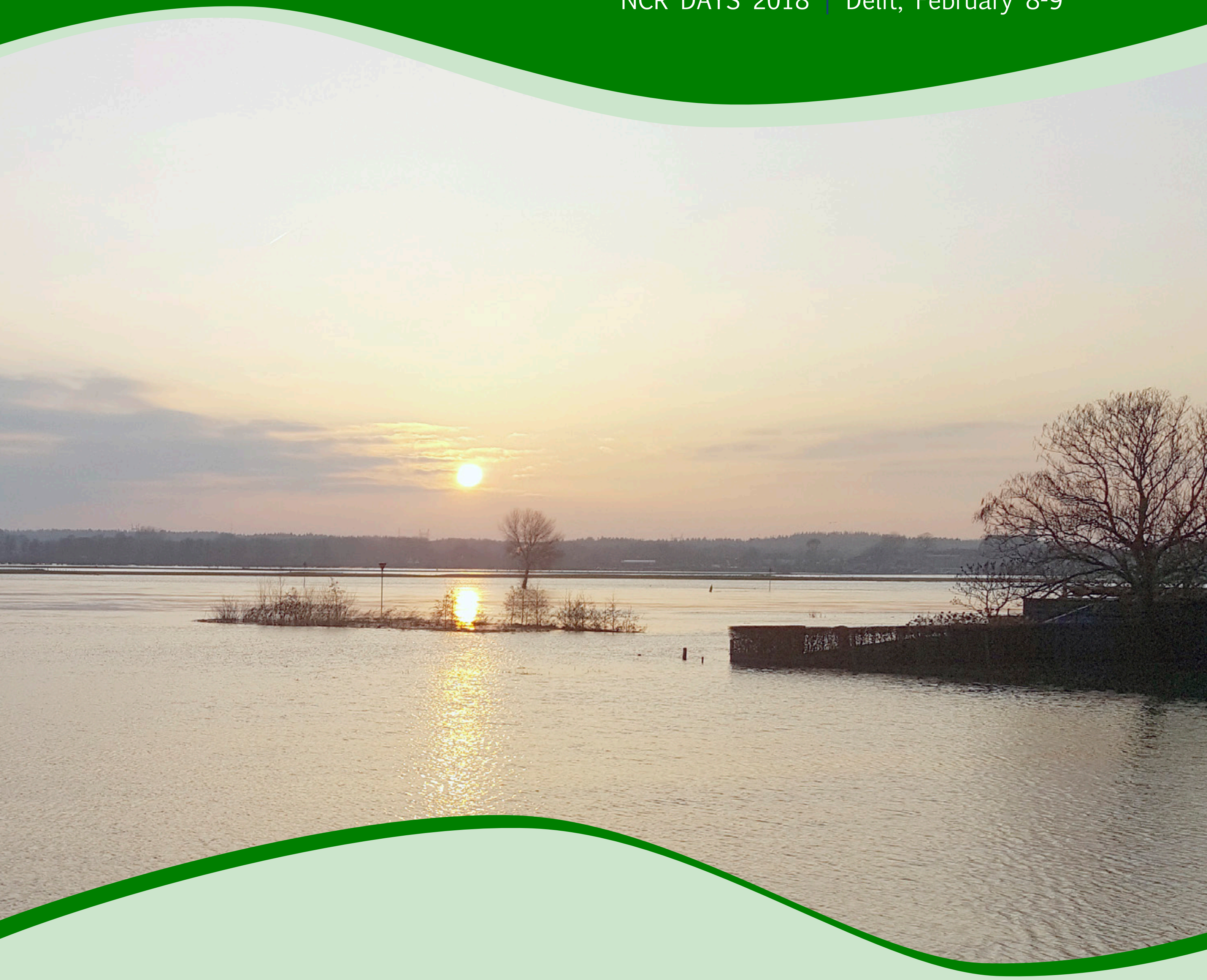
Book of abstracts

NCR DAYS 2018
The future river
Celebrating 20 years NCR

The Future River

NCR DAYS 2018 | Delft, February 8-9



Ymkje Huismans, Koen D. Berends,
Iris Niesten, Erik Mosselman (eds.)

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Netherlands Centre for River studies

NCR DAYS 2018

The future river

Ymkje Huismans, Koen D. Berends, Iris Niesten & Erik Mosselman (eds.)

Organising partner:

Co-sponsored by:

Conference venue
Deltares
Boussinesqweg 1
2629 HV Delft
P.O. 177
2600 MH Delft
The Netherlands

telephone: +31 88 335 82 73
fax: +31 88 335 85 82
e-mail: info@deltares.nl
www: https://www.deltares.nl

Contact NCR
ir. K.D. Berends (Programme Secretary)
Netherlands Centre for River Studies
c/o University of Twente
P.O. box 217
7500 AE Enschede
The Netherlands

telephone: +31 6 21 28 74 61
e-mail: secretary@ncr-web.org
www: http://www.ncr-web.org

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Top: Waal River from Slot Loevestein. E. Mosselman (2012)
Bottom: IJssel river from Zwolle. J.S. Huismans (2018)

Contents

Preface

It's an honour to welcome you at Deltares for the 20th edition of the NCR-days! Celebrating 20-years of collaboration in the Netherlands Centre for River studies (NCR), we will look back and especially forward, with a broad scope of keynote lectures, workshops, presentations, interactive posters and movies around the theme "the Future River".

Since 1998, the Netherlands Centre for River studies (NCR) provides an open platform for all people interested in fluvial scientific research and communication. This anniversary edition introduces a new element to the traditional two-day meeting: presentations are now given over eight parallel sessions, facilitating a record number of presentations. We do not break with tradition on all things though: the "Hyde Park Corner" poster pitches, NCR-quiz and a technical tour (which made a comeback at the NCR Days 2017) are on the program! Furthermore, we welcome special guests **Ad van Os**, NCR Programme Secretary from 1998 to 2008 and one of the founding fathers of NCR; and **Jolien Mans**, NCR secretarial support until 2014.

The first keynote lecture will be given by **Toon Bosch**, historian on water management and professor at the open University. In his lecture "the future of rivers in history" he will illustrate the modernisation of river engineering in five exposures, starting around 1750 up to present. In present days, communication and stake holder participation are becoming increasingly important. The second keynote lecture "Beauty in river management communication", is focussed on communication and visualisation of river management developments. This presentation will be given by **Ties Rijcken**, innovator and publicist on water at Flows and at Delft University of Technology. With advancing technology, numerous new measurement techniques have developed and introduced in river engineering. **Paul Kinzel**, from the United States Geological Survey in Colorado (USA), will show us new developments and discuss their future perspective for river management in his lecture "Riverine Remote sensing : present capabilities and future directions". An important and perhaps under-exposed (at least, in the scientific sense) function of the river is inland navigation. Rhine-commissioner and advisor on inland navigation at the Ministry of Infrastructure and Public Works, **Ivo ten Broeke**, will give a future perspective on inland navigation and the relation with river management.

Organising the NCR Days is a pleasant but time-consuming activity, in which we greatly benefited from the support of many colleagues. We thank Erik Mosselman for his support on selecting abstracts, Bas van de Pas for organizing the online registration and Monique te Vaarwerk, Paul Vreeswijk, Welmoed Jilderda, José Schrijer and Martijn Bregman, Amr Rouash and Gustav Nientker for their help during the days! We gratefully acknowledge Deltares and NWO Science for (co-)sponsoring the NCR Days 2018.

We hope you will all enjoy this special edition of the NCR Days!

Ymkje Huismans, Koen Berends, Iris Niesten, Truus Karlas - van Panhuis
Nick Leung, Gertjan Geerling and Jaap Kwadijk

Conference Details

Organising Partner

Deltares is an independent institute for applied research in the field of water, subsurface and infrastructure. Throughout the world, we work on smart solutions, innovations and applications for people, environment and society. Our main focus is on deltas, coastal regions and river basins. Managing these densely populated and vulnerable areas is complex, which is why we work closely with governments, businesses, other research institutes and universities at home and abroad. Our motto is Enabling Delta Life. As an applied research institute, the success of Deltares can be measured in the extent to which our expert knowledge can be used in and for society. For Deltares the quality of our expertise and advice is foremost. Knowledge is our core business. All contracts and projects, whether financed privately or from strategic research budgets, contribute to the consolidation of our knowledge base. Furthermore, we believe in openness and transparency, as is evident from the free availability of a selection of our software and models. Open source works, is our firm conviction. Deltares employs over 800 people and is based in Delft and Utrecht.

Local Organising Committee

Ymkje Huismans

Koen Berends

Iris Niesten

Truus Karlas - van Panhuis

Nick Leung

Gertjan Geerling

Jaap Kwadijk

Program

NCR Days 2018 Conference programme

Version: January 31, 2018

Thursday, February 8

Main Building - Delta Plaza		
09:00	Registration *Coffee and tea*	
09:40 – 9:55	**Opening & announcements** Jaap Kwadijk (*Deltares, University of Twente)*	
Main Building - Colloquium		
9:55 – 10:35	**The future of rivers in history** Antoon Bosch (*Open University)*	
10:35 – 10:55	**Poster pitches (sessions 1a, 1b, 2a, 2b)**	
Main Building - Delta Plaza		
10:55 – 11:30	Break	
	Pavilion 1	**Pavilion 2**
11:30 – 12:30	**1a - Morpho- and hydrodynamic processes** *Chair: Tjitske Geertsema (Wageningen University & Research)*	**1b - Rivers, health and ecosystems** *Chair: Gertjan Geerling (Deltares)*
11:30 – 11:45	**Decreasing lateral migration and increasing planform complexity of the Dommel River during the Holocene** Jasper Candel (Wageningen University & Research)	**Effect of longitudinal training dams on environmental conditions and fish density in the littoral zones of the river Rhine** Frank Collas (Radboud University Nijmegen)
12:00 – 12:00	**Nourishments as part of the future Dutch river management: insights from a pilot** Iris Niesten (Deltares)	**Spatial prediction of macrophyte species in rivers using environmental key factors** Rick Wortelboer (Deltares)
12:00 – 12:15	**Turbulence in scour holes of sharp bends** Rik Posthumus (University of Twente)	**Modelling effects of spatiotemporal temperature variation on native and alien fish species in riverine ecosystems using thermal imagery** Frank Collas (Radboud University Nijmegen)
12:15 – 12:30	**Dune response to non-equilibrium flow** Suleyman Naqshband (Wageningen University & Research)	**Is the trait concept applicable to floodplains of regulated, temperate, lowland rivers?** Valesca Harezlak (University of Twente)
Main Building - Delta Plaza		
12:30 – 14:00	Lunch & Poster sessions 1a, 1b, 2a, 2b *see poster programme*	
Main Building - Colloquium		
14:00 – 14:40	**Beauty in river management communication** Ties Rijcken (Delft University of Technology)	

Thursday, February 8		
	Pavilion 1	**Pavilion 2**
14:45 – 15:45	**2a - Effectively communicating & participating in fluvial science** *Chair: Robert-Jan den Haan (University of Twente)*	**2b - Advances in fundamental modelling and measuring** *Chair: Allessandro Cattapan (Unesco IHE)*
14:45 – 15:00	**Assessing sense of place to support river landscape planning** Sarah Gottwald (Leibniz University Hannover)	**Parametric model of wood-induced backwater in lowland streams** Tjitske Geertsema (Wageningen University & Research)
15:00 – 15:15	**Involving citizens in monitoring river interventions: Lessons learned from a river Waal case study** Laura Verbrugge (University of Twente)	**Secondary Flow and Bed Slope Effects Contributing to Ill-posedness in River Modelling** Victor Chavarrias (Delft University of Technology)
15:15 – 15:30	**Usefulness of storylines to increase the accessibility and transparency of RiverCare knowledge** Juliette Cortes Arevalo (University of Twente)	**The influence of transverse slope effects on large-scale morphology in morphodynamic models** Anne Baar (Utrecht University)
15:30 - 15:45	**A water availability serious game for the Rhine-Meuse delta** Remi van der Wijk (Deltares)	**Using a lightweight polystyrene sediment to resolve dynamic scaling issues in fluvial dune modelling** Bas Wullems (Wageningen University & Research)
15:45 – 17:45	Technical tour "Flood-proof Holland"	NCR boards meeting
19:00 - 22:30	Conference dinner & Pubquiz Restaurant t Postkantoor	

Friday, February 9		
Main Building - Colloquium		
08:30	Registration *Coffee and tea*	
09:00 – 9:10	**Opening & announcements** Jaap Kwadijk (*Deltares, University of Twente)*	
9:10 – 9:50	**Riverine remote sensing: present capabilities and future directions** Paul Kinzel (*USGS*)	
9:50 – 10:10	**Poster pitches (sessions 3a, 3b, 4a, 4b)**	
Main Building - Delta Plaza		
10:10 – 10:45	Break	
	Pavilion 1	**Pavilion 2**
10:45 – 11:45	**3a - Towards multifunctional self-sustaining rivers** *Chair: Jan Fliervoet (Radboud University Nijmegen)*	**3b - Advances in modelling large-scale systems** *Chair: Victor Chavarrias (Delft University of technology)*
10:45 – 11:00	**Residual biomass from riverine areas – transition from waste to ecosystem service** Astrid Bout (Radboud University Nijmegen)	**Finding common ground: uncertainty analysis made practical through Bayesian regression of correlated output** Koen Berends (University of Twente)

Friday, February 9		
11:00 – 11:15	**Quantifying biomass production in floodplains along the Rhine river distributaries** Remon Koopman (Radboud University Nijmegen)	**From time series to probability density functions at the boundaries in morphodynamic modelling** Liselot Arkesteijn (Delft University of Technology)
11:15 – 11:30	**Drivers and challenges for river management in the circular economy** Jeroen Rijke (HAN University of Applied Sciences)	**The influence of the vegetation structure on the water flow through the Noordwaard (Brabant, The Netherlands)** Derk Jan Stobbelaar (Van Hall Larenstein University of Applied Sciences)
11:30 – 11:45	**PRIMA: A method for performance based asset management of the rivers** Wouter Rozier (Rijkswaterstaat Ministry of Infrastructure and Water management)	**Numerical River Laboratory: platform for long term development of river systems** Aukje Spruyt (Deltares)

	ID Lab	Colloquium	Classroom
11:50 – 12:50	**Workshop** Communicate through storylines	**Workshop** Upstream: a documentary	**Workshop** Dare to share your river research datasets

Main Building - Delta Plaza	
12:50 – 14:20	Lunch & Poster sessions 3a, 3b, 4a, 4b *see poster programme*

Main Building - Colloquium	
14:20 – 15:00	**The future of inland navigation in Europe:** **climate change, transport economics and water level management** Ivo ten Broeke (*Ministry of Infrastructure and Water Management*)

	Pavilion 1	Pavilion 2
15:00 – 16:00	**4a - Estuaries and deltas** *Chair: Ymkje Huismans (Deltares)*	**4b - Understanding river engineering** *Chair: Bart Vermeulen (University of Twente)*
15:00 – 15:15	**Sedimentation in the mouth of the Magdalena river** Lindert Ambagts (Delft University of Technology)	**On the uptake of natural water retention measures in German flood risk management – How far have we got?** Mario Brillinger (Leibniz University Hannover)
15:15 – 15:30	**Morphology, water discharge and suspended load distribution along the Mara River Wetland, Tanzania** Francesco Bregoli (IHE Delft)	**Influence of water level duration on dike breach triggering in system behaviour** Alex Curran (Delft University of Technology)
15:30 – 15:45	**Water and sediment transport in the Biesbosch Freshwater Tidal Wetland** Eveline van der Deijl (Utrecht University)	**Response of flow and bed morphology to the introduction of large wood for sediment management** Judith Poelman (Wageningen University & Research)
15:45 – 16:00	**Scour holes in heterogeneous subsoil: A numerical study on hydrodynamic processes in the development of the scour holes** Sam Bom (Delft University of Technology)	**Flow Bifurcation at a Longitudinal Training Dam: a Physical Scale Model** Timo de Ruijsscher (Wageningen University & Research)

Main Building - Delta Plaza	
16:00 – 17:00	*Drinks and best poster award*

Poster programme

Thursday, February 8	
12:15 – 13:45 | Main Building - Delta Plaza	
1a - Morpho- and hydrodynamic processes	
Poster 01	**Morphodynamic Changes around a Bridge Pier** Fatima Azhar (IHE Delft)
Poster 02	**Analysis of sediment transport dynamics in the Piave River Basin to define hotspots of geomorphic change** Usman Ali Khan (IHE Delft)
Poster 03	**The historical river: morphology of the Rhine before river normalization** Bas van Meulen (University of Utrecht)
Poster 04	**Spatial and temporal variations in Meuse river terraces in the Roer Valley Rift System** Hessel Woolderink (VU Amsterdam)
2a - Effectively communicating and participating in fluvial science	
Poster 05	**Visual Problem Appraisal Rhine river branches. A film based learning strategy for sustainable river management** Jacomien den Boer (HAN University of applied sciences)
Poster 06	**How to prepare your River Studies Data for the future with 4TU.Centre for Research Data** Jasmin Boehmer (Delft University of Technology)
Poster 07	**How to create user-descriptions and scenarios to design a knowledge-base for RiverCare research?** Evelyn van de Bildt (University of Twente)
Poster 08	**Collaborative monitoring in Dutch river management: Case study WaalSamen** Lotte van den Heuvel (Radboud University Nijmegen)
Poster 09	**Prototyping Virtual River** Robert-Jan den Haan (University of Twente)
Poster 10	**PlanSmart: a research group exploring approaches to planning and governing nature-based solutions** Christian Albert (Leibniz University Hannover)
2b - Advances in fundamental modelling and measuring	
Poster 11	**Deriving Grain Size Distributions From UAVs Images** Alessandro Cattapan (IHE Delft)
Poster 12	**Numerical Modelling of Erosion of Sediment from Reservoirs** Sudesh Dahal (IHE Delft)

Friday, February 9

12:30 – 14:00 | Main Building - Delta Plaza

3a - Towards multifunctional, self-sustaining rivers	
Poster 13	**Water quality management in Upper Citarum River: understanding and influencing policy to improve water quality** Lufiandi (Institut Teknologi Bandung)
Poster 14	**The Rhine Meuse delta: an aspired UNESCO Global Geopark** Brendan McCarthy (Landkracht)
Poster 15	**Interorganizational Collaboration and innovation: towards Self-Supporting River Systems** Astrid Bout (Radboud University Nijmegen)
Poster 16	**Integral development and new combinations of functions at stone factory terrains in the floodplains** Sara Eeman (Van Hall Larenstein University of Applied Sciences)
3b - Advances in modelling large-scale systems	
Poster 17	**Large-scale uncertainties in river water levels** Matthijs Gensen (University of Twente)
Poster 18	**Discharge and location dependency in calibrated main channel roughness: case study Waal river** Boyan Domhof (University of Twente)
Poster 19	**Flood patterns in the Old IJssel Valley** Anouk Bomers (University of Twente)
Poster 20	**Flood modelling along the Dutch and German Rhine with extreme discharge waves by SOBEK1D2D** Asako Fujisaki (Deltares)
Poster 21	**Estimation of daily discharge for the river basins under different natural conditions in Latvia** Anda Bakute (Latvia University of Agriculture)
4b - Understanding river engineering	
Poster 22	**Flood level peaks at downstream terminations of Room-for-the-River projects** Jerry Gerges Tadrous (Delft University of Technology)
Poster 23	**Towards a quantitative assessment of the influence of heterogeneity on piping** Willem-Jan Dirkx (Utrecht University)
Poster 24	**Role of bhawana bridge on Chenab river flooding, Punjab, Pakistan** Muzaffar Khan (IHE Delft)
Poster 25	**Effects of groynes on opposite bank erosion: a modelling approach** Tsegaye Tiga (IHE Delft)
Poster 26	**Modelling assessment of the effectiveness of groyne lowering as a measure for bed stabilization** Simon van Laarhoven (Utrecht University)
Poster 27	**Response of engineered channels to changes in upstream controls: Simplified 1D numerical simulations** Meles Siele (Delft University of Technology)
Poster 28	**Subsurface heterogeneity at different spatial scales: Impact on piping hazard zones in the Netherlands** Tim Winkels (Utrecht University)

Invited abstracts

Future of rivers in history. Five moments in time and space – circa 1750-present

Invited abstract

Toon Bosch[a*]

[a]*Open University, P.O. Box 2960, 6401 DL, Heerlen, the Netherlands*

Keywords — History of river engineering

Abstract

River engineering is an old craft in the Dutch delta. Seminal works on the history of Dutch water management informs us about the cutting of meanders, damming of rivers and the construction of groynes and lateral diversions since at least the early Middle Ages. This kind of river engineering usually concerned smaller watercourses. Improving the navigability and safety of large rivers as the Lower Rhine, the Waal and the Meuse only became an issue of (large scale) importance since the beginning of the 18th century as one realized that these rivers were in a bad condition. This caused commercial damage, weakened the military defence and spread fear for catastrophic floods, which indeed occurred to an increasing extent. Under pressure of this deteriorating conditions civil servant, surveyors, hydraulic craftsmen, military engineers and scientist developed all kinds of propositions to improve the unruly Dutch rivers in future. In my opinion their work marks in several ways a turning point in the future of river engineering in the Netherlands, said in other words, we can speak in this respect of the birth of modern river engineering.

Modern because this ensuing – and still ongoing – 'river discourse' gradually introduces theoretical hydraulic knowledge in the craft of engineering (transnational knowledge exchange: Germany, Italy, France); modern because it accomplished a shift in river engineering from a local and regional approach to a national scale of river management; because its contribution to public debates in former papers and magazines and last but not least because of conducting several large scale works in the eighteenth century to redistribute the Rhine water on its Dutch branches. These kind projects, which grew in number, reflected both the state of the art in river engineering as the ideas and hopes for the future of rivers. In my presentation I'll frame this modernization of river engineering in five exposures, starting around 1750 and ending around 11 o' clock in the morning of 8 February 2018 in Delft.

Figure 1. Rhine breaches at Grebbedijk between Rhenen en Wageningen in 1855. Het Gelders archief.

Figure 2. Room for the River close to Nijmegen, completed in 2016. https://beeldbank.rws.nl, Rijkswaterstaat / Johan Roerink.

* Corresponding author
Email address: toon.bosch@ou.nl (Toon Bosch)

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The Meuse in the Dutch province of Limburg (1839 - 1925) in: Physics and Chemistry of the Earth Volume 34, Issue 3, pp. 109-118.

