area indicates sedimentation, while an increase in SSC indicates that erosion/re-suspension of sediment takes place.

A drowning or emerging Biesbosch?
To find out whether under the current conditions enough sediment is introduced in the system to counteract drowning and loss of delta land, the current sediment budgets and patterns in sedimentation and erosion in the three different areas will be compared to the prospected rates of sea level rise and soil subsidence. This will provide the necessary insight in whether the RfR areas will drown or emerge under the current conditions.

Optimizing sedimentation rates
Factors to optimize the amount of sedimentation and thereby increase the effectiveness of delta restoration will be obtained by analysing the differences in sedimentation or erosion rates and patterns in the three areas that are different with respect to hydraulic conditions. In area 1, there is a constant replenishment of water and sediment by the river. During a large part of the year, the water flows from north to south, through the area. Only when river discharge is very low, the tidal water level variation becomes dominant and water can flow temporary from south to north. In area 2, there is less influence of the river, therefore flow directions change during the tide. The third area is a storage area. There is only one entrance and water can either flow in or out, depending on the tide.

Acknowledgements
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References
Assessment of the impact of sea level rise on tidal freshwater wetlands – a case study

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Introduction

Wetlands in river deltas provide a great deal of natural resources. They are home to large numbers of plant and animal species, and supply local communities with many goods and services. They sequester carbon, provide water for irrigation and protect the shoreline from storm surges. At the same time, wetlands are affected by different forms of human activities: as most of them are located in fertile river deltas, they have to compete with other forms of land use like agriculture and settlements. This has resulted in the disappearance of about half of the original wetland area (Pendleton et al., 2012).

Apart from direct conversion of wetlands, there are other factors that threaten their continued existence. Sea level rise (SLR) in combination with factors such as decreased river sediment loads, local subsidence and the construction of levees is a major contributor to salt and brackish wetland loss at sites around the world, for example in the Mississippi Delta (e.g. Bloom and Roberts, 2012) and the Ebro Delta (Ibáñez et al., 2010).

More research is still needed to determine the effects of SLR, especially in the case of freshwater wetlands. Are they also at risk of drowning and if so, is there anything that can be done to prevent it? These are some of main questions that have sparked Utrecht University in September 2013 to start an STW-funded research project together with local stakeholders on the case of the Brabantse Biesbosch tidal freshwater wetland in the Netherlands. This wetland is suspected by the main stakeholders (State Forestry Service SBB and National Water Authority RWS) to be at risk of drowning.

The Brabantse Biesbosch is the name of a former inland delta in the Netherlands. It is located in-between the rivers Rhine and Meuse. It consists of a micro-tidal freshwater wetland as well as a number of polder systems used for agriculture. The wetland is part of “De Biesbosch” national park. A number of polders are currently being de-poldered, mainly as part of the Room for the Rivers project. The primary purpose of these activities is to increase the conveyance capacity of the river Rhine during extreme discharge situations and thereby lowering peak water levels upstream. A secondary purpose of the activities is to increase the space available for the wetland.

The PhD research project presented in this abstract focuses on the morphodynamic aspects of the effects of SLR for a number of future maintenance strategies and scenarios. It aims to quantify the water and sediment budgets of the area as well as the factors and mechanisms that affect these budgets.

Methods

There are many factors that determine whether the elevation of tidal wetlands is able to keep pace with SLR or not. These factors affect the primary components of the balance between SLR and net change in surface elevation. The net change in surface elevation is defined as the difference between deposition of sediments and autogenic primary production on the one hand and erosion and subsidence on the other hand (e.g. Reed and Cahoon, 1993).

When the different components of the balance are sufficiently quantified for different future scenarios, it becomes possible to evaluate the chance that the Brabantse Biesbosch will actually drown at some point in time.

The hydrodynamic and morphologic model Delft3D, developed by Deltares, will be used as a main method for the quantification of the different balance components. For two distinct pilot areas within the Biesbosch, detailed hydromorphologic schematizations will be constructed and calibrated based on the field data collected in a parallel PhD project. These schematizations will reflect both the current situation as well as possible future situations for a limited number of management strategies. Next, a number of future scenarios will be evaluated that consist of different combinations of climate-related variables (SLR, changes in discharges and sediment concentrations of Rhine and Meuse). The effects of local...
subsidence due to compaction will be included in the scenario simulations, possibly following the work of Van Asselen (2010). The effect of vegetation growth on wall friction, wetted area and autogenic primary production will be included as well, following on-going research (e.g. Van Oorschot, 2014).