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Beauty in river management communication

Ties Rijcken[a,b*]
[a]*Ties Rijcken Ontwerp en Advies | Flows, Berkenhof 2, 3612AK Molenpolder*
[b]*Delft University of Technology, Stevinweg 1, 2628 CN Delft*

Keywords — River management, river engineering, landscape quality, flood protection, freshwater conveyance, decision support

Beauty in river management

The central proposal in Ties Rijcken's talk at the NCR river days is to have future river management and science revolve around the concept of *beauty* – on various levels: beauty in the way the river system serves the needs of society, beauty in the way it is studied, beauty in the way it is perceived through the senses and beauty in the way all this is visualised and communicated among experts and between experts and stakeholders.
The talk builds on his dissertation *Emergo* (written between 2012 and 2017) and the internet platform *Flows* (under development since 2015).

Dissertation *Emergo*: the Dutch flood risk system since 1986

In 1986, the completion of the Eastern Scheldt barrier made Dutch flood risk policymaking world famous. What has happened since then? The comprehensive *historical policy analysis* in Ties Rijcken's thesis identifies three trends. National investments in flood protection have continued and were strongly supported by refined risk and acceptable risk analyses. The interplay between flood risk reduction and other water system objectives played a major strategic role and can be described by an upward movement in *'Maslow's hierarchy for water infrastructure development'*, a concept introduced in this thesis. Nature development and landscape quality have become increasingly important, but a policy discourse analysis reveals a struggle to get to grips with these objectives and to find a balance between quantitative and narrative decision support.

* Corresponding author
Email address: t.rijcken@tudelft.nl (T. Rijcken)
URL: www.flowsplatform.nl

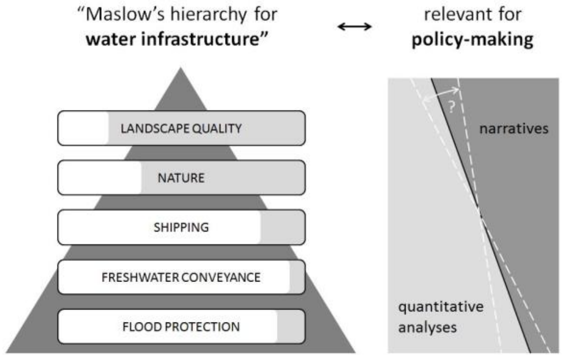


Figure 1. Roughly, objectives lower in 'Maslow's hierarchy for water infrastructure development' are more often supported by quantitative models and objectives higher up with narratives. This scheme suggests that narrative decision support grows when a society climbs the hierarchy.

Internet platform *Flows*: supporting water professionals and involved citizens with insight and inspiration

Flows is an independent stylized system map-based internet platform for science-policy interfacing that organizes, curates, filters and presents any document and map produced in the water sector. Flows allows users to be updated with the latest reports, papers and theses based on a personalized profile and to obtain quick insight into water system behavior through the clear maps based on a standardized, stylized graphic mapping style.
Current map-based science-policy interfaces are often communication efforts connected to (and not independent of) a knowledge project, and therefore pay only limited attention to effective interfacing and reaching a wider audience.
The Flows graphic mapping style and map interface are unique because

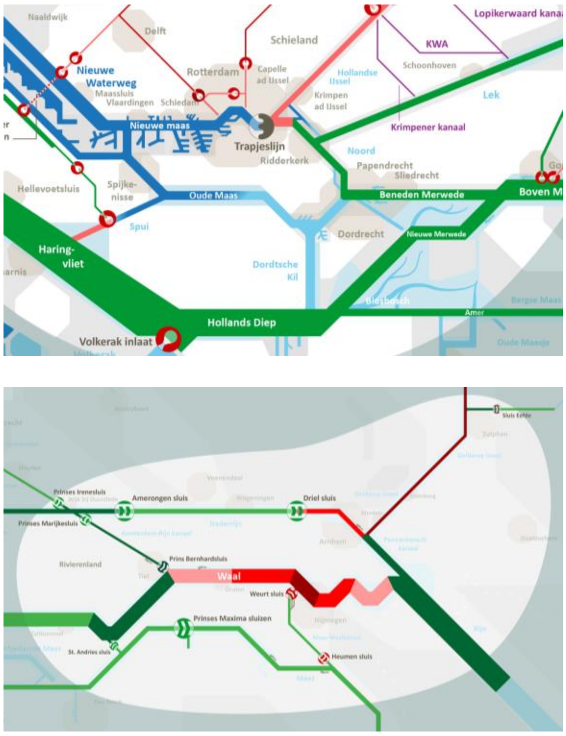
- They apply principles from transit maps (e.g. subway maps) that simplify the representation of systems based on the cognitive limitations that humans have for understanding complex networks.
- They are designed to redraw existing maps quickly on a rough level and then refine according to the wishes of clients and users.
- They allow for fast and intuitive understanding and comparison between

maps for shipping, flood control, freshwater supply, and ecosystem services (and their interdependencies), made by different institutions, in different times and for different future scenarios.

- They are designed to present data gaps and uncertainty as part of the status in which (parts of) a water system may occur.

The Flows algorithms apply smart aggregation methods to provide users with a personalized feed from the large supply of water-related (scientific) information that best match their scope of interest. Content uploaders apply tags; a ranking is added by the Flows algorithm with input from the editorial board; end users fill in a personal profile of preferences. The tags allow for filtering by end users, the personal profile and the ranking determine which documents are presented first to users.

In his NCR river days talk, Ties Rijcken will explain the essential aspects of Flows and talk about communication technology as a means to improve the relationship between river science and river landscape quality.



Figures 2 Flows representation of the freshwater conveyance system of the Dutch tidal rivers and the shipping system of the Dutch upper rivers (data from Deltares and other sources).

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Riverine remote sensing: present capabilities and future directions

Invited abstract

P.J. Kinzel[a*]

[a] *United States Geological Survey's Geomorphology and Sediment Transport Laboratory, Golden, Colorado, USA.*

In past few decades, river scientists have experienced a technical revolution with regard to the sensors and platforms available for collecting fluvial measurements at finer spatial and temporal resolutions. Satellites and manned platforms have and will continue to provide remote sensing data for river studies at large spatial scales. However, advances in micro-sensors and unmanned aerial systems (UAS) for reach-scale investigations offer the potential to acquire data at a fraction of the cost of conventional approaches and are progressing at a frenetic pace. We first present a project conducted along 50 river kilometers of the Kootenai River in Idaho, USA. This project used conventional manned platforms and a suite of sensors including bathymetric lidar to map the channel bathymetry, hyperspectral imaging to track the dispersion of a rhodamine dye plume, and thermal videography to measure surface velocity. In contrast, we present a small-scale field study at the River Experiment Center (REC) in Korea. At the REC we used multiple UAS and sensors to collect a suite of observations including hyperspectral imagery also to track a dye plume. Taken together, these projects demonstrate the present capabilities of both manned and unmanned systems and provoke several questions. At present, what place do UAS technologies have in our fluvial remote sensing toolbox? What are their current technological and regulatory limitations? More importantly, what are the future contributions of these platforms to both science and society?

* Corresponding author
Email address: pjkinzel@usgs.gov (Paul Kinzel)

The future of inland navigation on the european waterway network

Ivo ten Broeke[a*]
[a]Ministry of Infrastructure and Water Management, Rijkswaterstaat VWM, P.O. Box 2232, 3500 GE Utrecht

Keywords — Transport, Inland Navigation

Introduction

In our history and development since the Stone age we see that humans tend to live near the water. It is not a surprise when evaluating the growth of villages and cities the majority can be found near the larger rivers. When drinking water and water for irrigation might be the primary reasons, mankind has from the beginning also used the waterways for transport. Although not commonly known also today inland navigation transport is a very important transport mode looking at the model split and the total amount of goods carried. It is crucial that transport on rivers remains possible in the future. It would be an environmental disaster if these goods should be transported by road or rail having an enormous negative effect on the carbon footprint of transport.

Figure 1. Modern container vessel on the Waal.

Economic importance of Inland Navigation

In Europe – measured in tonnes transported – over 80% of the inland navigation can be found on the Rhine. The largest transport volume is sailing between the Port of Rotterdam and Duisburg. The annual volume of transshipment in the Port of Rotterdam is about 460 million tonnes of which 50% is being carried to the Hinterland by inland navigation. Looking at the added value of the maritime ports to the economy in the Netherlands the importance of inland navigation becomes evident. The same principles also apply to the ports of Antwerp and Amsterdam. The transport policy for continental transport tries to use all available transport modes to their optimal performance. Inland navigation has the biggest capacity for growth and is considered as an environmental friendly mode of transport. Although here newest information shows that this position may be in danger because of the more easy application of new technologies in road transport.

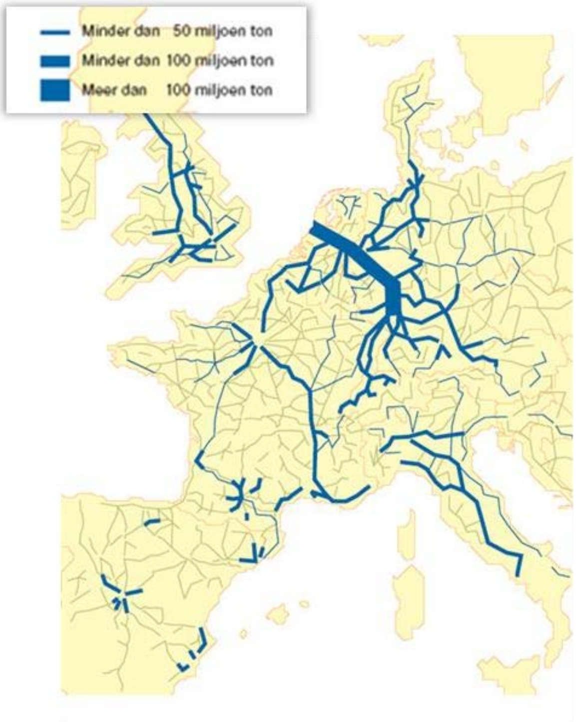

Figure 2. Continental transport volumes in Europe.

Inland Navigation developments

The inland navigation market mainly transports bulk cargo. Both dry bulk and liquid bulk are transported. However, over the last 30 years inland navigation has developed the transport of containers with great success. Around 35% of all container transport is now being executed by inland navigation. A typical inland container vessel carries up to 500 TEU which represents more than 250 trucks. Liquid bulk transport has

* Corresponding author
Email address: ivo.ten.broeke@rws.nl (Ivo ten Broeke)

transformed their fleet from single hull to double hull vessels for safety reasons. There is a general trend towards the use of larger vessels. The typical horizontal vessel dimensions have nowadays reached a length of 135m and a beam of 22,80m.

Climate Change

Important for inland navigation is the availability of sufficient water level in the waterway network. A general trend can be seen towards a less stable discharge in the rivers. Due to climate change especially longer periods of high and longer periods of low water are expected. Although some claim it is already happening, climate studies have indicated that in the second half of this century these developments will influence inland navigation. Especially the predicted longer periods of low water requires our attention. With longer periods of low water the transport prices will rise and the longer such periods will become the more industries will start looking for other means of transport. If the low waters will become lower other developments may occur. If for longer periods the water level will drop below 2 m it is expected that inland navigation will no longer be economically feasible. This may result in major problems for transport as the volumes being transported by inland navigation cannot easily be transported by other means of transport due to the lack of infrastructure and the lack of space for such infrastructure. Here too it is clear that especially in the Netherlands with the rise of the sea level, the increasing problem of saline ground water and the need for sufficient fresh water for drinking water and agriculture in combination with inland navigation poses new challenges to find solutions to serve all purposes.

International Treaties

In 1815 during the Congress of Vienna the Central Commission for Navigation on the Rhine (CCNR) was established. The purpose of the CCNR was to guarantee that navigation on the Rhine would be free of any charges in order to become a stimulating factor for the economy and prosperity of the nations through which the Rhine traveled from Switzerland to the North Sea. In 1868 the Member States signed the Act of Mannheim in which more detailed arrangements were settled among the members of the CCNR. Apart from the freedom of navigation it was also agreed that the CCNR should issue rules and regulations concerning the safety of navigation. And the member states committed themselves to remove obstacles in the flow of the Rhine and to establish better navigation conditions. Still following the Act of Mannheim today, the CCNR member states are obliged to safeguard the existing navigation conditions and if possible improve them.

Figure 3. Original signed Act of Mannheim.

Outlook

The major issue in the future of inland navigation in Europe will be – apart from the maintenance of canals and the construction of sufficient capacity of locks in canals – the development of the water levels in the rivers. Although not being considered realistic at the moment even the canalization of the Rhine with weirs and locks downstream of Iffezheim may be an options that requires serious consideration taking into account the future transport demands for the European development.

Upstream: a documentary

Invited abstract

Joren Janzing[a*] and Stan J. Schouten[a*]
[a]*Utrecht University, Department of Physical Geography, Faculty of Geosciences*

Keywords — Rhine, Climate Change, Adaptation

Introduction

The Rhine is of vital importance for Western Europe. From its source in the Alps, it crosses 6 countries on its ways to the Dutch delta. However, it also has a large potential for water related problems and climate change will only increase their frequency. The number of extreme precipitation events will increase and from modelling studies, it is known that this will lead to more extreme discharges in the Dutch part of the Rhine (Fig. 1) (Sperna Weiland et al., 2015). While this happens, other parts of the river's catchment area have to face different problems. Switzerland has to deal with a shift in its precipitation regime due to rising temperatures, which has consequence for its discharge (Sperna Weiland et al., 2015). Along the river, major adaptations are needed to prevent disasters related to climate change from happening.

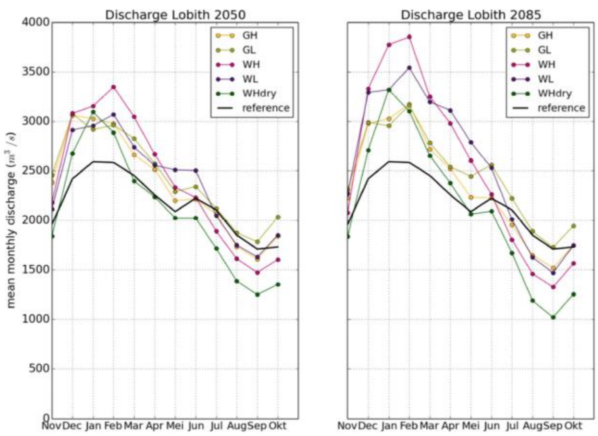

Figure 1. Modelled discharge regimes of the Rhine at Lobith in the KNMI'14 scenarios compared to the current regime (black). (Sperna Weiland et al., 2015)

Luckily, a lot of action has been undertaken to deal with these future problems in the Netherlands. It is no coincidence that it has been decades since a major flood has taken place. As a consequence, these kinds of climate related problems remain something vague for in the future. However, the preventive measures undertaken often have major consequences for the inhabitants of the areas along the Rhine. How can we make adaptations which not only protect us from the water on a longer time scale, but also benefit the local inhabitants in the short term?

* Corresponding authors
Email address: g.w.janzing@students.uu.nl (Joren Janzing)
Email address: s.j.schouten@uu.nl *(Stan Schouten)*
URL: facebook.com/upstreamdocumentary

Method

It was decided that the best way to reach our goal, was to make a documentary, since this medium allows showing the diversity of the Rhine and its problems. In addition, it facilitates reaching and informing a vast audience. The documentary is produced by five bachelor students. In the scope of one year, they carried out research into this topic, interviewed experts in the field of climate change and its effect on rivers and made appointments with project managers in Switzerland, Germany and the Netherlands. This was followed by one week in which they travelled along the banks of the Rhine to film the adaptations undertaken. To fund the documentary, a crowdfunding was organised.

The film is aimed at starting a discussion about the subject of adapting to climate change.

Results and Conclusion

The result of this project is the documentary 'Upstream', which had its premiere at the InScience Film Festival Nijmegen in November 2017.

In the documentary, we present different projects along the banks of the Rhine in an attempt to find the best way to adapt to threats posed by climate change. Every region faces different problems, but they all have the same goal in mind: to make sure that the Rhine can flow from the Alps to the North Sea without causing any trouble on its way, so it can play the important role it always has. The importance of giving projects more than one function is stressed: not only prevention, but also recreation is important in order to benefit the community. Furthermore, it is shown that it is important to involve local parties and citizens in the developing process to find support already in an early stage.

The authors express the hope that the viewers start to think about the process of developing landscape measures and how to improve this. In addition to that, they hope that people learn more about the adaptations in the field of water management around them.

Acknowledgements

The authors express gratitude to the experts interviewed and the people at Utrecht University who gave them the opportunity to produce this film. They want to thank Deltares, Royal HaskonigDHV, ScienceMedia.nl, Utrecht University, the Province of Gelderland and all private parties for their support. Finally, they thank the rest of the film crew, without who there would not have a film in the first place.

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Interactive notebooks: reproducible research for River scientists

Invited abstract

Fedor Baart[a,*], Aukje Spruyt[a]

[a] *Deltares*

Keywords — River research, Methods, Notebooks, Reproducibility

Introduction

The reproducibility crisis (Baker, 2016) that emerged in different fields over the last years has resulted in a higher expected research quality level. Many fields such as coastal research Ciavola et al. (2017), biology Forstmeier et al. (2017), and psychology Fox et al. (2017) have reset the quality standards for research methods. In the field of hydrology Fienen and Bakker (2016) concluded that there was a "lack of transparency and repeatability that may cover up mistakes, judgments based on thinking that can change over time, and, at worst, manipulation or fraud" and called for auditability of both code and data. Many other fields have also shifted from a closed to open-data approach, where it is now expected that you deliver highly reproducible research.

Reproducibility in this context refers to the possibility of others to confirm your results using the same methods and data. A related aspect is replicability, which refers to the possibility of others to come to the same conclusion using a different dataset or using a different research approach. Both are important aspects of the scientific method but have fallen into dismay under the increased publication pressure (Baker, 2016).

In this study, we show how reproducibility can be enhanced by the use of interactive notebooks Pérez and Granger (2007). We show which aspects of the more general concept of confidence can be addressed and discuss how we can improve the confidence river research using this modern approach to reproducibility.

Notebooks and their applications

The use of notebooks has grown popular over the last few years. A notebook is a browser-based interactive document that includes both formatted text, source code, and results. Notebooks are designed to make data analysis more interactive, shareable and reproducible. It is used by teachers to provide examples, researchers to share their methods, and by data scientists to explore their datasets.

It reuses some aspects previously seen in other systems. It has its origins in workbooks often used by mathematicians such as Mathematica (started with the idea of the notebook in the 1980's) and Sage (started with a web-based notebook in 2005). The focus on more general applicability and integration of functionality like making presentations, exporting to documents made the jupyter notebooks the most current installment of the concept.

The main applications that we have seen so far in river research are the following:

data analysis Processing of time series is very popular using notebooks. One can create interactive charts that allow to zoom in to certain parts of a time series. It is possible to use data brushing, a technique to show the relation between datasets shown in different plots. We have seen examples of deep-learning based salinity models that were build using jupyter notebooks.

interactive models Modern numerical models allow for interactivity during execution (as applied in Delft3D FM, 3Di, Lisflood Baart et al., 2014; Hoch et al., 2017).

visualization Notebooks have been used to create appealing visualizations that allow to comprehend relations between a wide range of variables.

For many researchers, the improved reproducibility is a side effect that comes with the improved interactive environment.

Confidence

It is relevant to note that using notebooks addresses more aspects than just the reproducibility. The more general aspect *confidence* Baart (2013) can be divided in *a)* reliability, the degree of consistency, and *b)* validity, the degree to which the research corresponds to the real world and is well founded.

Regarding the *reliability* several aspects are addressed. It can be confirmed whether research is: 1. reproducible, can other researchers can see all the details of an analy-

*Corresponding author

Email address: `fedor.baart@deltares.nl` (Fedor Baart)

URL: `www.deltares.nl.nl` (Fedor Baart), `www.deltares.nl.nl` (Aukje Spruyt)

Figure 1: example notebook (showing computation cells and results) by Anne Hommelberg showing results of a deep-learning model for salinity

sis? 2. replicable, other researchers can compare the results in detail to their own. 3. sensitive, researchers can use interactivity to study the sensitivity to certain assumptions..

Several aspects of *validity* are also covered. Because the source code is made available one can confirm the 1. integrity, is the integrity of the research covered. This is often addressed by putting the notebook under version control in one of the popular notebook hosting services, such as GitHub. 2. calibration used. This is important for measurements and forecasts. 3. construct validity, does the research cover the appropriate quantity? How was the quantity exactly derived? 4. external validity, does the method work in new situations, can be checked by rerunning the notebook as new data comes in. 5. convergent validity can be checked by applying the same notebook to different models 6. skill, a measure of external validity for forecasts, can be checked by adding a reference forecast.

Conclusion

Like in other fields, in river research, it is time to raise the bar for reproducibility of research. While other fields have moved to a community practice of open and auditable data and methods, this is not the common practice in river research. By providing concrete examples of other fields and guidance with implementation we think that this will also be the common practice within a few years in the river research community.

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Session Ia

Morpho- and hydrodynamic processes

Decreasing lateral migration and increasing planform complexity of the Dommel River during the Holocene

Jasper H.J. Candel*[a], Bart Makaske[a], Niels Kijm[a], Joep E.A. Storms[b], Jakob Wallinga[a]
[a]*Wageningen University & Research, Soil Geography and Landscape group, P.O. Box 47, 6700AA, Wageningen, The Netherlands*
[b]*Delft University of Technology, Faculty of Civil Engineering and Geosciences, P.O. Box 5048, 2628CN Delft, The Netherlands*

Keywords — Low-energy rivers, Lateral channel migration

Introduction

River planform and lateral activity largely result from the balance of flow strength, i.e. stream power, and bank erodibility (Nanson and Croke, 1992; Kleinhans, 2010). Floodplains of meandering rivers consist of a variety of depositional units with different erodibilities, such as point bar, backswamp and natural levee deposits (Allen, 1965; Nanson and Croke, 1992; Smith et al., 2009). Low-energy meandering rivers can have sufficient stream power to erode the non-cohesive units, but insufficient stream power to erode the cohesive units. Theoretically, low-energy meandering rivers may become laterally stable when the proportion of erosion-resistant floodplain deposits gradually increases, e.g. due to steady accumulation of fine-grained counter-point bar deposits (Makaske and Weerts, 2005; Smith et al., 2009). However, limited field evidence exists on the long-term evolution of low-energy meandering rivers, to test this relationship between lateral channel stability and the evolution of floodplain sediment composition. Therefore, we investigated the planform evolution of the low-energy Dommel River in the southern Netherlands, along with the Holocene evolution of its floodplain deposits.