When we consider SLR and local subsidence as a fact, the deposition of sediments and autogenic primary production remain as the two primary components that can be influenced in order to mitigate the effects of SLR. To this end, an optimization study will be carried out to determine the most effective way to increase the functioning of the pilot areas as ‘sediment traps’, using existing guidelines to enhance natural functions as much as possible.

After the methods have been properly validated on the scale of the pilot areas, they will also be applied to the Brabantse Biesbosch as a whole.

The research so far has focused on the “Kleine Noordwaard” pilot area. This is a former polder system that has been converted into a wetland by excavating a semi-natural channel network of ditches and creating openings in the surrounding embankments. During peak floods, this pilot area serves as a flood water storage and conveyance area. Daily tidal range is in the order of around 30-40cm. Average sediment concentrations in the system are in the range of 10-20 mg/L. The area was opened in 2008, allowing renewed flooding and sedimentation to take place. By 2014, most of the area is permanently inundated and vegetation is sparse.

Data sources available for model construction include AHN1 & AHN2 DEM, LIDAR elevations, yearly surveyed bathymetry (dual-beam echosounder) of the channel network, continuous water level measurements (diver), flow velocity measurements (H-ADCP) and sediment concentrations (STM) at a number of fixed gauging stations in and around the area. A Delft3D FLOW/SED/MOR model was constructed for the current situation. Calibration and validation of the model is currently underway.

Preliminary results
Since the research project only started recently, final results are not yet available. However, preliminary analysis of field experiments and model simulations has already provided some interesting results.

The sediment concentrations of the water entering the pilot area at the upstream boundary are low compared to other wetlands. This is reflected in the thickness of the sedimentation layer in the “Kleine Noordwaard” pilot area, which is estimated to be very thin (1-3cm in most places since the opening of the system in 2008) and appears to be very mobile due to the unconsolidated nature of the top soil.

The sedimentation pattern throughout the area is very non-uniform, and seems to be influenced by other factors than the distance from the inlet and the main channels (and subsequent gradients in flow velocities). We theorize that the process of (re)suspension due to wind may play an important role. It seems that the system depends on medium-high river discharge (with corresponding high sediment concentration) events for input of sediment and strong wind events for (re)distribution of sediment throughout the area.

It seems probable that different combinations of Rhine/Meuse river discharges, wind conditions and maintenance settings of the Haringvliet sluice barrier (which influences downstream boundary levels through backwater) will lead to very different net sedimentation rates in the pilot area. Some combinations will probably lead to net erosion.

Acknowledgements
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References
Explicit computation of dynamic bed form roughness for operational flood modelling using a time-lag approach

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Introduction
Accurate forecasts of water levels are essential for flood protection management. Hydrodynamic models are applied to predict water levels, which are used to estimate the risk of flooding, the design of dikes and assure timely warning. Recent studies have shown that the hydraulic roughness of the main channel is one of the largest sources contributing to the uncertainty in water levels.

Under flood conditions the river bed is highly dynamic; bed forms grow and decay as a result of the changing flow conditions. Knowledge of bed form evolution and associated roughness is limited. Most flood prediction models are calibrated using a constant and uniform roughness coefficient. However, in many bed form dominated rivers, a clear hysteresis between bed form geometry and discharge is observed, which occurs because there is a time-lag between changing flow conditions and the size of the bed forms. After the discharge peak, bed forms continue to grow about 20% in height (Paarlberg et al. 2010; Warmink, 2014). This effect is currently not taken into account in operational water level modeling for flood safety management.

Data
We modelled the discharge wave of October/November 1998, because extensive dune dimension data were available by Frings and Kleinhans (2008). They measured the dune dimensions at three locations at Pannerdensche Kop (Figure 1, Table 1).