Methodology

Lithological cross-sections were created of three cut-off bend complexes in the Dommel valley based on 103 corings with an average depth of 4.7 m. These bends have been cut off by humans in the process of channelization during the 20th century. Ground-penetrating radar (GPR) cross-sections were made to distinguish different floodplain depositional units. Finally, 11 samples for optically stimulated luminescence (OSL) and one sample for radiocarbon (^{14}C) dating were taken from different units.

Results

Figure 1 shows the dominant lithologies around one of the cut-off bend complexes. Secondary bends have formed within the cut-off bend complex, which form a ‘zigzagging’ pattern. On the inside of these secondary bends, sand is present with a clear fining upward sequence and loamy/organic beddings (Fig. 2). The GPR cross-section shows steep inclination (14 to 28°) of strata in these sandy deposits, here interpreted as point-bar deposits with lateral accretion strata. The secondary bends and associated point-bar deposits are located within thick deposits of strongly compacted loam and peat (Fig. 1 and 2), which form erosion-resistant layers. We defined peaty or loamy layers with a minimum thickness of 0.5 m as erosion-resistant. In our study we interpreted erosion-resistant sediment units as counter-point bar deposits, channel-fills of cut-off channels, in-situ peat, overbank deposits and older non-valley fill deposits.

Conceptual model

A relation seems to exist between the channel planform complexity, i.e. presence of sharp irregular bends, and the floodplain heterogeneity of the low-energy Dommel River. During the Holocene, the floodplain

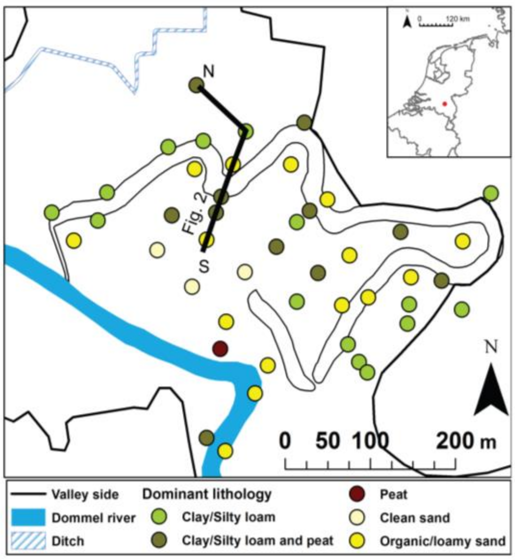

Figure 1. Planview of one of the studied cut-off bend complexes located in the Dommel valley. The circles indicate the dominant lithology in the corings, being loam or peat when thicker than 0.5 m. The location of Fig. 2 is indicated.

* Corresponding author
Email address: jasper.candel@wur.nl (Jasper Candel)
*URL:*https://www.wur.nl/nl/Personen/Jasper-JHJ-Jasper-Candel-MSc.htm (Jasper Candel)

heterogeneity increased due to the variety of depositional units that formed. Especially when compacted, the clayey and peaty deposits can form erosion-resistant river banks. Consequently, the river flow is deflected and can be directed to an erodible bank, e.g. a sandy point bar, resulting in the formation of sharp river bends.

Here we point at the positive feedback that exists when sharp bends form in low-energy meandering rivers. Flow separation, i.e. counter-rotating flows, occurs in sharp bends either on the concave or convex side (Blanckaert et al., 2013). Very loamy and organic deposits can form within the flow separation zones, which differ from normal sandy point bar deposits in meandering rivers (Makaske and Weerts, 2005; Smith et al., 2009). Neck cut-offs are also enhanced when the sandy point-bars are eroded rather than the relatively erosion-resistant deposits on the outer bend, leading to formation of fine-grained oxbow channel-fills on the long term. Both counter-point bars and oxbow channel-fills can become erosion-resistant layers, especially when compacted, resulting in the formation of new sharp bends, a more complex planform and limited lateral migration.

Conclusions

The lateral migration of low-energy rivers decreases over time as a result of preservation of fine-grained and erosion-resistant depositional units typically formed by these rivers. Coarser grained depositional units also formed by these rivers are more easily eroded and therefore have less preservation potential. As a result, planform complexity increases over time, leading to more and more irregular sharp bends, which are relatively laterally stable.

Acknowledgments

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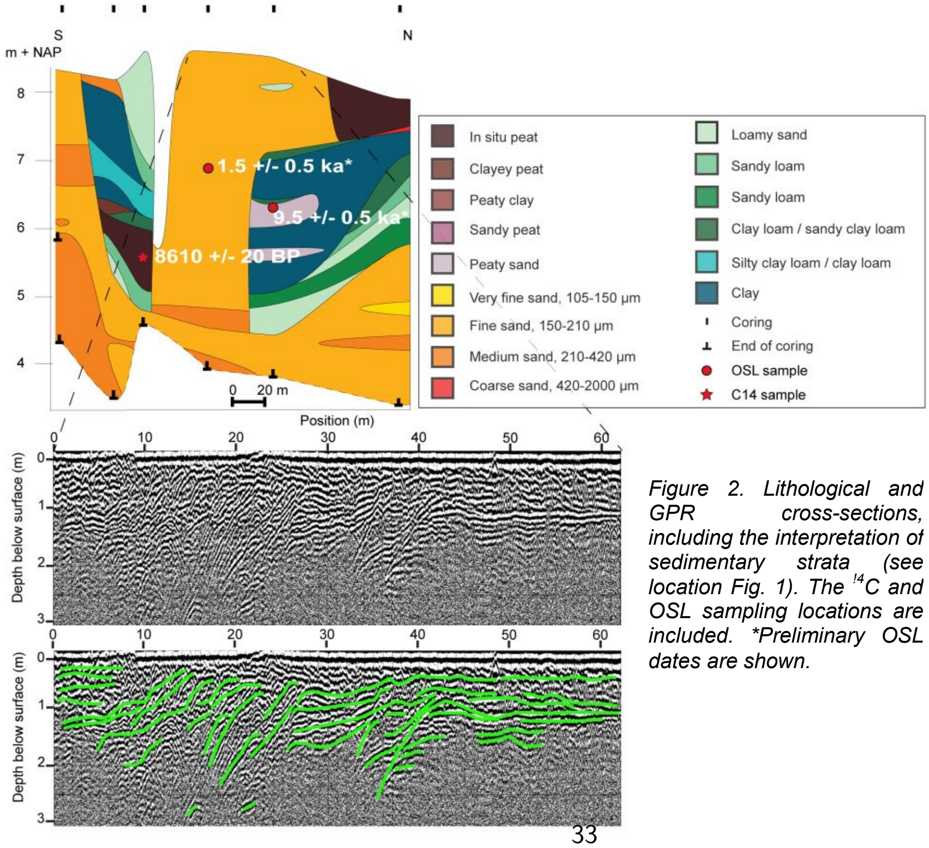

*Figure 2. Lithological and GPR cross-sections, including the interpretation of sedimentary strata (see location Fig. 1). The ^{14}C and OSL sampling locations are included. *Preliminary OSL dates are shown.*

Nourishments as part of the future Dutch river management: insights from a pilot

Iris Niesten*[,a], Anke Becker[a]
[a]Deltares, department of River dynamics and inland shipping. Boussinesqweg 1, 2629 HV Delft, The Netherlands

Keywords — Nourishment, Rhine, Monitoring techniques, Numerical modelling

Introduction

Bed degradation in the Rhine branches is a continuous process that reaches up to 2 cm per year. Due to this lowering of the bed, water levels decrease and locations where fixed layers are present (for example at Nijmegen, Sint Andries or at structures), may cause serious bottlenecks for navigation within less than 20 years from now. Moreover, the ongoing bed degradation threatens the stability of groynes, bank protections and hydraulic structures. A solution for this problem might be the application of nourishments at strategic locations in the Rhine and Waal. However, up until today, nourishments are no part of the Dutch river management.

To test the applicability of sand nourishments, Rijkswaterstaat has issued a pilot nourishment in the German Rhine close to Lobith. A first nourishment was carried out in the summer of 2016, a second nourishment is scheduled for the summer of 2019. The first nourishment was carried out conservatively, having a uniform thickness of 30 cm and a streamwise length of 2.2 km. The overall aim of this pilot is to increase our understanding of the effects of a nourishment to assess how a nourishment strategy could be integrated in the Dutch river management. The effectiveness of the nourishment is defined by two (qualitative) criteria:

- The nourishment should contribute to a decrease of downstream bed erosion.
- The nourishment should increase upstream water levels.

The aim of this study is two-fold. The first aim is to assess the effectiveness of the first nourishment, using field observations together with the outcomes of a numerical model. The second aim of this study is to assess whether numerical modelling can be used to reproduce the morphodynamic response to this nourishment, as well as possible future nourishments.

Methodology

We studied the hydraulic and morphodynamic response to the nourishments, using field observations and a numerical model.

Field observations

As part of the monitoring strategy, the nourishment was partly carried out with a tracer material (granite), which can be followed by radiometric observations (medusa method). The remaining part of the nourishment was carried out with gravel with a similar grain size distribution as the natural river bed (see Figure 1). Medusa-maps were made once every month. Furthermore, monthly bed level-maps were created and at Lobith water levels and discharges were recorded continuously. To complete monitoring, grain size distribution was measured at specified locations using sampling and during different discharge levels the water level gradient and flow velocities were measured.

Figure 1. Overview of the nourishment at Lobith. The areas "vak 1" and "vak 3" were carried out with granite, "vak 2" consists of gravel. Water flows from right to left.

Numerical model

Next to the effect of the nourishment on the bed level, it is expected that the construction of the fixed layer in 2012 at Spijk, just upstream of Lobith, still affects the bed dynamics at this location. A numerical model was thus used to isolate the effect of the nourishment. A validation of the existing DVR-model of Ottevanger et al. (2015) was included based on the mentioned field measurements. The nourishment was added to the model as a separate layer, to mimic the observations of the tracer-material. Sediment transport rates were calculated with an adapted MPM-transport formula. In Delft3D, an underlayer-concept is used to take into account different grain sizes. The upper layer (active layer) is always fully mixed.

* Corresponding author
Email address: iris.niesten@deltares.nl

Therefore, the chosen active layer thickness largely controls vertical mixing and hence horizontal transport. The active layer thickness is often calculated as 50% of the dune height (Sloff, 2008). Because of unrealistic results, we revised this choice and related the active layer thickness (D_{act}) to the water depth (H) as:

$$D_{act} = \alpha H$$

where α is 0.12, and the minimum layer thickness is set to 0.5 m.

Results

The observed tracer material shows an average velocity of 6 m d^{-1} in the first months, whereas the sedimentation front, visible in longitudinal bed profiles, moves with an average of 1.2 m d^{-1}. During discharges below 2000 m^3 s^{-1}, hardly any movement of the tracer is observed. Another effect that becomes apparent from the observations as well as the model, is that on the right side of the river, opposite to the nourishment, the bed erodes, followed by a sedimentation front downstream (see Figure 2). This is a morphodynamic response to the nourishment, even though the nourished material itself stays on the left side of the river. Due to the increased bed level at the location of the nourishment, the flow velocity increases, also on the right hand side of the river, enhancing erosion opposite to the nourishment.

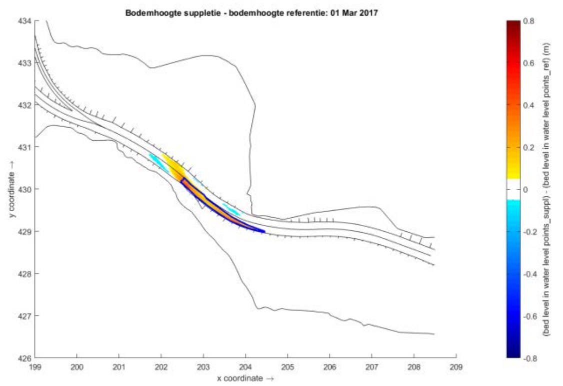

Figure 2. Modelled erosion and sedimentation as a result of the nourishment (indicated with thick blue contour line).

Both the observed and modelled water levels increase with a maximum of 1 cm due to the nourishment.

By comparing the model outcome to the provided bathymetry maps, we concluded that the morphodynamic response was reproduced reasonably well by the model, as was the horizontal transport rate of the tracer material. Due to the absence of high discharges this conclusion can be drawn only concerning the performance during low discharge. Keeping in mind that numerical modelling might be used to predict the effect of future nourishments however, some model limitations should be mentioned, among which the absence of shipping in the model and the thickness of the active layer play the most important roles. An active layer thickness of 0.5 m is most likely an overestimation, resulting in high vertical mixing rates. Indeed, part of the modelled tracer material "disappears" from the surface due to mixing in the active layer. Remarkably, the horizontal tracer transport velocity is modelled well (see Figure 3), although vertical mixing and horizontal transport rates are strongly correlated.

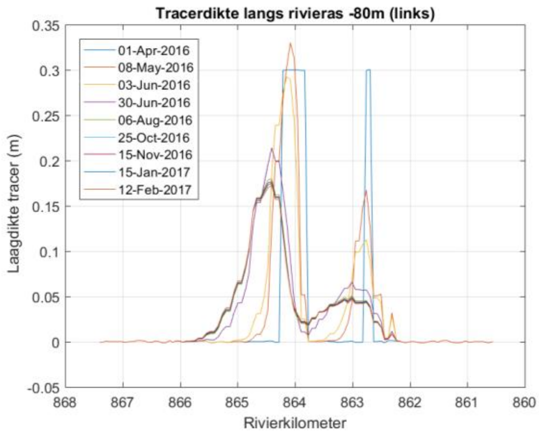

Figure 3. Modelled tracer velocity. The two original tracer areas have a thickness of 0.3 m.

Conclusions

From the medusa-maps could be derived that the calculated transport rate corresponds well with the observed transport rate, in spite of the large vertical mixing. For future nourishments, numerical modelling can well be used to predict the bed response, although one should take into account local shipping effects and actual grain sizes on a different location, for the response of a sand bed river will be different than that of a gravel bed river.

The nourishment is effective when it comes to increasing the upstream water level. Due to low river discharges during the observation period, it is not yet clear to what extent downstream bed degradation is decreased by the nourishment.

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Turbulence in scour holes of sharp bends

Rik Posthumus[a*], Bart Vermeulen[a], Kathelijne Wijnberg[a]
[a] University of Twente, Department of Water Engineering and Management, Faculty of Engineering Technology, P.O. Box 217, 7500 AE, Enschede, the Netherlands

Keywords — Scour holes, Turbulence

Introduction

Many deep and stable scour holes were recently observed in sharp bends along the Mahakam River in Indonesia (Vermeulen et al., 2015). Understanding where they may develop, how deep they can become and why they remain stable is important for the safety of buried infrastructure (Sawatsky et. al., 1998, Beltaos et. al., 2011) and buildings near the river banks (Klingeman et. al., 1984, Huismans et. al., 2016). However, the current knowledge is insufficient to explain the cause of the observed characteristics in scour holes of sharp bends (MacVicar and Rennie, 2012, Vermeulen et al., 2015).

A detailed study of the hydrodynamics in scour holes may elucidate the physical processes that govern the dynamics of scour holes. Here, we explore the possibility to quantify terms in the momentum balance from in-situ field measurements (Niesten, 2016) and compare them with the results of a hydrodynamic model (Vermeulen et al., 2015).

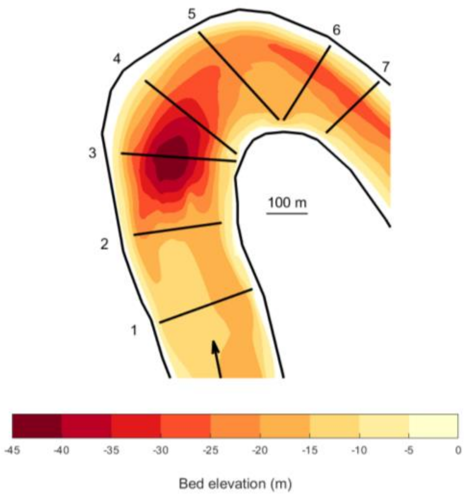

Figure 1. Location of transects in sharp bend where flow velocities were measured.

Methods

Detailed flow velocity measurements, collected in one of the sharp bends with a scour hole in the Mahakam River, are used for a quantitative study. The scour hole in this sharp bend is representative for other scour holes found in the river (Vermeulen, 2014). The data was collected with an Acoustic Doppler Current Profiler at seven transects around the scour hole (Fig. 1). The data is processed in such way, that most terms in the Reynolds Averaged Navier Stokes equations could be determined. We analyzed the terms in the balances, and determined the relative contribution of accelerations, pressure gradient and the divergence of the Reynolds stresses.

We compared these field based results, with the results obtained from a three-dimensional finite element model (Vermeulen et al., 2014). The model results are evaluated in such way that the terms in the momentum balance can be studied along the whole bend. Therefore, the curved coordinate system is transformed into rectangular coordinates, which makes it easier to compare the processes at different locations along the bend. The results from the hydrodynamic model were calibrated with the data from the flow velocity measurements and show good agreement (Vermeulen et. al., 2015) (Fig. 2).

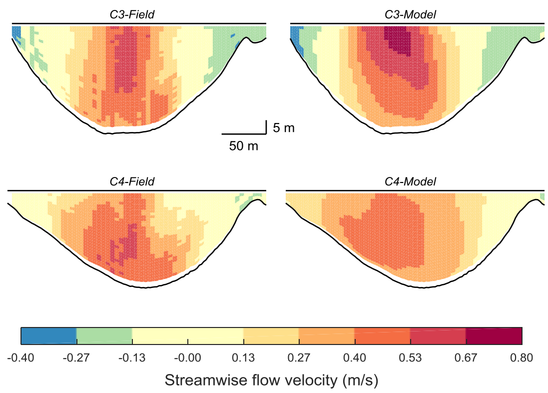

Figure 2. Streamwise flow velocity from measurements and model simulations in transects 3 and 4.

Results

A comparison between the terms in the momentum balance along the bend, reveals, as expected, a large influence of the scour hole. In the streamwise and transverse momentum balance, the dominant terms upstream and downstream of the scour hole are the acceleration and pressure gradient. In the scour hole, the turbulent stress gradient increases and reaches the same values as the other two terms. In the vertical momentum balance, the

* Corresponding author
email address: posthumusrik@gmail.com

pressure gradient and the turbulent stress gradient show a huge increase in the scour hole and become more than 6 times larger than the acceleration (Fig. 3).

A detailed evaluation of the terms in the vertical momentum balance reveals that the large increase of the turbulent stress divergence is mostly caused by an increase in the vertical normal stress. Because there is no vertical flow at the water surface and the river bed, the normal vertical stress also vanishes. The largest variances are found around mid-depth in the deepest part of the scour hole. This may explain why the normal stress gradient in vertical direction shows such a huge increase (Fig. 4).

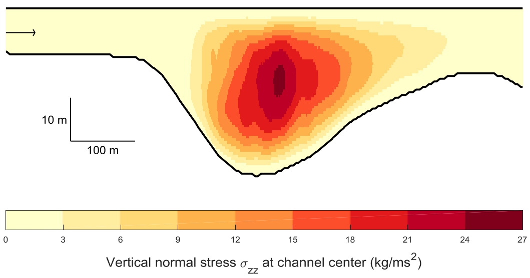

Figure 4. Peak of vertical normal stress around mid-depth in the deepest part of the scour hole.

Discussion

Although the model results show good agreement with the field measurements, there are some differences. The hydrodynamic model underestimates the vertical flow velocity, and predicts larger turbulent stresses in the scour hole, compared to the measured ones. However, the detection of vertical stresses from ADCP is still experimental, and the uncertainty involved in these measurements is unclear.

Conclusions

A study of how the terms in the momentum balance change near a sharp bend with a scour hole reveals that the turbulent stress divergence strongly increases in the scour hole and becomes a significant term in the vertical momentum balance. First, this suggests that turbulent stresses are important to consider in improving the understanding of scour hole formation and stability. Furthermore, this result confirms that advanced turbulent models (such as LES) are needed to reproduce the flow through scour holes. This also highlights the need to develop new techniques to measure turbulent stresses in the field, to understand the dynamics of complex three-dimensional flow.

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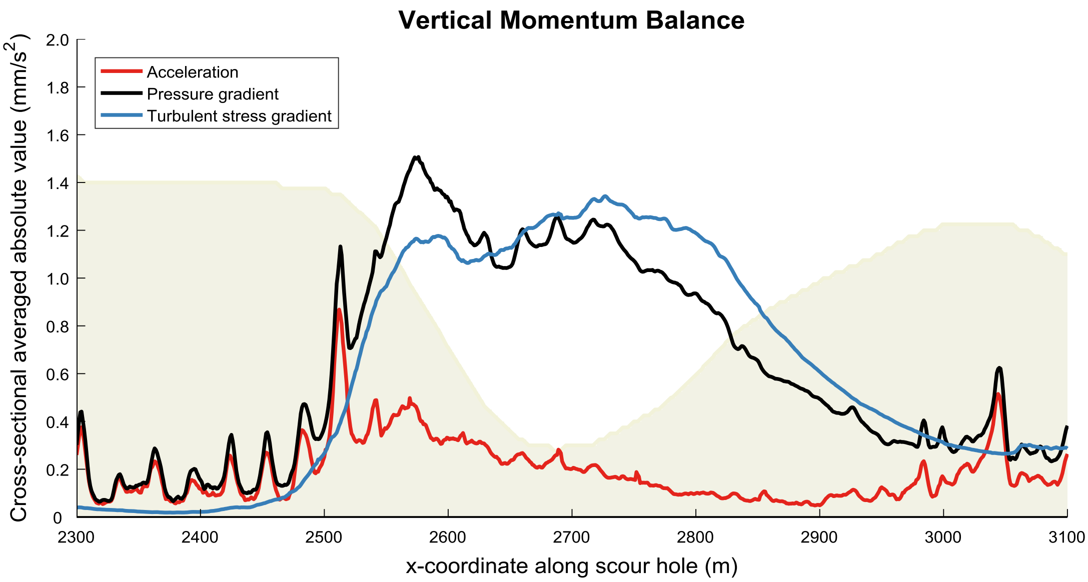

Figure 3. Hydrodynamic processes along scour hole in vertical momentum balance

Dune response to non–equilibrium flow

S. Naqshband[a*] and A.J.F. Hoitink[b]
[a,b] *Wageningen University & Research, Department of Environmental Sciences*
Droevendaalsesteeg 4, 6708 PB Wageningen, the Netherlands

Keywords — River Dunes, Turbulent Flow, Sediment Transport

Introduction

Flow and sediment transport are key processes in the morphodynamics of river dunes. During floods in several rivers, dunes are observed to grow rapidly as flow strength increases, undergoing an unstable transition regime, after which they are washed out in what is called the upper stage plane bed (USPB). This morphological evolution of dunes to USPB is the strongest bed-form adjustment during non-equilibrium flows and it is associated with a significant change in hydraulic roughness and water levels (Nelson, 2011).

Dune related experimental investigations of turbulent flow and sediment transport have mainly focused on dune morphology and dune kinematics under equilibrium conditions that are quite rare in natural rivers. Detailed experimental investigations of turbulent flow fields and analogies for sediment transport rates are often limited to measurements over fixed laboratory dunes (e.g., Venditti, 2007; Kwol et al. 2016). As a result, most of our understanding of dune dynamics, kinematics, flow resistance and sediment transport originates from steady flows, whereas a fundamental property of rivers is that flow fluctuates on different time scales due to backwater effects, anthropogenic effects, and meteorological and astronomical forcings. Consequently, we do not yet have a proper understanding of how dunes respond to non-equilibrium flows. In particular, there is no mechanistic explanation of how changes in a turbulent flow field and the corresponding changes in sediment transport gradients along the dune bed result in the transition of dunes to upper stage plane bed. One of the most important reasons for this knowledge gap is the inherent limitation of instruments available for the simultaneous, co-located and bed-referenced measurement of flow velocity and sediment concentration over migrating dune bed, especially in the near-bed region (see Naqshband et al. 2014). By deploying the ACVP (Acoustic Concentration & Velocity Profiler) in the present study, we are able to quantify the exact sediment transport distribution (both bed and suspended load) over changing dune morphology under non-equilibrium flow. This enables us to obtain quantitative knowledge of the mechanisms governing the transition of dunes to upper stage plane.

* Corresponding author
Email address: Suleyman.naqshband@wur.nl

Flume experiments

Large-scale experiments were carried out at the Technical University of Braunschweig (Germany) in a 0.5 m wide and 30 m long flume. The experimental procedure is briefly outlined below. For more details on experimental methods reference is made to Naqshband et al. 2016.

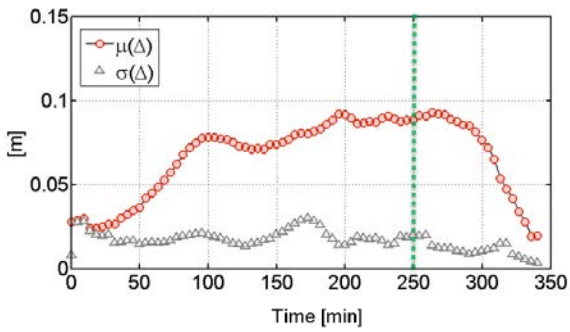

Figure 1. Average μ and standard deviation σ for dune height Δ during the flume experiments. The green dotted line indicates the increase in discharge from Q_0 to Q_1 leading to the transition of dunes to USPB.

To investigate dune transition to upper stage plane bed under non-equilibrium flow, firstly, a dynamic dune equilibrium was achieved at a predefined flow discharge Q_0 and water depth H by continuously monitoring the effective measurement section of the flume (x = 10 m to 18 m) with three echo-sounders mounted on a semi-automatic measurement carriage. Starting from plane bed, after approximately 150 min, the dynamic dune equilibrium was obtained. Equilibrium dune dimensions (height, length and migration velocity) were calculated by monitoring the effective measurement section of the flume over the entire course of experiments (Fig. 1). Next, flow discharge was increased instantaneously to Q_1 (T=250 min) and ACVP was used to quantify the initial response of flow and sediment transport to non-equilibrium flow.

Flow, sediment concentration and flux

A measured dune profile during the initial stage of dune transition to upper stage plane bed together with mean flow field, sediment concentration and sediment flux is shown below (Fig. 2). Dune characteristic flow features are observed that are caused by topographic forcing and flow interaction with the free water surface, that includes a zone of flow separation, a region of flow acceleration on the dune stoss side followed by a zone of flow deceleration in the dune trough, and an outer near-surface region overlying the zone of flow reversal that is associated with high velocities and low pressure. Compared to equilibrium migrating dunes under steady flow with similar shape and dimensions, the flow separation zone during dune transition is significantly smaller and weaker, with relatively less pronounced near-bed negative flow velocities. Accordingly, large-scale streamwise and vertical turbulent motions in dune troughs (eddies and vortices) are significantly smaller during dune transition. This so-called suppression of turbulence in dune troughs is caused by high near-bed sediment concentrations, especially in the flow separation zone as is observed in Fig. 2b. Furthermore, during dune transition, a significantly larger amount of sediment is advected downstream towards the following dune contributing to dune deformation.

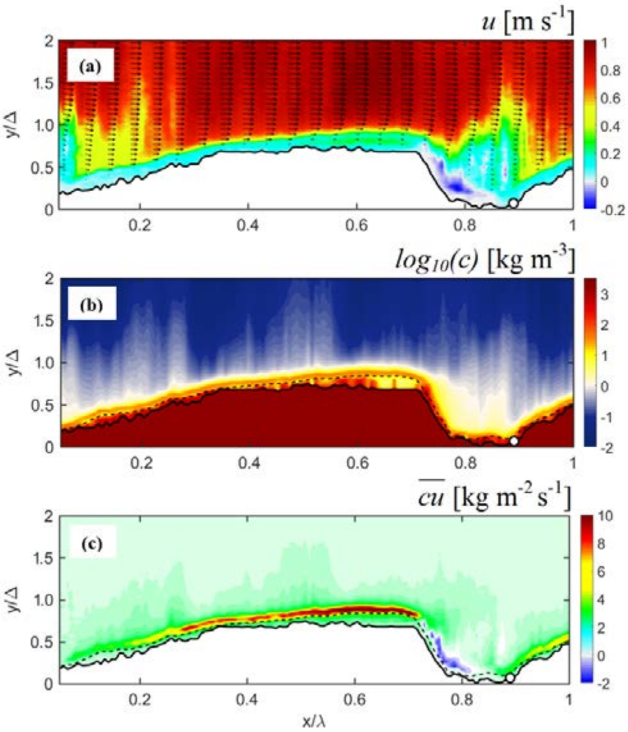

Figure 2. Contour maps of mean streamwise flow velocity (a), mean sediment concentration (b) and mean streamwise sediment flux (c).. The solid black line is the measured dune profile, with the open circle indicating the location of flow reattachment point with flow direction from left to right. The dotted black line is the acoustically determined interface between the suspended load and the near-bed load layer.

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Morphodynamic Changes around a Bridge Pier

Fatima Azhar*, Alessandra Crosato
IHE Delft, Department of Water Science Engineering, PO Box 3015, 2601 DA Delft, the Netherlands

Keywords — bridge pier, bars, variable discharge

Background

River structures, like bridge piers and groynes, obstruct the flow thereby modifying the flow field around them and causing development of localized scour. Deposits often develop at the tail of a bridge pier and upstream of it. Piers act as forcing elements for development of bars (Figure 1). Since the forcing element is static, these bars are also static. Two types of bars may develop; forced and hybrid (Duró et. al. 2016). Forced bars are the deposits near a bridge pier. Hybrid bars develop downstream if the river bed is morphodynamically unstable forming a series of periodic deposits. As these bars pose obstruction to flow and hinder navigation, it is important to study their formation as a part of river control engineering.

Figure 1. Forced bar near the downstream face of a bridge pier in River Adige, Verona, Italy.

Field observations and laboratory experiments suggest that local scour holes may effect overall river morphology and thus the bar formation (Mosselman and Sloff, 2002).

Previously, work has been carried out by Oliveto and Hager (2014) to predict the temporal variation in the geometry of bars developed at the tail of a bridge pier. This work does not address the effects of variable discharge. Therefore further research is required so that bar formation may be predicted in real rivers.

Objectives

The following research questions are addressed in this study:

- What are the morphological developments caused by a bridge pier?
- What are the effects of variable discharge on the formation of these morphological developments?
- What is the effect of channel width-to-depth ratio on these developments?
- What mitigation measures can be taken to control them?

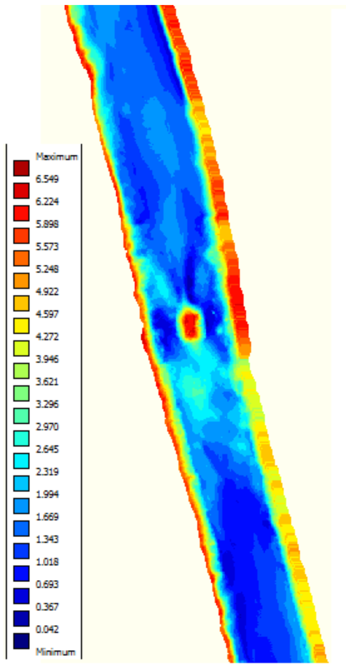

Figure 2. Bed topography (year 2012) showing a large sediment deposit upstream of a bridge pier at Gennup and two central bars downstream.

Methodology

The investigation is carried out using a 2D morphodynamic model as a tool. The model

* Corresponding author
Email address: azhar6@unesco-ihe.org (F. Azhar)

is first applied to a real river to assess its capability to study the morphological developments around a bridge pier. A 13 km long reach of the Meuse River from Boxmeer to Mook is used as case study, where the river bed shows developments in the vicinity of bridge pier (Figure 2). The model is then applied to study several scenarios including increasing the river width to assess the morphological behaviour of a river with different bar regimes.

2D Model Development

The Delft-3D code is used to model the Meuse River reach with variable discharge, uniform grain size and capacity-limited sediment transport (Figure 3). The daily discharge at Venlo and the water levels at Mook are taken as boundary conditions. The model that includes the floodplains is calibrated and validated against the available water levels and measured bed topographies considering dredging and sediment dumping interventions in the area. Upon verification of the accuracy of the model, the effects of water level regulation at the downstream navigation lock on the bed morphology is analyzed. This is done to be able to understand the effects of the bridge pier in the Meuse River.

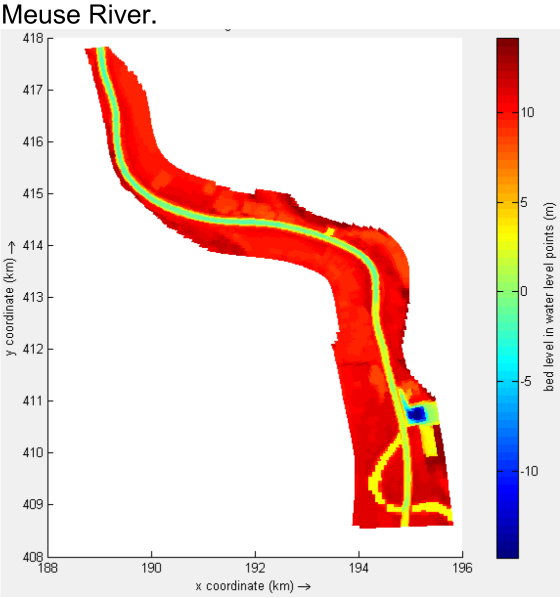

Figure 3. Sample morphodynamic output from Delft3D, showing main channel and floodplain from Boxmeer to Mook.

The following scenarios are then analysed:

- Constant and variable discharge
- Different main channel widths

Preliminary Results

A rough schematization of a straightened Meuse River (Figure 4) shows that a central bar forms in the river due to a single pier in an otherwise bar-free reach. If banks are not protected, channel widening will cause the bar mode to increase and alternate bars shall be seen in the river. It is however unknown at this stage how different river bar regimes interact with the formation of a forced bar at the tail of a pier.

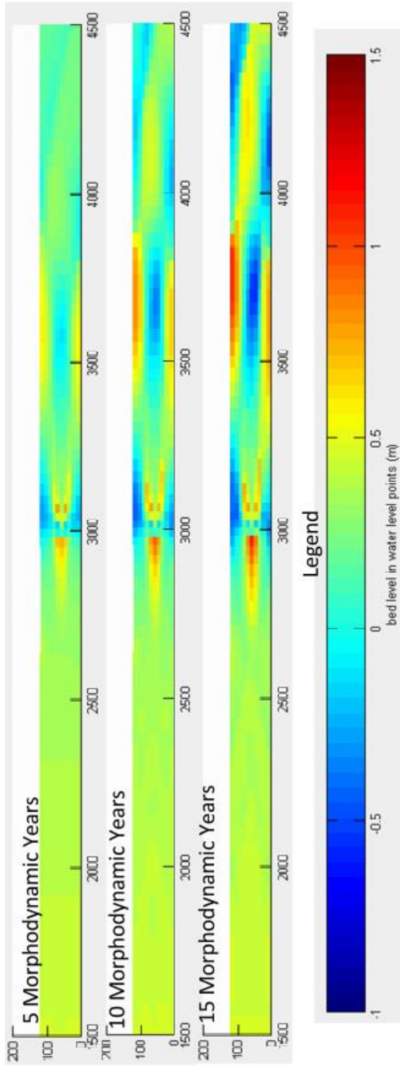

Figure 4. Schematization of a straightened Meuse River, showing temporal evolution of bed in proximity of bridge pier with constant discharge

Fixing the bed around a bridge pier may affect bar formation at tail of the pier because this prevents the formation of local scour. This study will provide an insight on the management of deposit formations caused by bridge piers.

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Analysis of sediment transport dynamics in the Piave River Basin to define hotspots of geomorphic change.

Usman Ali Khan[a] Alessandro Cattapan[a] Mário J. Franca[a]
[a]IHE Delft Institute for Water Education, Water Science and Engineering Department Westvest 7, 2611 AX Delft, The Netherlands

Keywords — River network, Sediment Transport

Introduction

Rivers are dynamic systems changing both in space and time. Beside natural processes, human's activities also influences sediment transport at basin scale in a number of ways e.g. through the construction of sediment retaining impounding structures such as dams or through sediment extraction (Syvitski & Kettner, 2011). Sources of sediment might vary from one river to another e.g in mountainous areas rivers are usually fed by mass movements (i.e. landslides and debris-flows) which are singular in time and space, whereas in low land rivers usual sources are river banks and the nearby watershed, which typically act continuously and diffusively along the channel network.

In the last 80 years the Piave River basin has been under heavy anthropogenic pressure due to the construction of a large amount of dams and gravel extraction which altered the morphology of the river.

The main objective of this research is to identify the areas within the Piave River basin (Italy) that, due to their long term sediment transport dynamics, will represent hotspots of geomorphic change. This objective will be reached using a new sediment routing framework that takes into account the geomorphological structure of the river network and allows the identification of the river reaches where the transport dynamics of different sediment types are expected to produced higher sedimentation.

Methodology of Research

Model Framework

The modelling framework adopted in this research (Czuba, J. A., and E. Foufoula-Georgiou, 2014) schematises the river network as a series of directionally interconnected links. Sediments are routed from the sources to the outlet of the basin along different pathways. Each link in a pathway will therefore be at a certain distance from the outlet. The width function of the river basin is defined as the distribution of distances of each link from the outlet along the network. The adopted framework translates the width function into an "environmental response" function (characteristic for each sediment size) performing a scaling of the former through different velocities which are functions of the hydraulic properties of each link in the network (Fig. 2).

1. River network development

In this study a 30 m horizontal resolution DEM of the Piave River basin has been obtained from tiles (5x5° or 1000 km x 1000 km) downloaded from the European Environment Agency's website. The DEM tiles have been mosaicked and clipped at extent up to the study area and projected into WGS_1984_UTM_33N coordinate system in the ArcGIS. For the delineation of the river network a threshold limit on the drainage area of 3 km^2 has been applied. The obtained network is represented in Fig. 1.

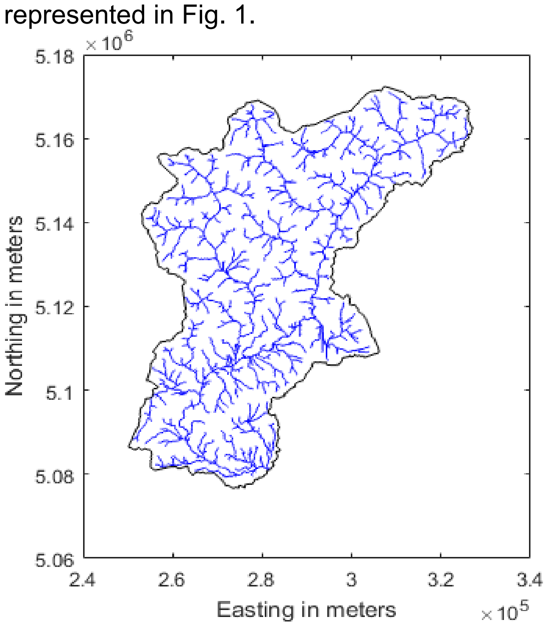

Figure 1 Extent of Piave River Basin drainage network which composed of around 1000 links with mean length of 1.8 km and total length of approximately 2000 km.

* Corresponding author
Email address: Khan43@unesco-ihe.org (U.A. Khan)

2. Scaling of geometrical and hydraulic properties

Leopold and Maddock (1953) expressed the hydraulic characteristics of a river reach in the form of power functions of discharge in which B is the channel width, H is the flow depth, V is the flow velocity, Q is the flow discharge, and a, b, c, d, k, and m are empirical coefficients and exponents respectively.

$$B=aQ^{b}\ ,\ H=cQ^{d},\ V=kQ^{m} \quad (1)$$

In order to perform the hydraulic scaling of geometrical properties, the reference discharge will be chosen as the bankfull discharge; defined as the discharge with 2-years return period (Q_2). This discharge will be defined fitting discharge data collected at several cross-sections with a Gumbel's distribution. Hydraulic geometry characteristics (B, H and V) at each gauge and downstream will be developed following the approach used by Czuba, J. A. and E. Foufoula-Georgiou (2014) for the Minnesota River Basin, therefore linking the hydraulic and geometrical properties to the upstream drainage area.

3. Sediment input to the network

Sediments will be added to river network following a Poisson process in the shape of parcels having a constant volume Vp=10 m^3 (independent parcels can be considered as a coherent unit of sediments) for example, an input with rate of 40 m^3 yr^{-1} would be broken into four parcels each as independent inputs recurring through time with interarrival times randomly selected from an exponential distribution with a mean of one year. The model will simulate the sediment transport dynamics for a 500 year time span; during this period parcels will move from upstream to downstream towards the basin outlet which is chosen at Nervesa della Battaglia.

4. Model simulations

The modelling framework described above will be applied in the two following setups:

- **"Natural" river network**

The DEM will be changed in order to consider an idealized "natural" condition where all the existing reservoirs have been removed. Moreover, the scaling of the hydraulic properties of each link with the drainage area will be performed adding the withdrawals due to hydropower and irrigation infrastructures, therefore trying to reproduce the "natural" flow of the basin.

- **Actual river network**

The model will be applied to the actual DEM as downloaded and the scaling of Q_2 on the drainage area will be performed using the measured discharge data in a series of gauging stations monitored by the environmental protection agency of the Veneto Region (ARPAV), therefore including the antropogenic effects, like withdrawals for hydropower production, lamination of floods performed by reservoirs etc..

Expected Results

The expected outcomes of this research work include the definition of the areas of major geomorphic change and the analysis of the effects of major hydraulic infrastructures on the long term dynamics of the basin. This comparison will provide insights on the relative importance of different reservoirs and diversions on the morphology of the Piave River basin and suggestions for their management.

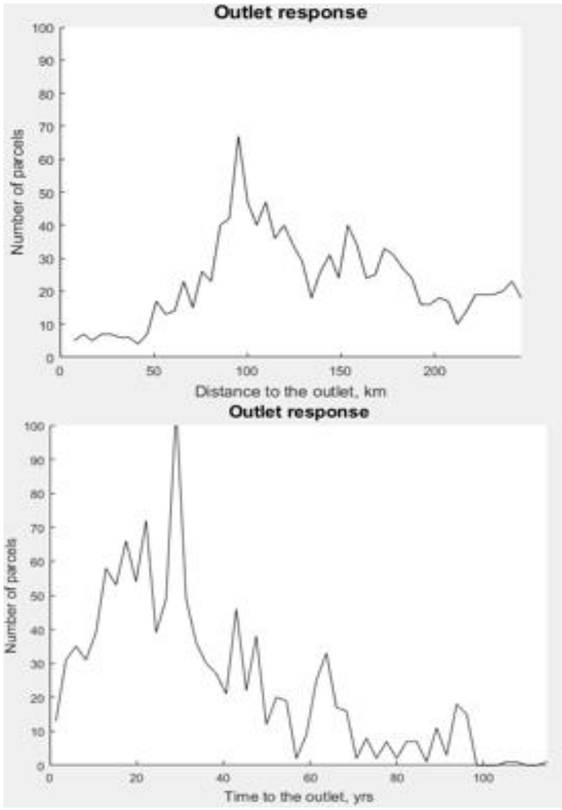

Figure 2 Conversion of Width function to process scaled width function whereas process is sediment transport

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The historical river: morphology of the Rhine before river normalization

Bas van der Meulen[a*], Tessa S. Deggeller[a], Anouk Bomers[b], Kim M. Cohen[a,c], Hans Middelkoop[a]
[a]*Utrecht University, Department of Physical Geography, Heidelberglaan 2, 3584 CS Utrecht, the Netherlands*
[b]*University of Twente, Department of Water Engineering and Management, Dienstweg 1, 7522 ND Enschede, the Netherlands*
[c]*Deltares, Department of Applied Geology and Geophysics, Daltonlaan 600, 3584 BK Utrecht, the Netherlands*

Keywords — Rhine river, Historic maps

Introduction

In order to improve understanding of potential future high discharges, historic extreme floods of the Rhine river are studied in the project Floods of the Past - Design for the Future. The main objective is to numerically simulate these floods, which requires detailed reconstructions of the river and its floodplains at times of flooding. These reconstructions are made using a combination of geological and historical information.

In this presentation we illustrate the use of historic maps and measurement data in river reconstruction, focusing on the first edition of the Algemene Rivierkaart by Goudriaan and the Hydrographisch und militairische Karte von dem Nieder-Rhein by Wiebeking. Both maps come with water depth information. The reconstructions based on these maps and data will be used to simulate the large flood of 1809 and other historic floods of the river Rhine. The study area extends from Andernach in Germany to approximately halfway the Rhine river branches in the Netherlands.

Data description

The first edition of the Algemene Rivierkaart covers the Dutch large rivers and their surroundings at a scale of 1:10,000. The map sheets of the Rhine river branches Waal, Nederrijn and IJssel were produced in the periods 1830-1832, 1833-1839 and 1840-1844 (van den Brink et al., 2002), which is before large-scale river regulation started in 1851. Therefore, this maps series appropriately resembles river geometry around 1809. Depth measurement data accompany the maps in separate registers (Boode, 1979).