<table>
<thead>
<tr>
<th>Sect.</th>
<th>Q_{peak} [m^3/s]</th>
<th>h_{peak} [m]</th>
<th>S_{mean} [m/m]</th>
<th>H_{max} [m]</th>
<th>L_{max} [m]</th>
<th>D_{50} [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>P0</td>
<td>9413</td>
<td>12.7</td>
<td>2.8e^{-4}</td>
<td>1.2</td>
<td>33.1</td>
<td>3.1</td>
</tr>
<tr>
<td>P1</td>
<td>6172</td>
<td>10.5</td>
<td>0.8e^{-4}</td>
<td>0.48</td>
<td>12.5</td>
<td>1.1</td>
</tr>
<tr>
<td>P2</td>
<td>3302</td>
<td>11.2</td>
<td>0.8e^{-4}</td>
<td>0.49</td>
<td>16.6</td>
<td>7.2</td>
</tr>
</tbody>
</table>

* Maximum dunes (H,L) occurred not at the same time as maximum discharge.

Method
As a test case, we followed the Sobek model approach presented by Paarlberg and Schielen (2012). Cross sections were defined approximately every 500 m, so large scale variations in river geometry are accounted for. We used the Sobek model for the three main distributaries of the river Rhine in the Netherlands with the upstream boundary at Ruhrort, Germany (Figure 1).

Coleman et al. (2005) bed form model
To predict the dune dimensions, we use the analytical time-lag approach presented by Coleman et al. (2005). This dune evolution model predicts the (non-equilibrium) dune dimensions based on only data of the water levels.

Coleman et al. (2005) adopted the commons scaling relationship for sand-wave development from an initially flat bed from Nikora & Hicks (1997) valid for $0.01 < t/t_e < 1$:

$$\frac{P}{P_e} = \left( \frac{t}{t_e} \right)^{-\gamma}$$

where $P$ is the average value of dune length or height, $P_e$ is the equilibrium value, $t$ is time, $t_e$ is the time to achieve $P_e$, and $\gamma$ is a growth rate parameter, resulting in different growth rates for dune height and dune length. The Allen (1968) predictor was used for equilibrium dune dimensions.

Coleman et al. (2005) used flume data to derive an empirical equation to predict the time-
to-equilibrium for dunes, based on shear velocity, \( u_* \), water depth, \( h \), the Shields number, \( \theta \), and critical Shields number, \( \theta_{cr} \):

\[
t_e \left[ \frac{u_*}{D_{50}} \right] = 2.05 \times 10^{-2} \left[ \left( \frac{D_{50}}{h} \right)^{-3.5} \right] \left[ \left( \frac{\theta}{\theta_{cr}} \right)^{-1.12} \right]
\]

SobekDune model
We imposed the observed discharge in Sobek to compute the water depths, given an initial roughness. For this water depth, the dune dimensions and associated roughness were computed for the three branches connecting to the PK bifurcation point. If at time, \( t \), the water depths or roughness changed more than 5\% compared to the start of the run, the water levels are re-computed using the updated roughness. These steps were repeated until the end of the modelling period. The results of the SobekDune model are compared to the calibrated Sobek model, without bed evolution.

Results
Both dune height and dune length are overestimated by the equilibrium predictor, which consequently results in an overestimation using the Coleman model (Figure 2). But, the time-lag was well represented.

The SobekDune model yields similar water levels as the calibrated Sobek model, but without the need for calibration. It shows a slower increase (more time-lag) of the roughness during the rising limb of the flood wave. The resulting water levels show a similar trend. The SobekDune and calibrated water levels show an error of around 20 cm, respectively, before to the flood wave (Figure 3). The peak water level was overestimated by 40 cm using the SobekDune model and by 60 cm for the calibrated Sobek model.

Conclusions
We conclude that
- The Coleman method can predict bed form evolution during a flood wave, but its accuracy mainly depends on an appropriate model to predict the equilibrium bed form dimensions.
- The Coleman dune model coupled with Sobek can explain a large part of the bed form roughness that is normally calibrated in a field situation.

In future work we will apply more detailed physically based models to predict dynamic bed form roughness.

Acknowledgements
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![Figure 2. Dune height predicted by Coleman using observed water levels just upstream of PK (Upper Rhine branch).](image2)

![Figure 3. Water level differences from the SobekDune model for location P0.](image3)
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NCR’s goal is to build a joint knowledge base on rivers in the Netherlands and to promote (and bring into practice) cooperation between scientific institutes in the field of river studies in the Netherlands. This cooperation strengthens the national and international position of Dutch scientific research and education and contributes to the leading role of the Netherlands in river engineering and river management.

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