The Hydrographisch und militairische Karte von dem Nieder-Rhein extends from Linz am Rhein up to Arnhem. The map has a scale of 1:30,000 and was finished in 1796 (Wiebeking, 1796). Water depths are drawn upon the map at semi-regular intervals (Fig. 1).

Georeferencing

Both map series have a high degree of geometric accuracy, making georeferencing relatively straightforward. For all maps an affine (first order polynomial) transformation was used, which means that the maps were not deformed, only shifted, scaled and rotated.

The maps of the Algemene Rivierkaart were georeferenced in two ways. First, by using the edges of the original map grids as control points after conversion of the original map projection system. Secondly, by using locations of unmodified dike stretches as ground control points. The results were checked by comparing locations of features (selected landmarks and roads that are unaltered over the past 200 years) on the georefenced maps and on a modern digital elevation model. On average deviations were small (lower than the model resolution of 50 m) after both georeferencing methods, but maximum deviations on a few map sheets were up to 150 m after the first method. The second method was therefore preferred and also used to georeference the maps of Wiebeking. The accuracy of this map series was found to decrease away from the river and therefore ground control points were chosen close to the river Rhine.

Bathymetry reconstruction

After successful georeferencing we created vector data sets of river shores and islands by digitally tracing these features. The resulting planform geometry of the Lower Rhine and upper Rhine delta was extended with depth information leading to a three-dimensional reconstruction of river morphology.

The German river maps depict depths at the respective measurement locations, which could be converted into point data in a straightforward manner. The Dutch river maps depict only a few depths. However, more measurement data exist, stored in extensive tables with locations and orientations of measurement lines and distances between

* Corresponding author
Email address: b.vandermeulen@uu.nl
URL: www.uu.nl/staff/bvandermeulen

individual depth measurement points. We are currently implementing these data into GIS and finding suitable options to interpolate between depth points and profiles.

Application of results

The resulting three-dimensional reconstruction of the Lower Rhine and Rhine river branches forms a good representation of the morphology between the last 18th century artificial cut-off (IJssel bifurcation in 1775) and the onset of river normalization, making the reconstruction appropriate to use as input in hydraulic model of the 1809 flood.

For this we will use a two-dimensional hydraulic model with flexible mesh in which the main channel and its floodplains are discretized by curvilinear grid cells and the embanked areas by triangular grid cells. Dike breach locations are well known and included in the model. Calibration of two-dimensional hydraulic models is normally performed by changing the roughness of the summer bed, which requires a known upstream discharge. Since the upstream discharge is part of the output and unknown, a range of roughness values will be used based on calibration results of the 1926 and 1995 flood waves. The ultimate result is a simulation of the historic extreme flood of 1809 in the landscape setting of that time, making it possible to quantify the historic discharge magnitude and flooding pattern with limited uncertainty.

Acknowledgements

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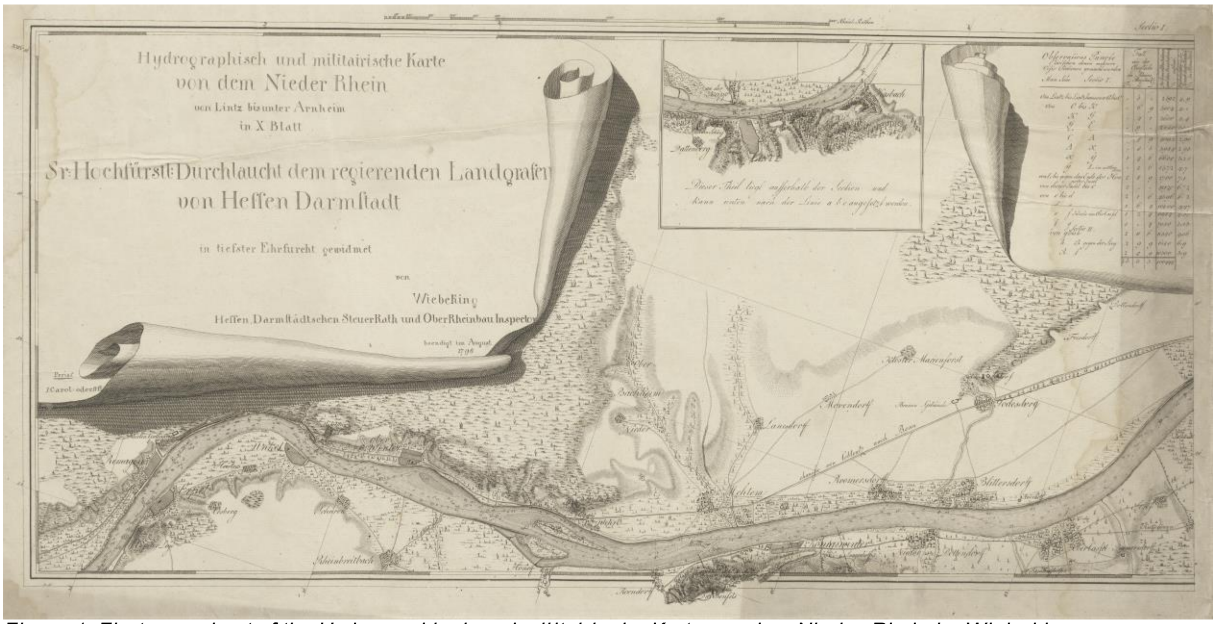

Figure 1. First map sheet of the Hydrographisch und militairische Karte von dem Nieder-Rhein by Wiebeking.

Spatial and temporal variations in Meuse river terraces in the Roer Valley Rift System

H.A.G. Woolderink[1]*, C. Kasse[1], K.M. Cohen[2,3,4], W.Z.Hoek[2], R.T. Van Balen[1,3]
[1] *Vrije Universiteit Amsterdam, Faculty of Science, cluster Earth & Climate*
[2] *Universiteit Utrecht, Faculty of Geosciences, department of Physical Geography*
[3] *Department of Geomodelling, TNO Geological Survey of the Netherlands, Utrecht, The Netherlands*
[4] *Department Applied Geology and Geophysics, Deltares, Utrecht/Delft, The Netherlands*

Keywords — River Terraces, Morphology, Tectonics

Introduction

Fluvial systems are controlled by internal processes determining hydraulic gradient, sediment mobility, channel dimensions and rates of migrations as well as by responses to external forcing such as climate change, base level fluctuations and tectonic conditions (Kleinhans and Van den Berg, 2010; Vandenberghe, 2003; Holbrook and Schumm, 1999; Blum and Tornqvist, 2000). A river terrace is defined as an abandoned and higher elevated patch of a former floodplain (Leopold et al., 1964) which, in tectonically uplifting areas, tends to be preserved along the sides of the river valley. River terrace formation, preservation and style of dissection can be accentuated by changes in climate, vegetation cover, sediment supply or the presence of permafrost (Antoine et al., 2000; Bridgland and Westaway, 2008). In addition they may vary due to reach-specific conditions (Schumm, 1981; Erkens et al., 2009), something that has been underappreciated in past studies. An outstanding example of preserved Lateglacial and Holocene river terraces with diverse fluvial styles has been formed by the Meuse river in the active rift structure of the Roer Valley Rift System (RVRS; Figure 1) of which the tectonic activity is well-known (Geluk et al., 1994; Houtgast and Van Balen, 2000; Cohen et al., 2002; Van Balen et al., 2005). The RVRS comprises the Campine-Block (CB), Roer Valley Graben (RVG), Peel-Block (PB) and Venlo-Block (VB) (Figure 1). The Feldbiss Fault Zone (FFZ) separates the subsiding RVG from the CB in the south and the Peel Boundary Fault Zone (PBFZ) forms the boundary between the RVG and PB in the north. The Meuse river crosses these fault bounded blocks and fault zones in the Lower Meuse Valley (the area between Maastricht and Nijmegen) and acted, therefore, as a study site for the research on spatial and temporal variations in river terrace formation, preservation and morphology (Woolderink et al., submitted.)

* Corresponding author
Email address: h.woolderink@vu.nl (H.A.G.Woolderink)

Methods

To study the spatial and temporal variations in river terraces a digital mapping was performed which splits mapping of geomorphological elements (such as abandoned meanders or terrace fragments) from cataloguing naming, dating and literature referencing for the individual elements (Berendsen et al., 2001, 2007; Cohen et al., 2012). First of all, existing information on dated geomorphological features was acquired from published sources and institutional databases, which were subsequently made browseable in a GIS. This resulted in a database consisting of 381 dates from 255 unique site locations. Hereafter, this dataset was manually (re)interpreted into geomorphological and geological maps which honour the original dating information as well as geomorphic cross-cutting relations. These maps were subsequently digitized, which resulted in a map of labelled polygons with an attached non-spatial database containing an ID-number, name and start- and end- date of the geomorphological unit. From this, a terrace map and a series of palaeogeographic maps were generated in a GIS computing step, after which these maps were compared to the corresponding analogue maps and, where needed, modified.

Results and conclusion

The collected data and performed analysis indicate that the Meuse river within the Lower Meuse Valley (LMV) had a varying planform since the Last Glacial Maximum (LGM), alternating form fully braided during the LGM, to multi-channel low-sinuosity during the Bølling, meandering during the Allerød, to a braided/wandering system during the course of the Younger Dryas to again a meandering planform at the onset of the Holocene. However, reach-to-reach variations in the geomorphological and sedimentary responses occur in the LMV. Lateglacial terrace fragments are best

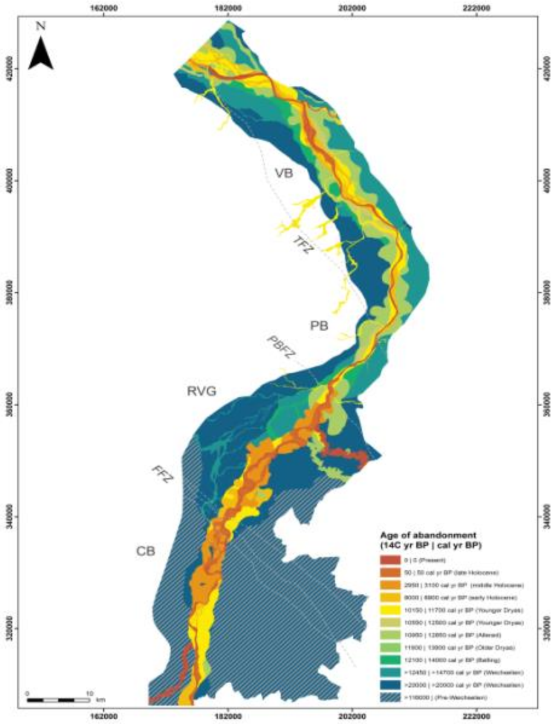

Figure 1: Weichselian and Holocene terraces of the Meuse in the Roer Valley Graben (Woolderink et al., submitted).

preserved on the uplifting Peel-Block and Venlo-Block, while remnants of the Holocene Meuse are best preserved in the Roer Valley Graben and on the Campine-Block (Figure 2). Furthermore, Holocene channel belts are narrow with a low-sinuosity to straight channel pattern on the Peel-Block and Venlo-Block while channel belts are wider and contain channels of greater sinuosity in the Roer Valley Graben and the northern part of the Campine Block (Figures 1 & 2). In addition, where the river crosses fault zones, fluvial style and local terrace preservation show anomalies to the overall trend, such as a meandering pattern during the Younger Dryas at the Feldbiss Fault Zone and an upstream meander migration at the Peel Boundary Fault Zone during the Allerød (Figure 2). Overall, the regional variation in the tectonic setting in the Lower Meuse Valley had a pronounced effect on the formation, preservation and morphology of fluvial terraces.

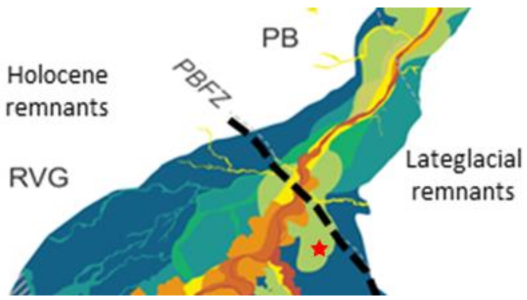

Figure 2: Preservation of Lateglacial terrace fragments on the PB, while Holocene terrace remnants are best preserved in the RVG. Red star indicates anomalous Allerød meander. For Legend see Figure 1 (Woolderink et al., submitted).

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Session Ib

Rivers, health and ecosystems

Effect of longitudinal training dams on environmental conditions and fish density in the littoral zones of the river Rhine

Frank Collas[a,b], Tom Buijse[c], N. van Kessel[a,b,d], Rob Leuven[a,b]
[a] Radboud University, Institute for Water and Wetland Research, The Netherlands
[b] Netherlands Expertise Centre on Exotic Species (NEC-E), Nijmegen, The Netherlands
[c] Deltares, Department of Freshwater Ecology and Water Quality, Delft, The Netherlands
[d] Bureau Waardenburg b.v., Culumborg, The Netherlands

Keywords — Alien species, ecological rehabilitation, fish species, habitat stability, river training

Introduction

Biodiversity and functioning of rivers is increasingly threatened by hydraulic engineering facilitating navigation (e.g., channelization, dredging and protection of embankments). These changes reduce channel sinuosity and habitat diversity. In addition, navigation causes water displacements, increased wave action and changes in, shear stress, flow velocity and underwater sound.

The decreased habitat diversity due to navigation deteriorates spawning and nursey habitats and affects diversity and productivity of migratory and riverine fishes (Wolter and Arlinghaus 2003). Embankments and groynes are often constructed using basalt stones and other rocks serving as habitat for several alien species (Leuven et al. 2009).

With the implementation of the Water Framework Directive the focus of river management changed from technology based to taking ecological values into account. This vision culminated in the Netherlands in the 'Room for the River' programme. As part of this programme existing groynes structures were removed and replaced with longitudinal training dams (LTDs) along a 10 km stretch in the river Waal.

LTDs are novel river training structures placed parallel to the river bank thereby protecting the littoral zones from navigation induced impacts (Collas et al. 2018). The LTDs in the river Waal serve multiple functions: 1) to increase and maintain water depth for navigation, 2) to increase discharge capacity for improved flood safety, 3) to facilitate the safe discharge of ice to protect hydraulic infrastructure and river dikes, 4) to reduce fairway maintenance costs (dredging), and 5) to increase habitat diversity and stability by creating sheltered shore channels (Eerden, 2013).

The objective of the present research is to assess the effects of the LTD on abiotic conditions and fish density in the river Waal.

* Corresponding author
Email address: f.collas@science.ru.nl (F. Collas)
*URL:*http://www.ru.nl/environmentalscience/staff/individual-staff/collas/ (F. Collas)

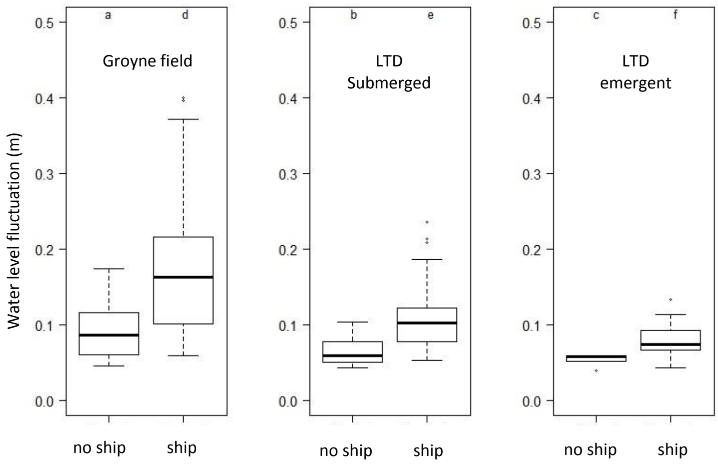

Figure 2. Whisker plots of range of water level fluctuations in the groyne field location, submerged lowered LTD location and emergent lowered LTD location during periods with and without ship passages. Different letters depict significant differences.

Method

Monitoring was performed in the river Waal in several traditional groyne fields and behind the novel LTDs. Separate monitoring campaigns were performed in order to assess the effect on 1) abiotic conditions and 2) fish density and diversity.

Several abiotic measurements related to navigation induced effects were performed (e.g., flow velocity, water level fluctuation, flow stability and underwater sound level). Measurements were repeated at various water levels.

Fish sampling was undertaken in July in 2016 and 2017 after sunset in the littoral zone using seine nets targeting small-bodied fishes. Sampling locations were grouped into three categories: 1) groyne field, 2) shore channel behind a sheltered LTD section, and 3) shore channel near a dynamic LTD section. Fish assemblages near the stony substrate of the LTD were analysed using boat mounted electrofishing equipment. Transects of 50 m were sampled at regular intervals of 200 m along the entire LTD (total length: 4 km).

The acquired abiotic data was analysed using generalized linear mixed effect models using R statistics. Fish densities were analysed using anova models and fish diversity was assessed using permutational multivariate analyses of variance.

Results and discussion

Water level fluctuation during the passage of ships was significantly lower behind the LTD compared to the traditional groyne fields (Figure 2). The effect of navigation on flow velocity did not significantly differ between groyne fields and the LTD, though the variation in flow velocity fluctuation was higher in the groyne field than in the shore channel. Flow stability was significantly higher in the shore channel compared to groyne fields, indicating that conditions in the littoral zones of the shore channel are less dynamic compared to groyne fields. Underwater sound frequency and intensity was strongly reduced in the shore channel compared to the groyne fields further decreasing ship induced stressors in groyne fields. The LTD significantly mitigates abiotic effects of navigation in the littoral zones in intensively used rivers like the river Rhine. Improved hydrodynamic conditions will reduce energy expenditure in relation to swimming and reduced the risk of wash-out for fishes (Schiemer et al. 2003; Trinci et al. 2017).

Fish densities in the littoral zone were significantly higher in the shore channel compared to the groyne field (Figure 3). Native fish densities were also significantly higher in the shore channel compared to the groyne field (Collas et al., 2018). The same effect was found for rheophilic and eurytopic fishes. Fish diversity did not differ between the littoral zone of groyne fields and shore channel. Fish density in and near stony habitats of the LTD increased with increasing distance to dynamic sections. The added value of the shore channel is expected to increase as erosion and sedimentation processes will further increase habitat diversity over the coming years.

Conclusion

- Abiotic effects of navigation are greatly reduced in the shore channel of LTDs compared to groyne fields.
- Environmental conditions are more stable in the shore channel
- Shore channels provide valuable habitat for juvenile fishes and show
- higher fish densities compared to groyne fields.
- LTDs allow ecological rehabilitation of littoral zones of highly navigated rivers while simultaneously enabling an increased river usage.

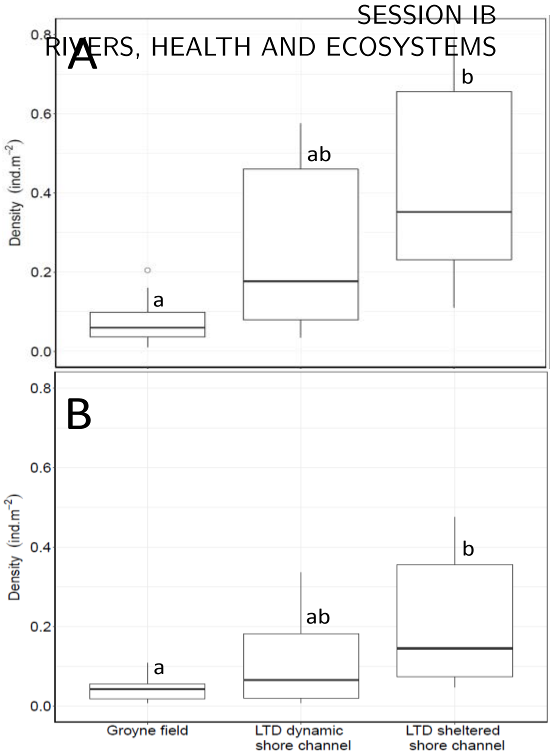

Figure 3. Whisker plots of fish density caught during 2016 with a seine net at the groyne field location, LTD dynamic shore channel location and LTD sheltered shore channel location of (a) all species pooled and (b) native fish species pooled. Different letters depict significant differences.

Acknowledgements

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Spatial prediction of macrophyte species in rivers using environmental key factors

Frederick G. Wortelboer[a*]
[a]Deltares, P.O. Box 177, 2600 MH Delft, The Netherlands.

Keywords — Environmental key factors, Macrophytes, Prediction, Water Framework Directive

Introduction

The European Water Framework Directive (WFD) aims at good ecological status for surface waters to be reached by 2027. Measures are proposed to improve ecological status for waters that have not reached this state yet. Ecological status is defined for the ecological quality elements fytoplankton, fytobenthos, macrophytes, macrofauna and fish. Macrophytes are especially interesting in riverine ecosystems as they define habitat structure both by their presence and by interacting with fluvial processes such as sedimentation and flow (Van Oorschot, 2017). For a large number of species of macrofauna and fish, the presence of submerged macrophytes in river ecosystems is essential in providing food, hiding spots and habitat for reproduction.

The Water Framework Directive Explorer (WFD Explorer) is a general framework for the calculation of water quality and the assessment of the ecological status for the WFD. Is consists of a number of modules for the calculation of flow, nutrient fluxes and a neural network model linking nutrient concentrations and environmental characteristics directly to Ecological Quality Ratios (EQR's) for the WFD. For large rivers and lakes a new method is developed to improve the prediction of future EQR values as a result of measures planned. This paper describes the first results for the River IJssel and discusses the lessons learned.

Method

Tolerance ranges of macrophytes for environmental factors are confronted with the spatial distribution of the values of these environmental factors. If all the environmental factors fall within the tolerance boundaries of a species, that species can occur under these conditions. Thus the potential occurrence is calculated. Tolerance ranges of macrophytes species were derived from a data set of 600 Dutch surface waters which were monitored for macrophytes and physico-chemical characteristics of surface water and sediment in the period 1980-1983 (De Lyon & Roelofs, 1983). Additionally, environmental factors were added from literature (Table 1).

Table 1. Environmental key factors used for the prediction of the potential occurrence of macrophytes species in the river IJssel and source of tolerance data for macrophyte species. Source: 1: De Lyon & Roelofs (1983); 2: Janauer et al. (2000); 3: SynBioSys: Schaminée et al., (2011); 4: Expert judgement.

Key factor	Unit	Source
Alkalinity	meq/l	1
Ammonium	meq/l	1
Chlorinity	meq/l	1
Depth	M	1, 3
Dessication	0/1	3
Seepage	0/1	3
Light on the bottom	0/1	4
Nitrate	meq/l	1
pH	-	1
Sediment type	-	1
Stream velocity	m/s	2
Waves	0/1	4

Values for environmental factors were estimated from the ambient national water monitoring programme (MWTL), modelling results and literature. The water body of the river IJssel was subdivided into spatial units from coarse (subunits) to fine (ecotopes). Values of environmental variables were assigned to every spatial unit. Translation of units between tolerance data and environmental data was taken into account.

* Corresponding author
Email address: rick.wortelboer@deltares.nl (F.G. Wortelboer)
URL: www.deltares.nl

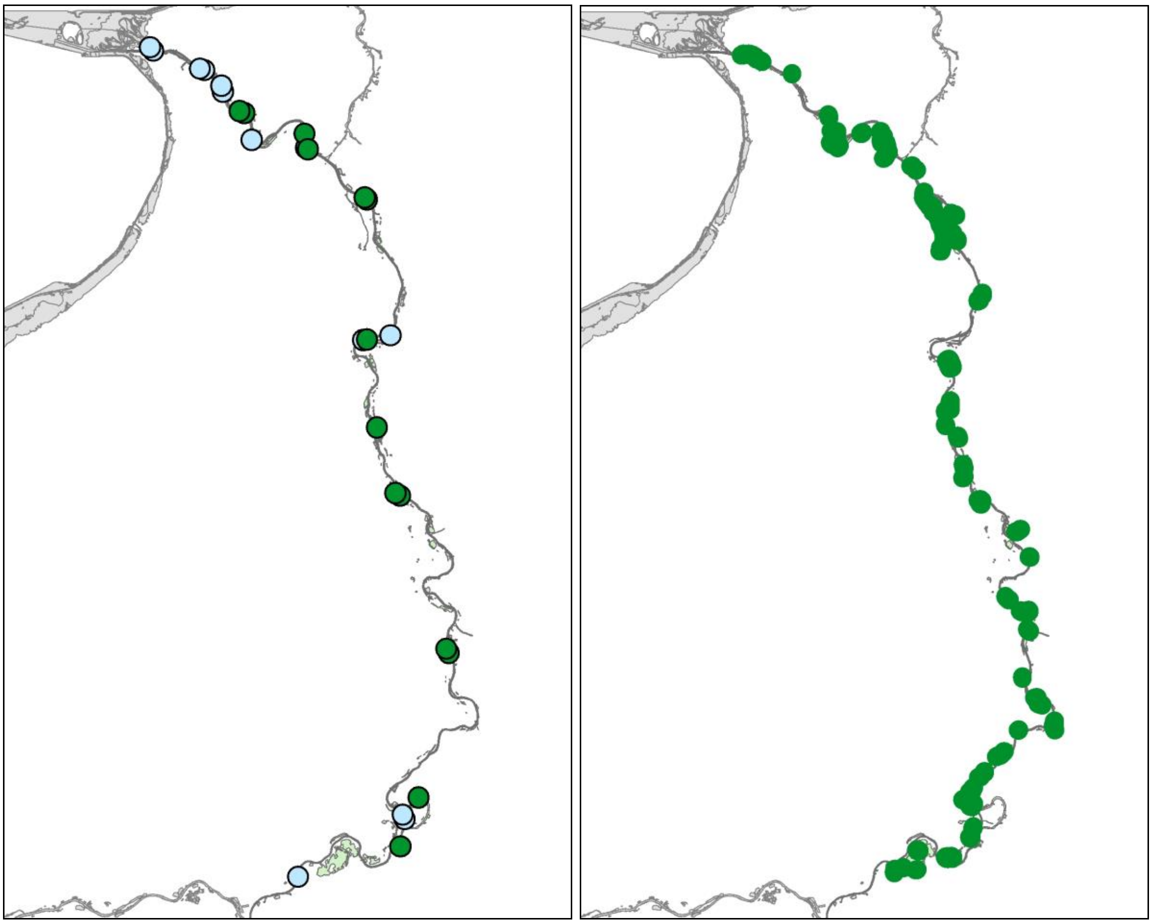

Figure 1. Observed (left) and calculated (right) occurrence of Water mint (Mentha aquatica) in the river IJssel. Left: data MWTL: blue dots: not present; green dots: present.

Results

The spatial distribution pattern of 109 aquatic macrophytes species was calculated (Figure 1). The potential presence of 29 species was calculated, of which only 16 were observed in the river IJssel, Additionally, 19 species were observed but were, on the basis of their tolerance ranges and estimates of environmental factors, calculated to have no suitable habitat available. These results need to be scrutinized further. Possible sources of error are the original tolerance data, which originate from a specific period in time and may not represent the complete tolerance range of species. 13 species were calculated to be present, but were not observed. Here, monitoring may be insufficient or estimates of environmental factors may not be adequate. The results need further analysis.

Conclusion

First results revealed that the method generates plausible spatial patterns of the distribution of aquatic macrophyte species throughout the water body of the river IJssel. Further research will focus on improving the method and applying it to more water bodies.

Acknowledgements

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Modelling effects of spatiotemporal temperature variation on native and alien fish species in riverine ecosystems using thermal imagery

Frank Collas[a,b,*], Wimala van Iersel[c], Menno Straatsma[c], Rob Leuven[a,b]
[a] *Radboud University, Department of Animal Ecology and Ecophysiology, Institute for Water and Wetland Research, The Netherlands*
[b] *Netherlands Centre of Expertise on Exotic Species (NEC-E), Nijmegen, The Netherlands*
[c] *Utrecht University, Geosciences, Utrecht, The Netherlands*

Keywords —biodiversity; remote sensing; river rehabilitation; species sensitivity distributions, UAV

Introduction

Environmental stressors such as global warming and invasive alien species are increasingly impacting riverine ecosystems, thereby influencing water usage and biodiversity (Leuven et al. 2011; Van Vliet et al. 2013).

Water temperature is a key factor affecting distribution of native and alien freshwater fish species. When temperatures become too high detrimental stress occurs in many species ultimately resulting in mortality. The thermal limits of fish species were used to derive species sensitivity distributions (SSDs; Leuven et al. 2011), which allow to predict potentially affected fractions and habitat suitability in relation to changing water temperature regimes.

As water temperature of riverine ecosystems are expected to increase, thermal limits of fish species can be exceeded, urging the need to assess effects of ecological rehabilitation measures on temperature regimes of rivers. Recently, several side channels have been built in the floodplains of the river Rhine, though temperature regimes remain unclear.

The high spatiotemporal variability of water temperature limits the use of point measurements to accurately assess effects on fish species in rivers and side channels (Leuven et al. 2011). Potentially, unmanned airborne vehicles (UAVs) could provide temperature field with a spatial resolution of less than 1 m depending on flight elevation. UAVs can be employed with a thermal infrared sensor, potentially enabling spatial monitoring of water temperature in side-channels with a width up to 30 m.

The temperature of an object can be derived from its thermal infrared radiation (TIR) after correction for its emissivity. Water temperature assessed with remote sensing measures only the upper 0.1 mm of the water column (Handcock et al., 2012). The highly reflective water surface can disturb the thermal signal of the water by reflecting thermal radiation from the sun and surrounding objects via the water surface into the sensor (Anderson and Wilson, 1984). This effect varies over time, due to changes in solar angle and wind conditions. Hence, it remains unclear whether water temperature can be estimated with sufficient accuracy for freshwater fish habitat monitoring using UAV thermal imagery.

The present research aims to predict the ecological potential of a side channel during a hot summer day using UAV derived water temperature measurements. The research questions are: 1) How accurate can water temperature in side-channels be measured using UAV thermal imagery? 2) What is the spatiotemporal temperature variation of a side channel during a summer day? 3) What is the ecological potential of a side channel taking water temperature into account?

Method

Monitoring consisted of simultaneously collecting thermal imagery using a UAV and *in-situ* water temperature measurements using temperature loggers. The Sensefly Ebee UAV (SenseFly, 2017) employed with the ThermoMAP sensor was used to collect thermal imagery at 07:15h, 13:00h, 15:00h and 19:30h on August 29th 2017. Flight duration was approximately 15 minutes. *In-situ* water measurements were carried out with the Hobo Onset sensor 10 cm below the water surface at 24 locations distributed across the side channel covering variation in its depth and width. Before each flight, the vertical position of each logger was adjusted to ensure the positioning at 10 cm below the water surface. The loggers measured water temperature with a frequency of 0.1 Hz.

The UAV imagery were processed into orthophotos using SenseFly Postflight Terra. UAV imagery was geo-referenced using 23 ground control points. The TIR values of the

* Corresponding author
Email address: f.collas@science.ru.nl (F..Collas)
*URL:*http://www.ru.nl/environmentalscience/staff/individual-staff/collas/ (F. Collas)

orthophotos were converted to temperature (T_{UAV}) with eq. 1:

$$T_{UAV} (°C) = TIR / 100 – 100 \quad (1)$$

We validated the T_{UAV} with median temperature of *in-situ* reference data over the time interval of the corresponding flight (T_{ref}). Subsequently, a linear regression was used to analyse the relation between T_{UAV} and T_{ref} for each flight separately.

We created a temperature map by applying the the regression equations to the T_{RS} map. Subsequently, we calculated the potentially not occurring fraction (PNOF) of native and alien freshwater fish based on the river specific species sensitivity distribution (SSD) of alien and native fish published by Leuven et al. (2011) and the temperature maps.

Results and discussion

T_{ref} was estimated with a mean absolute error (MAE) of 0.81±0.61°C by T_{RS}. Lower temperatures (< 24°C) of the morning flight were mostly underestimated and higher temperatures during the afternoon were overestimated (Figure 1).

The regression equation of the afternoon flight at 15:00 had an intercept close to zero and slope close to one. The morning and early afternoon flight performed the worst with an R^2 of 0.45 and 0.57, respectively. These results show that UAVs with a ThermoMAP sensor can be used to spatially explicit measure ambient water temperature, but the accuracy varies during the day.

Water temperature in the side-channel was lower in the morning compared to the main channel. A reversed pattern was observed

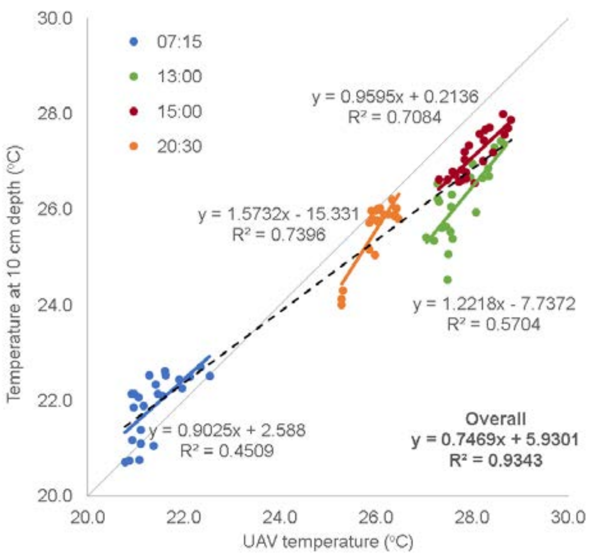

Figure 1. Linear regressions of UAV ThermoMAP sensed temperatures and in-situ temperature measurements for each of the separate flights. Light grey line is y=x; Black dashed line reflects the overall linear regression.

during the afternoon.

The PNOF maps showed a limitation of habitat suitability for native and alien fish species throughout the day (Figure 2). Native species were more limited in the side channel compared to alien species. The highest limitation occurred during the afternoon when water temperatures were close to 28°C. These results show that under hot summer conditions the function of side-channels as refugia for cold water species is limited. In order to increase the ecological value of the side channels, flow velocity and depth could be increased thereby reducing water temperatures. Moreover, side channels in areas with high seepage of groundwater are expected to be more suitable for native cold water fish species.

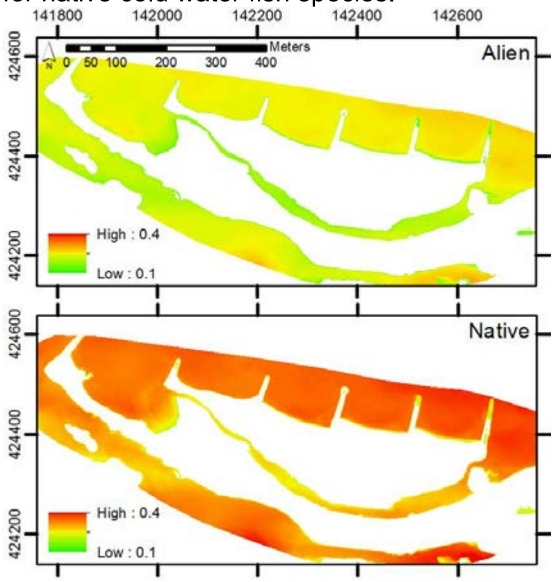

Figure 2. Potentially not occurring fraction of alien and native fish species at 07:15h, August 29th 2017.

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Is the trait concept applicable to floodplains of regulated, temperate, lowland rivers?

Valesca Harezlak[a,b,*], Denie Augustijn[a], Gertjan Geerling[b,c], Rob Leuven[c] and Suzanne Hulscher[a]

[a] *University of Twente, Dept. of WEM, Faculty of ET, P.O. Box 217, 7500 AE, Enschede, the Netherlands*
[b] *Deltares, Dept. of Freshwater Ecology and Water Quality, P.O. Box 85467, 3508 AL, Utrecht, Netherlands*
[c] *Radboud University, Faculty of Science, Institute for Science, Innovation and Society, P.O. Box 9010, 6500 GL Nijmegen, the Netherlands*
**Corresponding author: v.harezlak@utwente.nl*

Keywords — Plant traits, Environmental filters, Floodplains

Introduction

In floodplains, the succession of vegetation towards its climax stadium can be reset, delayed or brought to a hold by abiotic and biotic processes (hereafter: filters, sensu Laughlin et al., 2012) (Walker and del Moral, 2008). Floodplain vegetation of natural free flowing rivers may mature into floodplain forests, but will be, over the course of many years, reset to bare sediment. Vegetation in floodplains of regulated rivers are *not* exposed to the fierce sedimentation and erosion powers of free flowing rivers. If no measures are taken, most of the vegetation of these floodplains likely reach the climax stadium (Poff et al., 1997).

Unlike the floodplains of free flowing rivers, the floodplains of regulated rivers often need to fulfil several law-enforced ecosystem services, like providing water safety during high river discharges and as nature areas. Unfortunately, combining several ecosystem services is complex and puzzles floodplain managers (Geerling et al., 2008). As plant traits offer a two-way link between filters and vegetation composition (Violle et al., 2007), studying plant traits and how they link to filters, can aid in uncovering the dominant filters steering the maturation of floodplain vegetation.

Filters such as substrate type, flooding characteristics, and grazing pressure act on floodplain vegetation of the larger Dutch rivers. Also, in international literature, single or combined (i.e. a strategy) plant traits have been identified that are specifically coupled to one or just a few filters. Combining the available knowledge on both filters and traits or trait strategies, resulted in the theoretical framework depicted in Fig. 1. In this study, this framework is used to investigate whether the trait concept also holds in floodplains of regulated rivers because of the more gentle gradients in filters than is the case for floodplains of free flowing rivers, and as such can be a useful concept for the optimization of ecosystem services

Material and Methods

In 2016, in each of three Dutch floodplains (Duursche Waarden, Erlecomse Waard, Millingerwaard), ten non-woody 1 m^2 plots were marked. The following proxies of filters were measured: elevation above mean river level (Elev, m), soil moisture (SoilM, %), soil organic matter content (L550, %), grain size (lutum, silt, and fine and coarse sand), and being

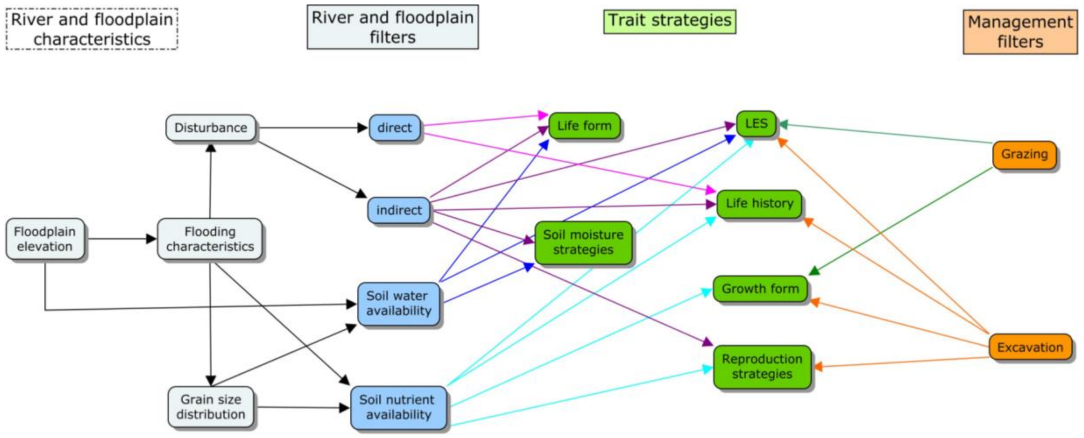

Fig. 1: Conceptual framework of filters and traits. The boxes on the top indicate the group to which the similarly coloured boxes in the network belong to. The arrows indicate the effect of a characteristic on a filter or indicates connection between a filter and a trait or trait strategy. The arrow colours only indicate that those arrows stem from the same characteristic or filter.

flooded during the summer of 2016 (Flooded, y/n), excavated (Exc, y/n) and/or grazed (Grazed, y/n). The vegetation was mapped with the Braun-Blanquette method and of the species covering over 15% of a plot, the leaf economic spectrum traits (LES, dry weight (g), surface area (m^2)) and leaf N (LeafN, g/g)) were measured. The Turboveg software supplied the trait values for life history, life form, growth form, reproduction an soil moisture strategies for all the mapped plant species.

A principal component analysis (PCA) revealed the dominant filters. Fuzzy c-means clustering (a non-hierarchical and unconstrained clustering method) was used on both the proxies and the traits to identify possible coherent relationships between filter proxies and traits. Moreover, this method is a check on how much impurity (i.e. omission of relevant processes) is introduced when using a constrained clustering method (De'ath, 2002). Next, multiple regression trees (MRTs), with the proxies as constraining variables, were constructed to identify relationships between proxies and traits.

Results

The first PCA axis explained 63.7% of the variance and grouped SoilM, Lutum, Silt, Elev and L550. The second PCA axis explained 20.1% of the variance and coincided with Exc and fine sand. Fuzzy c-means clustering indicated that there were no coherent relationships between proxies and traits. Comparison with the MRT results, indicated that other processes, such as chance, grazing intensity or starting conditions, can also be important filters. The results of the MRT, partly shown in Fig. 2, indicated that Elev, SoilM, and Exc were the most influencing variables for trait composition: Elev selected for more acquisitive species in lower areas, and more conservative species in higher areas due to both water and nutrient availability or scarcity, SoilM influenced the onset of flowering, indicating differences in competition strength, and the ability of species to cope with wetter conditions (Anatomy), and Exc influenced life history and growth form strategies by initiating secondary succession.

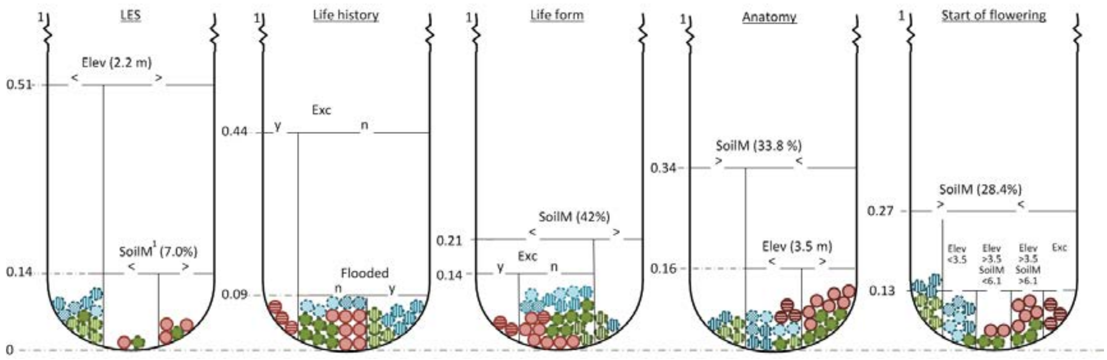

Fig. 2: Overview of part of the summarized results of the MRTs for LES, Life history, Life form, Anatomy and Start of flowering. The left axis on each vial represents the explanatory power of the filters on the trait composition: 0 means 'explains nothing', 1 means 'explains all'. The horizontal lines indicate a filter (for example 'Elev') including its critical value and its explanatory power. The balls in the vial represent the plots and the colours represent the floodplains: blue for Duursche Waarden, green for Erlecomse Waard and red for Millingerwaard. Vertically striped balls represents plots that were flooded in the summer of 2016, horizontally striped balls excavated plots and balls with dotted lines non-grazed plot. [1]: L550 (0.94%) gives the same result.

Conclusion

Although floodplains of regulated rivers do not have as steep gradients in filters as floodplains of free flowing rivers, the trait concept proved to be an aid in understanding how specific processes shape vegetation composition spatially. Higher and dryer locations selected for conservative species: species with low growth rates and thus low biomass production. Lower and wetter locations (but not the wettest), selected for acquisitive species: species that grow fast and therefore have high biomass production. Excavating floodplains initiates secondary succession, allowing also trees to thrive at those locations. Grazing as management, although not identified by the methods used, led to lower vegetation height and less tree development. All in all, the trait concept is indeed a functional tool in understanding spatial vegetation development.

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NCR

The Future River

Session IIa

Effectively communicating & participating in fluvial science

Assessing sense of place to support river landscape planning

Sarah Gottwald[a*], Christian Albert[a]
[a]*Institut for Environmental Planning, Leibniz University Hannover, Herrenhäuserstr. 2, 30419 Hannover, Germany*

Keywords — Sense of place, river landscape planning, Geodesign

Introduction

Navigating landscape development towards more sustainable pathways puts forward the challenges of dealing with complex interactions between the underlying social and ecological systems, as well as with the need to integrate the interests and values of diverse stakeholders. A case in point are efforts in the field of river landscape restoration which need to balance diverse interests such as the improvement of ecological conditions, the enhancement of recreational qualities, and continued protection of downstream communities from flood risks.

In response to these challenges, landscape planners have developed various approaches for assessing and evaluating landscapes, exploring the impacts of plausible scenarios of future changes, and delivering relevant knowledge in ways useful to support decision-making. In this context, applying the concept of ecosystem services has recently gained much attention as a way to more explicitly investigate the effects of landscape changes on human well-being.

Despite of much research on methods for assessing relationships between nature and people, little attention has so far been put on approaches for assessing and integrating information on the personal attachment of people to particular places in planning exercises especially as part of geospatial information and planning literature (Manzo and Perkins 2006, Ryan 2011).

We propose the theory of sense of place to highlight the different meanings of a diverse river landscape. Sense of place theory describes the affective bond between people and place – consisting of place attachment (Low and Altman 1992) and meanings attributed to places (Stedman 2016). It reflects upon the interrelation between the social and the biophysical sphere (Masterson *et al.* 2016), and its application in planning could help ensuring that local knowledge and values are appropriately considered in sustainable river development.

* Corresponding author
Email address: gottwald@umwelt.uni-hannover.de
URL: www.plansmart.info

Therefore the aim of this paper is to present and discuss how spatial data on sense of place have been assessed and analysed for the further planning process. To do so, we used a participatory mapping survey to assess sense of place data, analyse the data in relation to the biophysical components of the river landscape and the personal characteristic of the respondents, and outline our design for integrating this information in a participatory planning process.

Our case study is the Lahn river landscape in Hesse, Germany, and the ongoing transdisciplinary planning process to explore alternative futures for the region as carried out by the PlanSmart research group in collaboration with the Integrated EU LIFE Project Living Lahn.

Method

A Public Participation GIS (PPGIS) survey was carried out in summer 2017 at the middle and lower stream of the Lahn River in Germany. They gave some additional information for that place and answered questions concerning their local knowledge, environmental citizenship and general background.

For the analysis we will apply the Latent class method (Sevenant and Antrop 2010), where biophysical characteristics (land use, protection status, accessibility) serve as explanatory variables and personal characteristics (environmental citizenship, local knowledge, socio-economic characteristics) represent covariates.

First results

A total of 700 respondents located 1100 meaningful places in the river landscape, of which 745 correspond to the study area used in the further process. The ongoing analysis sheds new light on the relation between sense of place, land uses and personal characteristics in a river landscape. Meaningful places cluster around urban as well as rural areas, areas with a lot of recreation infrastructure as well as very natural areas.

The frequency of meaningful places decreases with increasing distance from the river and adjacent lakes.

Integrating sense of place data in participatory planning processes

The PPGIS data will be fed into a Geodesign participatory planning workshop, which will be held in spring 2018. Using the Community VIZ software extension for ArcGIS, participants will be able to change land uses and estimate the impact on a small set of indicators including one on the significance for sense of place.

The Geodesign workshop is part of a row of five workshops carried out with local practice partners. The Geodesign workshop uses a digital and interactive touch table, where participants are able to visualize different data layers and change land uses. Using the Community Viz tool, impacts of land use changes on ecosystem services and sense of place are calculated and communicated.

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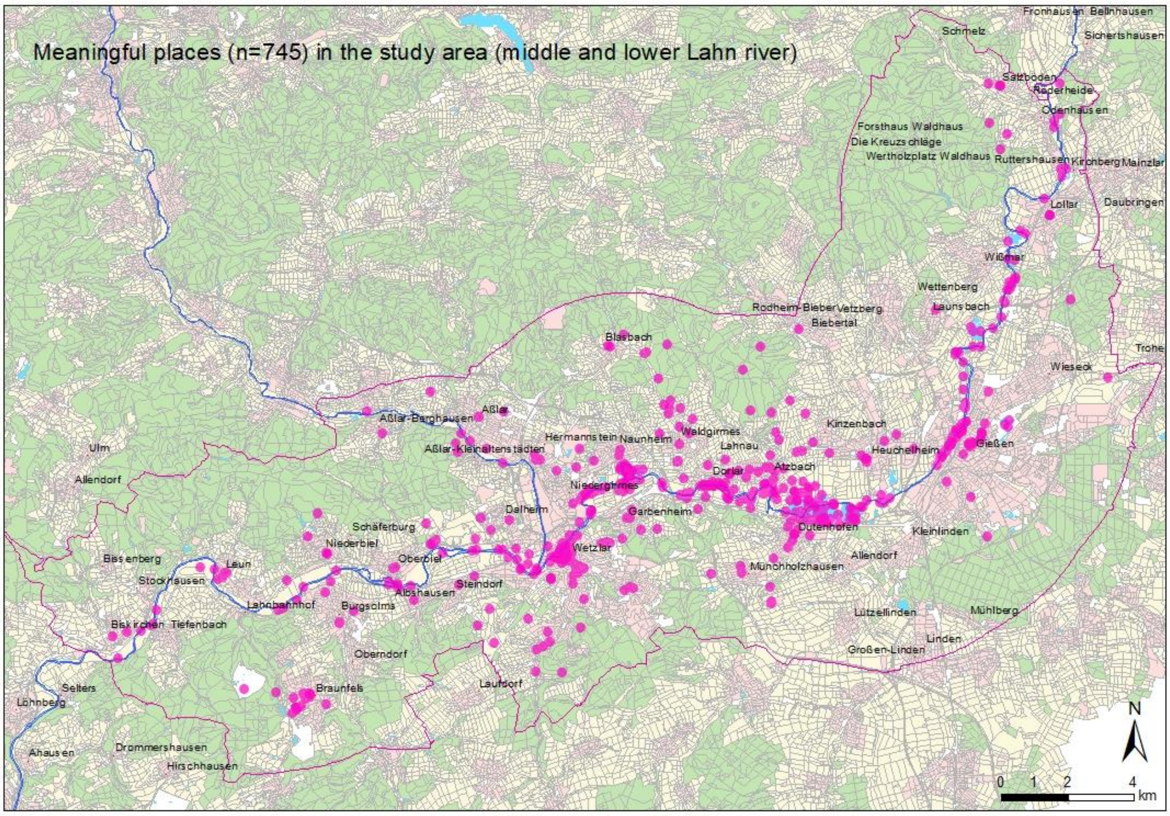

Figure 1. Map of the study region showing the spatial distribution of meaningful places located by participants.

Involving citizens in monitoring river interventions: Lessons learned from a river Waal case study

Laura N. H. Verbrugge[1,2*], Riyan J. G. van den Born[2]

[1] University of Twente, Department of Water Engineering and Management, Faculty of Engineering Technology, P.O. Box 217, 7500 AE, Enschede, The Netherlands
[2] Radboud University, Institute for Science in Society, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands

Keywords – citizen science, longitudinal training dams, participatory monitoring, public participation

Introduction

Adequate monitoring and evaluation of large-scale river interventions is vital for successful adaptation to environmental and social change. Participatory monitoring refers to the active involvement of local stakeholders in the systematic collection of information (Villaseñor et al., 2016). Intended outcomes of stakeholder inclusion in monitoring are both process and outcome related, including (1) increased public support, (2) increased levels of trust between participants, (3) integration of lay and expert knowledge facilitating (social) learning, or (4) more or better data (Breman et al., 2014).

This case study concerns the substitution of traditional groynes by longitudinal training dams (LTDs) in a 10 kilometre stretch of the Waal river (the main Rhine branch in The Netherlands), dividing the river in a main channel and secondary channel. The main objectives of this intervention are: (1) to improve conditions for navigation during low water levels, (2) to increase discharge capacity for improved flood safety, (3) to protect hydraulic infrastructure and river dikes from potential ice damage, (4) to reduce dredging costs, and 5) to improve ecological conditions in the secondary channels (Eerden, 2013). The completion of the LTDs in December 2015 marked the beginning of an intensive monitoring program (2016-2019) in which governmental, societal and research partners collaborate (Verbrugge et al., 2017; Van den Heuvel et al., this issue).

The monitoring results facilitate adaptive management, i.e. adjusting to the changing conditions in the (physical) environment. Citizen observatories have the potential to contribute to the evaluation of LTDs, in terms of their impacts on recreational and ecological values. For example, with the removal of groynes, local recreational anglers lose one of their favourite fishing spots, which may force them to relocate. On the other hand, the creation of a more protected side channel may create more opportunities for nature development and may sustain a more diverse fish population.

In a previous paper, we reported on the incentives of organized stakeholders to actively participate in monitoring the effects of the LTDs, as well as on the outcomes of pre-intervention surveys among local residents, recreational anglers and boaters, and shipping professionals (Verbrugge et al., 2017). These results fed into the design of a participatory monitoring pilot project involving recreational anglers, based on their concerns for negative impacts on fish habitats and a lack of trust that sufficient monitoring would be carried out (resulting from previous experiences, i.e. lowering of the groynes). Here, we describe the design, implementation and outcomes of this participatory project during the first two years (2016-2017). Finally, we present the lessons learned and our next steps in research.

Methods

A group of volunteer anglers was involved in the monitoring activities in two ways:

(1) By reporting their catches in the study area in the period April-October of 2016 and 2017, using an (online) form documenting date and time, location (GPS-coordinates), species name and fish size (in cm).

(2) By participating in online surveys asking questions about the accessibility and suitability of locations, their level of satisfaction regarding catches, and their appreciation of the landscape during an angling session (on a 5-point scale).

In addition, a number of (outreach) activities were organized (Table 1) in close collaboration with the Royal Dutch Angler Association (and its regional division). At the end of 2016, an evaluation survey was conducted.

* Corresponding author
Email address: l.n.h.verbrugge@utwente.nl (L. Verbrugge)

Table 1. Overview of (outreach) activities.

Activities	Frequency
Competitions	2-4 times a year
Meetings	Once or twice a year
Newsletters	Monthly in the period April - November
Facebook website	From spring 2017 onwards
Email	At regular intervals

Results

In 2016 and 2017, respectively 44 and 118 catches were reported by volunteers, representing 11 fish species (Table 2). Fish size was reported for 72% (in 2016) and 65% (in 2017) of the reported catches, of which approximately half were at least 30 cm in length. In 2016, volunteers reported one species not caught during research monitoring (i.e. Gibel carp).

Table 2. Overview of fish species caught by volunteers.

Year	Species
2016	Kessler's goby (*Neogobius kesslerii*), Perch (*Perca fluviatilis*), Ide (*Leuciscus idus*), Pike perch (*Sander lucioperca*), Eel (*Anguilla anguilla*), Barbel (Barbus barbus), Flounder (*Platichthys flesus*), Bream (*Abramis brama*), Gibel carp (*Carassius auratus gibelio*), Asp (*Aspius aspius*), Roach (*Rutilus rutilus*)
2017[a]	(+) Vimba (*Vimba vimba*), White bream (*Blicca bjoerkna*), Wels (*Silurus glanis*). (-) Flounder, Gibel carp, Asp

[a] compared to 2016

Results from online surveys show above average scores for the accessibility of fishing locations and the appreciation of the landscape.

Open-ended questions reveal that respondents saw little influence of the LTDs on these two aspects. The lower scores given to suitability and satisfaction were explained by high flow velocity in the secondary channel and the frequent loss of fishing gear due to debris and irregularities in the riverbed profile.

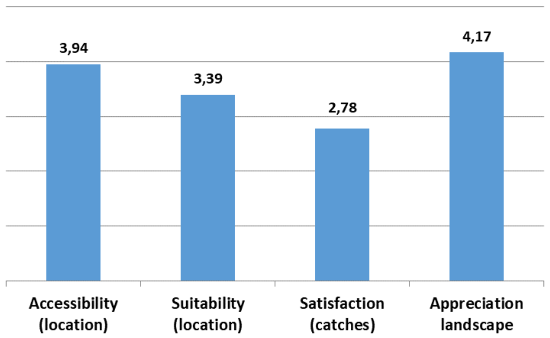

Figure 2. Average scores for anglers' experiences while fishing, measured on a 5-point scale (n = 18).

Lessons learned

- Additional data on presence of adult fish is valuable for ecological monitoring and complements traditional monitoring techniques applied in formal research (Collas et al., 2017).
- The outcomes provide an informational basis for improving management, public engagement and communication practices.
- Cooperation with (local) stakeholder groups is crucial for establishing effective communication with and recruitment of participants in monitoring activities.
- Follow-up perception studies among recreational anglers showed more positive evaluations of the LTDs in 2016 compared to 2014 (unpublished results), possibly due to a positive influence of participatory processes.

Next steps

Recognizing the benefits of citizen science is important but these should also be evaluated. A next step in this research is to compare species diversities resulting from different datasets (e.g. university research and citizen observatories) which will inform us on the complementarity of these sources. This project is continued in 2018 and 2019. This will allow for a temporal assessment of the contribution of volunteers to biodiversity monitoring, as well as of the impacts of participation on social learning.

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Usefulness of storylines to increase the accessibility and transparency of RiverCare knowledge

Juliette Cortes Arevalo[1*], A. Sools[2], L.N.H. Verbrugge[1], M. Brugnach[1], R.P. van Denderen[1], J.H.J. Candel[3], J.E.W.C. van Gemert-Pijnen[2] and S.J.M.H. Hulscher[1].

[a] *Department of Water Engineering and Management, University of Twente*

[b] *Department of Psychology, Health, and Technology, University of Twente, P.O. Box 217, 7500 AE, Enschede, the Netherlands*

[c] *Soil Geography and Landscape group, Wageningen University, P.O. Box 47, 6700AA Wageningen, The Netherlands*

Keywords — science communication, river management, knowledge-base

Introduction

Communication and outreach is a fundamental concern for river research. River management increasingly requires adaptive, collaborative and integrated approaches. Such approaches challenge the way knowledge is produced and communicated between the actors and disciplines involved (Dieperink et al., 2016). Increasing awareness and shared understanding between researchers and practitioners start by acknowledging both technical and experiential knowledge (Ingram et al., 2015). Modelling approaches play a central role in research for innovation or understanding. However, the models and their outputs need to be better communicated to be useful for multi-disciplinary researchers and practitioners. On the other side, practitioners are concerned with the temporal and spatial scales of the problem at hand, possible solutions, related stakes and benefits according to their perspective (Acreman, 2005). Therefore, river researchers are increasingly required to improve their communication efforts, both for a multi-disciplinary technical and management-driven audience.

As part of the RiverCare research programme, we explore the use of online storylines as main component of a knowledge-base (KB) that is under design. The storylines include "*distinctive narrative elements such as questions and answers, images of the research context and interactive charts to effectively communicate river research outcomes in a way that is captivating and easily understood by multi-disciplinary water professionals*." (Cortes Arevalo et al., 2017) The aim of the KB is to communicate the context of the programme, its projects, outputs and updates while linking to existing platforms to reach a wide water professional audience. Our storyline methodology involves a co-creation approach to increase the accessibility and transparency of RiverCare knowledge (research context, collected datasets, modelling outputs and publications). The perceived accessibility includes the availability of scientific outputs but also the perceived usefulness to allow the user interaction with the knowledge and retrieve the potential relevant (useful) information for own work or interest (Zulkafli et al., 2017). Moreover, transparency regarding the methodological assumptions and limitations of the outputs is needed to place the research in context (Brugnach and Pahl-Wostl, 2008).

* Corresponding author
Email address: v.j.cortesarevalo@utwente.nl

Co-creation of storylines

Narrative approaches are used in science communication to increase user engagement and ease of understanding (Dahlstrom, 2014). We used the framework of Murray and Sools (2015) to create our storylines. This methodology allows to outline the key story elements, highlight benefits and limitations as well as the central problem to be solved. We followed a five-step approach to co-create and integrate the storylines into the RiverCare KB:

1. Define the storyline structure based on design considerations as identified from interviews with potential users (Cortes Arevalo et al., 2017).
2. Co-create an outline of the storyline with the RiverCare researchers.
3. Create maps and visualizations to communicate both the context and key outputs of the research.
4. Incorporate the storyline into the KB and review its content with a multidisciplinary group of RiverCare researchers and practitioners.
5. Evaluate the usability of storylines via online feedback and face-to-face workshops with potential users.

Usefulness of the storylines

To evaluate the perceived usefulness of the online storylines, examples were created from RiverCare results in environmental management, geomorphology and river dynamics (see one of the examples in Fig. 1). Two storylines were evaluated by a group of 10 master students in Water Systems studies and members of the RiverCare programme board, as part of preliminary research (See Fig. 2).

Figure 1. Storyline "How do side channels develop?" based on published work by Van Denderen et al., (2017).

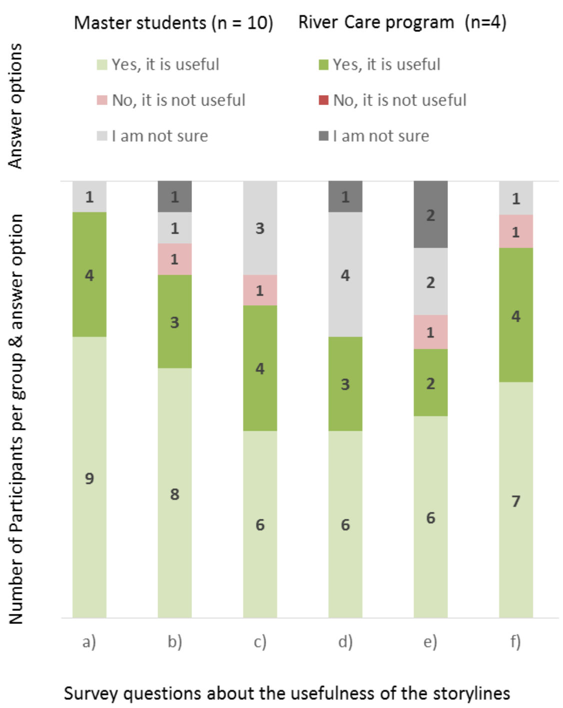

Figure 2. Results for the storyline "How do side channels develop?. Survey questions to evaluate the usefulness of storyline examples included :

a) Explain why the study was done
b) Give examples about how results can be useful
c) Share it with other colleagues or friends interested in river management
d) Revisit it anytime I would like to explain or understand about this topic
e) Trigger my interest to read the paper
f) Use storylines as communication method for my own study or project

Fig. 2 shows first results. Participants positively evaluated the storyline mainly referring to its ability to explain why the study was done and its potential use as communication method for its own project.

Next steps

To further evaluate the storyline usefulness for a wider scientific and practitioner audience a series of workshops is being prepared. The first of these workshops will be held at the NCR days. Come and join us to discuss in sub-groups: the take home message from the results presented in the storyline; and co-create your own storyline on the potential usefulness of RiverCare knowledge for your work.

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A water availability serious game for the Rhine-Meuse delta

Remi M. van der Wijk[a*], Olav J.M. van Duin[a], Marlous van Herten[b], Roel Burgers[c], Ymkje Huismans[a], Rutger van der Brugge[a] and Saskia Hommes[a],
[a]*Deltares, P.O. Box 177, 2600 MH, Delft, The Netherlands*
[b]*Rijkswaterstaat West-Nederland Zuid, Boompjes 200, 3011 XD, Rotterdam, The Netherlands*
[c]*Rijkswaterstaat Water, Verkeer en Leefomgeving, Griffioenlaan 2, 3526 LA, Utrecht, The Netherlands*

Keywords — Drought, Salt Intrusion, Water Availability, Smart Water Management

Introduction

Scientists and water managers want to exchange high level knowledge of the workings of complicated water systems. Furthermore, a combination of climate change and increasing demand for water has led to a push towards smart water management. This requires an understanding of physical processes of the water system and a communication tool that transfers that knowledge in a relatively simple way.

A serious game can explain these complicated issues to a wide range of stakeholders. Additionally, such a game brings different water managers together to learn and discover the mechanisms within their own and other areas.

Deltares made several serious games in 2015-2017 for water shortage and high water scenarios for Rijkswaterstaat and the water boards in various regions. This abstract is about the serious game for the Rhine-Meuse delta (Fig. 1), focussed on water shortage. The game is still in beta, but has proven to be a success on the Smart Water Management day of the region on the 4th of December, 2017.

Figure 1. Board of the Rhine-Meuse delta serious game

Set-up of the game

The game has the following components: a scenario, physical processes, players, measures and consequences. The water managers, the intended players, were involved from the start to make sure that the used information of their systems was correct and to understand some of the measures that can be taken in the region as well.

Mechanically the game is divided in two modules with their own set of measures: one for the main water system and one for the regional systems. If a measure affects multiple players, each player involved has to agree to its implementation.

The game uses salt concentration classes instead of absolute values. This because using absolutes values has certain challenges which were not feasible to solve for a game. One challenge is the fluctuation in salt concentration over the time period of a single turn (>5 days). The uncertainty of the exact salt concentration is high, especially when certain measures are taken. The difference in acceptable salt values for different functions is another challenge.

For the main water system a hypothetical but plausible drought scenario was created, which lasts 65 days and is divided over 6 turns. During this time the river discharge is relatively low which leads to salt intrusion in the entire Rhine-Meuse delta. The salt intrusion worsens when a storm surge takes place. Some measures, like redistributing the water between the Lek and Waal or stopping the intake of water to the Volkerak-Zoommeer, affect the salt concentration in the delta.

The (effects of the) measures and the scenario were pre-determined based on the current agreements between the various water managers and the research carried out within the Program Fresh Water Availability (Huismans et al., 2018).

The module of the regional systems handles the water balance, including salt influx and damages due to shortage of (fresh) water. Each water board is divided into one or more water storages. Each storage has several functions which require water. Each function has a threshold value for the amount and the quality of water, which was determined together with the water boards. When a function can't be fulfilled the amount of missing water is multiplied with a factor (based on the

* Corresponding author
Email address: Remi.vanderWijk@deltares.nl (Remi van der Wijk)

importance of the function) to obtain the damage.

The water balance of each storage has the following components (Fig. 2): in- and outlets, water storage and water demand. The salt concentration in each storage changes according to the salt concentration of the water at the inlet. It's up to the players to decide when to start or stop using each inlet.

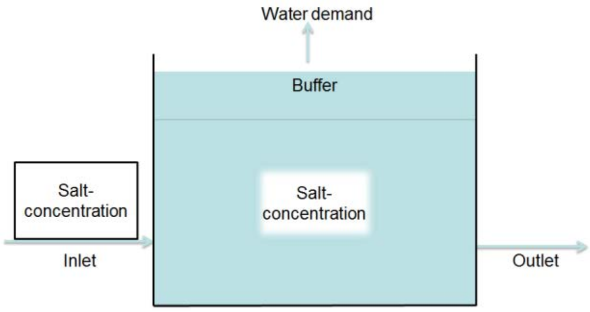

Figure 2.Conceptual overview of water balance model

The serious game communicates the results of the measure in a single screen (Fig. 3), which summarizes the results of both submodules.

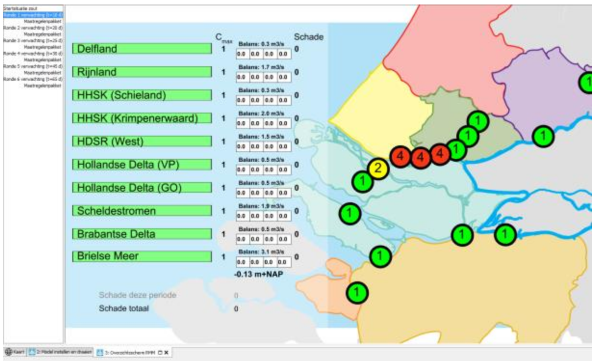

Figure 3. Serious game overview screen

Playing the game

On the 4th of December two sessions were played with people from Rijkswaterstaat and the water boards (Fig. 4). The beta game was well received in both sessions.

Each turn started with a newsflash with the expected weather conditions up to the next turn. On the screen a prediction for the starting situation of the next turn was given, both for the salt concentration and the water balance. After that the players had to decide which measures to take, which required the agreement of the other players in some cases.

In both sessions the players were intrigued by the response of the system after the measures were taken. At first everybody was trying to understand their own system and the working of the game. When the salt intrusion was becoming more of a problem the players tried to minimize the damage for all water boards. Especially the distribution of water in the water boards north of the Lek and Nieuwe Maas was discussed into detail by all players. These water boards fare well with extensive cooperation since there was little fresh water available.

Figure 4. Impression from the sessions on the 4th of December 2017 (Bakker, 2017)

Discussion

For a serious game there are always choices to be made between incorporating realistic processes and interesting choices for the players. It is important to be aware of the limitations of the physical processes within the game, especially for the salt concentration module.

Conclusions

The developed beta version of the serious game gives a general overview of processes that play a role during a drought scenario. It enables water boards to enhance their understanding of the system and possible measures that can be taken. Furthermore, this game enhances the cooperation between water managers by providing a communication tool.

Recommendations

In the next development stage reactions on the player's actions from other stakeholders can be included to enhance the player experience. Based on the reactions of the players it is clear that this is one of the most valuable additions in the near future.

Acknowledgements

We would like to thank the water boards and Rijkswaterstaat for their valuable input and the constructive discussions during the play sessions. The development of this game was funded by the "Deltafonds – Deltaprogramma Zoetwater".

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Visual Problem Appraisal Rhine river branches. *A film based learning strategy for sustainable river management.*

Loes Witteveen[a*], Jacomien den Boer[b], Jeroen Rijke[a,b]
[a] *Van Hall Larenstein University of Applied Sciences, research theme community resilience, participation & social learning, research group Sustainable River Management. Larensteinselaan 26a, Velp*
[b] *HAN University of Applied Sciences, Ruitenberglaan 26, Arnhem*

Keywords – Visual problem appraisal (VPA), stakeholder consultation, Rhine river

Introduction

The applied research group for Sustainable River Management of the Universities of Applied Sciences Arnhem-Nijmegen and Van Hall Larenstein focuses on integral, circular and adaptive approaches for the management of riverine areas in the Netherlands. In this group, the research theme Community Resilience, Participation & Social Learning aims to create practical insights and to develop actionable tools that support the re-configuration of unsustainable systems in nowadays river management. Sustainable river management requires active reconsideration of the diverse networks, communities and interactions entrusted with maintenance and redevelopment of the rich riverine areas of the Netherlands. Such multi–actor systems are dynamic and constantly transforming while re-interpreting their interests, ambitions and actions. The design and implementation of sustainable alternatives require participation of all actors involved in governance, from community to international levels, which often challenges system practices and patterns.

Urgency for this project lies in the general need to overcome issues in the shift to sustainable practices. Visual Problem Appraisal (VPA) is a tool that helps to envision this urgency, by portraying stakeholders perspectives in river management.

Visual Problem Appraisal

Visual Problem Appraisal is a film based learning strategy, which aims to enhance the problem analysis of complex issues and to facilitate the development of actions (Witteveen et al. 2010). The VPA is used in workshop settings focusing on learning and change both in contexts of current policy processes as well as in a more long-term imperative context.

The core of a VPA series is based on 'mediated stakeholder consultations'. Filmed interviews with stakeholders and the accompanying documentaries offer a chance to explore the complex and conflictive arena of the issue at stake and consequently engage in problem analysis and social dialogue. The active observation makes the audience to realize that stakeholder consultation is not about finding out one final truth, but about experiencing personal versions and diverse framings of reality.

Participants in a VPA workshop go through a three-tier program of scoping, stakeholder consultation and action. They analyse and structure the information encapsulated in the interviews and formulate ideas for action. This can take various shapes such as scenario development, policy design or elaborated project proposals. The VPA workshop creates a space where the VPA interviewee tells her or his story, filmed in a way that the audience or VPA workshop participants experience the role of interviewer.

VPA Rhine river branches: goals

The Visual Problem Appraisal Rhine river branches searches to develop strategic guidance for the complex, multi stakeholder setting of sustainable river management for the river Rhine and its branches in the Netherlands. With the VPA, we aim to create a tool to support innovative governance, as it shapes processes of participation and social learning, creating social imaginaries of sustainable resource management and policy platforms to communicate about sustainable river futures. The applied research group for Sustainable River

*Corresponding author: Loes Witteveen, loes.witteveen@hvhl.nl

Management initiated this VPA project in cooperation with Rijkswaterstaat Oost-Nederland, the executive agency of the Ministry of Infrastructure and Environment (Min. I&M).

Methods

From 2018 – 2020, the project team will work with a professional film crew to document the social and natural environment of river Rhine river branches in a series of filmed portraits and documentaries of farmers, local entrepreneurs, tourists, nature conservationists, water managers, policy makers, fishermen, residents and governmental administrators, to show the diversity of the involved actors. The VPA methodology is based and developed in the academia (see e.g. Witteveen et al. 2007; Witteveen & Lie, 2012) and is used in e.g. the UK, Ghana, Indonesia and Australia. Future projects that are initiated are on climate change issues in the Philippines and cultural heritage in coastal communities in Europe. The methodology has been adopted to portray many issues (e.g. rural livelihoods in Kwazulu-Natal, South-Africa, and integrated coastal zone management in Kerala, India) and it was found that the visual strategy has many advantages for learning on so-called ‘wicked problems’, as it simulates a real-life experience.

Deliverables

The VPA Rhine river branches will consist of a series of 28 interviews with stakeholders in the entire Rhine river branches area (IJssel, Waal and Nether Rhine), concerning their life, work and livelihoods related to the river. Two documentaries will accompany those interviews, together with a facilitators guide for the VPA workshops. The VPA will be used in higher education and the public domain. In both areas, the VPA will contribute to better understanding of issues in the area at stake, and will create venues for both research projects and policy development.

In this presentation we report on the justification and scenarios for the filming and use of the VPA Rhine river branches. We will envision the interest and commitment of concerned actors and potential users. We will also explore the relevance of this VPA in higher education as a simulation of action research or a preparation for field research. The first results of the VPA Rhine river branches prototype that was produced in November and December 2017, will be presented.

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How to prepare your River Studies Data for the future with 4TU.Centre for Research Data

Jasmin Karoline Böhmer[a*]
Robin Duinker, Delft University of Technology
Maarten van Bentum, University of Twente
[a] *Delft University of Technology, Library – Research Data Services*
Prometheusplein 1, 2628 ZC Delft

Keywords — data management, FAIR data, data archive

Introduction

Due to the latest funder requirements on data management and Open Data, documenting and managing research data during the research and preparing it for publication gained in importance. Making research data findable and accessible for decades via a trusted and certified data archive – such as 4TU.Centre for Research Data – and therefore enabling the interoperability and reusability of its content can positively impact the future of river studies.

About 4TU.Centre for Research Data

4TU.Centre for Research Data (http://researchdata.4tu.nl) is the central and certified data-archive of the four Dutch universities of technology (TU Delft, TU Eindhoven, Twente University, Wageningen Uni-versity & Research), joining forces as the 4TU.Federation. The mission of 4TU.Centre for Research Data is to ensure the accessibility of technical scientific research during and after completion of research to give a quality boost to contemporary and future research. It is specified for research data in netCDF and has over 3.700 datasets of the Geoscience communities. The complete collection of the Zandmotor-Project (https://data.4tu.nl/repository/collection:zandmotor) is openly available in 4TU.-Research Data and the RiverCare-Project has decided to publish and preserve its research output via this archive as well (https://data.4tu.nl/repository/collection:rivercare). 4TU.Research Data offers 100GB of free data publication per year for researchers affiliated with the Dutch universities of technology, and it is also available for international researcher, including a free data publication feature of 10GB.

* Corresponding author
Email address: j.k.boehmer@tudelft.nl (Jasmin Böhmer)
*URL:*http://researchdata.4tu.nl/over-4turesearchdata/contact/ (Jasmin Böhmer)

The services(S), features(F), and benefits(B) of 4TU.Centre for Research Data:

Services (S):

- Reservation-service for data-DOI: While you are writing your scientific publication, you may reserve a data-DOI in the upload-form of the archive. By providing the link to the underlying data of your publication in the text or reference section, you enable the ideal link between these two types of research output. The data-DOI will be activated once you published the data-set online, its metadata section will include a link to the related publication. With the paper-DOI and the data-DOI available, you will receive citations and tracking for both publications seperately.
- Free Data Deposit: Researchers affiliated with Delft University of Technology, University of Twente, and Eindhoven University of Technology can deposit up to 100GB individually each year. International researcher can archive 10GB for free annually. Exceeding these free limits leads to a one-time fee of 4.50 EURO per GB.

Features (F):

- Claiming your Data: To ensure accurate citation and retrieve-ability of your datasets by other researchers in the future, datasets must be equipped with an identifier (prefer-ably a persistent identifier). Every dataset in 4TU.Centre for Research Data is provided with a unique, persistent Digital Object Identifier (DOI), which can be linked to or cited in publications.

- Link between publication and dataset: Previous studies have indicated that publications containing links to the underlying data are cited more frequently than are publications without such links. By storing your research data in 4TU.Centre for Research Data, you can encourage the reuse of your data for new research or verification. DOIs can be assigned at every level of detail or size within a publication. For example, a DOI can be assigned to an entire data collection, as well as to each component within. In the choice of which levels should be registered with a DOI, researchers should proceed from the expectations of future data users.

Benefits (B)

- Search-ability and findability of research data: The data in 4TU.ResearchData are also available through NARCIS, DataCite, NedDat Hub, Index, Google, Google Scholar and many other search engines and portals.
- Make your data FAIR: By using 4TU.ReserachData and providing your data-sets in the requested form – which includes DOI, metadata body, the openly accessible data-files accompanied by a readme-file – your data complies to the FAIR data principles.
- Long-term archiving and availability of research data: 4TU.ReserachData guarantees that the deposited data will be findable, accessible, and usable in its authentic form for at least 15 years. All creators and contributors are listed and linked to their ORCID-ID, if possible.

River Studies Data in 4TU.Research Data

A popular way to use the services and features of the data archive is to deposit the publication related and receive a data-DOI for it. PhD supervisors encourage their PhD-candidates to publish data in relation to their thesis to keep the link between them over time and prevent data-loss due to the PhD-project finishing. Complex and long-term research projects make use of the collection-feature of the archive, which enables them to represent their research output appropriately and publish relevant data at suitable times throughout the project duration.

4TU.ResearchData is categorized as valid long-term data archive by funding bodies. By publishing data via its service the data-creators adhere to Open-Data and FAIR-Data demands.

Related to the proposed workshop on data documentation 'To document, or not to document? How to write a readme file and what is metadata.' this poster illustrates the benefits, features and services of 4TU.Centre for Research Data that are relevant for the NCR Days 2018 attendees. Although it is an institutional data archive, it serves as hub for multi-disciplinary data-sets. Next to finding existing data and reusing it for new projects, researcher can improve their visibility and impact by publishing data via 4TU.Research-Data. Transferring the responsibility of long-term preservation and data access to an certified institution helps to reduce risks and responsibilities for the research team after the project has ended. Due to the correct indexing of ownership and engagements, creators and contributors are recognised and accredited for decades.

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How to create user-descriptions and scenarios to design a knowledge-base for RiverCare research?

Evelyn van de Bildt[1*], V.J. Cortes Arevalo[2*], R.J. den Haan[1], C.P.J.M. van Elzakker[3]
University of Twente, Department of Design, Production and Management, Faculty of Engineering Technology [1]
University of Twente, Department of Water Engineering and Management, Faculty of Engineering Technology [2]
University of Twente, Department of Geo-Information Processing, Faculty of Geo-Information Science and Earth Observation [3], P.O. Box 217, 7500 AE, Enschede, the Netherlands

Keywords — Scenarios, User profiling, Usability test, Knowledge-base design, River Management

Introduction

Increasingly, online knowledge platforms are being designed in river management (Maurel et al., 2007). The benefits of these platforms differs for the varieties of user groups which include water professionals of government, private and stakeholder organizations. Users have preferences for different data types, information means, and needs for understanding (Janssen et al., 2009). Therefore, users may benefit from having multiple and complementary options for interaction to understand water systems (Rijcken et al., 2012). Recent literature shows an increased interest in the role of user descriptions for driving the design process (Anggreeni & Van der Voort, 2008). User profiles allow the design team to focus on and effectively communicate the needs, desires, capabilities, and limitations of the intended users (Nielsen, 2002). User profiling generates scenarios for testing developed prototypes and evaluating the design (LeRouge et al., 2013). The definition of scenario is '*a description of the future use of a system or a web site from a specific user's point-of-view*' (Nielsen, 2002). In Scenario Based Design (Van der Bijl-Brouwer & Van der Voort, 2013), users are analysed in the design process to ensure that the resulting prototype fits the way people will actually use the product.

The RiverCare programme is designing a web-based knowledge-base (KB) as part of the communication strategy. The KB is designed to provide (Cortes Arevalo et al., 2017): 1) easy access, search and overview of research programs such as RiverCare; 2) ease of understanding by explaining results from a river management perspective via storylines; and to 3) get feedback about the potential interest in and use of the results. The KB is envisioned to be part of the Netherlands Centre for River studies (NCR) network. The study introduced in this abstract focuses on how to present the website content while linking to existing platforms for accessibility and reach to water professionals. Following Scenario Based Design, we are involving users in creating and developing the KB itself as well as an understanding of the context of its use. The KB is developed iteratively with both NCR and RiverCare stakeholders through several user tests and feedback sessions.

* Corresponding authors
Email address: e.m.vandebildt@student.utwente.nl (Evelyn van de Bildt)
v.j.cortesarevalo@utwente.nl (V.J. Cortes Arevalo)

User profiling

Due to the multidisciplinary audience, it is important to investigate information needs for both researchers and practitioners related and not-related to RiverCare. Referring to previous research (Cortes Arevalo et al., submitted), the objective was to gain insights into user goals and characteristics. User profiling is the starting point for the user requirement analysis, limiting the research to particular users (Delikostidis, van Elzakker, & Kraak, 2016). Based on the interviews, we consider two types of users: 1) researchers and technical-driven experts; and 2) experiential and management-driven practitioners. Those are represented by the “personas” Alex and Tina. The user profiles help to determine the type of knowledge users want to access, search, understand and visualize. They are used as design features during the design process of the KB. To reflect these features, the analysis of the interview outcomes consisted of the following steps: 1) developing an user profile that focuses on the participants’ experience with the effects of riverine interventions; 2) completing the profile with information about data type to access and share*;* and 3) embedding the profile in a scenario. Therefore, to further define the user requirements, scenarios were created and described from Alex’s and Tina’s perspective.

Scenario creation

Two scenarios were created, one for Alex and one for Tina to: 1) introduce the two types of users; 2) state their interest towards river management; 3) explain why they visit the KB; and 4) describe the river management related problem they are dealing with. To do so, we selected the two most relevant types of scenarios:

1. The p*roblem scenario* describes problematic events related to the user's problems and needs dissatisfactions.
2. An *interaction scenario* describes the solution through interaction between user and product.

These scenarios needed to be validated by users to verify whether the elements were realistically integrated into the scenario. Therefore, a workshop with the communication team was conducted. Fig. 1 shows the generative techniques used in the session which produced varied and rich feedback about the explored context.

Usability testing

In the evaluation phase, the first prototype was tested through an experimental set up in real use and user contexts. The goals were: 1) to collect empirical data while observing potential end-users using the product to perform realistic tasks; and 2) to determine the satisfaction, effectiveness, efficiency, and overall usability. The evaluation indicators that were evaluated are shown in Table 1. Typical usability evaluation methods, such as an interview, and thinking-aloud, supported the elicitation of these issues (Dumas and Redish, 1993). During the experiment, the test persons represented either Alex or Tina and validated their respective user profiles. The feedback acquired from this experiment provides guidelines to improve the prototype and to increase its usability further.

Table 1. List of evaluation criteria for the usability test.

Criteria	Description	Indicator
Effectiveness	Do users find the answer they need?	Accuracy
		Representativeness
		Timeliness
		Relevance
		Completeness
Efficiency	Do they find the answer to a question in as little time and effort as possible?	Time on task
		Simplicity
		Lostness
		Number of control actions
		Responsiveness
Satisfaction	How does the user feel about the tasks to complete?	Comfort
		Positive attitude

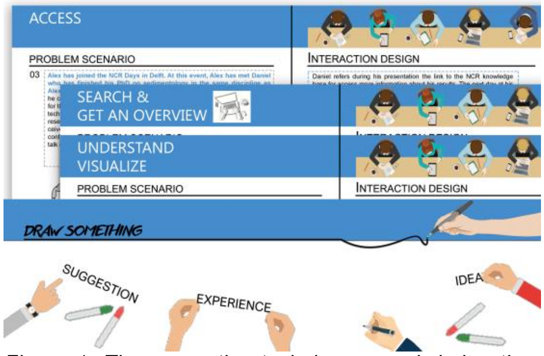

Figure 1. The generative techniques used during the workshop to discuss user experience and needs.

Acknowledgements

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Collaborative monitoring in Dutch river management: Case study WaalSamen

Lotte van den Heuvel[1], Laura N. H. Verbrugge[1,2], Riyan J. G. van den Born[1]

[1] Radboud University, Institute for Science in Society, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands
[2] University of Twente, Department of Water Engineering and Management, Faculty of Engineering Technology, P.O. Box 217, 7500 AE, Enschede, The Netherlands

Keywords – collaborative management, longitudinal training dams, participatory monitoring

Introduction

The involvement of civil society in water management has increased over the past decades (Pahl-Wostl et al., 2010). Public participation in water management facilitates governmental organisations to include a variety of knowledge and skills with the intention to gain public support and to successfully implement policies (Bressers et al., 1994). Innes and Booher (2004) state that solving complex problems, as in water management, requires collaboration with stakeholders.

Previous literature provides numerous criteria for evaluating successful collaboration with stakeholders in water management. These criteria can be narrowed down to three core principles: trust, communication and learning. These three principles respectively promote a transparent process (Lee et al., 2010), clear goals and expectations (Broerse et al., 2009), and mutual understanding of each other's problems (Mostert et al., 2007).

In 2013 Rijkswaterstaat, the Dutch national water authority, initiated a project called 'Pilot Langsdammen type WaalSamen' (Eerden, 2013). The project entails the construction of innovative longitudinal training dams on a 10 km stretch of the river Waal, which is the first time these dams are built on such a large scale in the Netherlands. Therefore, the effects of this intervention need to be monitored closely.

The monitoring programme 'WaalSamen' is set up as a collaborative exercise, in which Rijkswaterstaat works together with research institutes and representative stakeholder organizations (Verbrugge et al., 2017). The idea behind this approach is to get an integral view of the different problems and values perceived by the different stakeholders in the project area. The monitoring activities focus on three main issues: ecological, technical and nautical effects. In addition, a perception study among the local community is performed (Verbrugge et al., 2017). Each partner organisation is allowed to plan and execute its own monitoring activities, but this has to be in consultation with the other partners.

This study presents the results of a mid-term evaluation study on the collaborative monitoring programme 'WaalSamen'. The aim of this study was to evaluate the collaborative process and the outcomes so far in order to support adaptive management. Additionally, the results formed the basis for an advisory report for Rijkswaterstaat about collaboration with (local) stakeholder organisations.

Methods

We performed 15 in-depth, semi-structured interviews with people that are currently involved in the WaalSamen partnership (Table 1). The interviews consisted of four themes: the collaborative practices, communication, trust, and learning. In addition, partners were asked to list the strengths and weaknesses of WaalSamen. Interview transcripts were analysed using descriptive and axial coding methods (Saldana, 2009). In addition, the principal investigator attended one partnership meeting to make observational notes. These were used to assess group dynamics and to see whether problems raised in the interviews were also shared within the group.

Table 1. Information on and number of interviewees.

Partner	Organisation	#
Research	Deltares	2
	Radboud University	2
	TU Delft	2
	Wageningen UR	2
Societal	Regional Angling Federation	1
	Royal BLN-Schuttevaer	1
	The Royal Dutch Angling Association	1
Government	Rijkswaterstaat Oost Nederland	4

Results

Overall, all interviewees had positive experiences with collaborating in WaalSamen. The results reiterate the importance of trust, communication and learning as core principles for collaboration. The most often recognized strengths of WaalSamen were:

- Different disciplines with different perspectives working together
- Mutual understanding of problems, viewpoints and backgrounds
- Listening to and respecting each other creates pleasant interactions

One of the researchers about WaalSamen:
"The most special feature of WaalSamen is that we work together with partners that we normally don't work with, based on equality. Everyone is strongly involved in the monitoring. I haven't seen this in any other project, and I think it is an important strength."

Despite the positive evaluation, there were also some critical remarks. Nine partners worried about the future course of the monitoring programme, as they feel this is still unclear. A clear overview containing all of the monitoring activities was not available, but could be useful to improve clarity. Furthermore, five partners said that more intensive communication between the partners is needed to achieve more clarity on the programme's progress and future course. Communication and clarity on activities and goals are essential for trust building and collaboration (Broerse et al., 2009).

The need for communication is expressed by one of the researchers:
"We should think about the interaction between the monitoring groups. On this line of communication not much is happening. (…) I don't hear that much from Rijkswaterstaat. They are in the centre of the programme, so I expect them to notify us about the progress."

Implications for future participatory water management

Our research validates and highlights connections between the core principles identified in previous studies (Figure 1). The WaalSamen partnership was formed based on trust, which is strengthened by effective, transparent communication, facilitating learning processes. The arrows in figure 1 indicate that all three of these principles have the ability to influence each other. They are all equally important for a partnership to succeed.

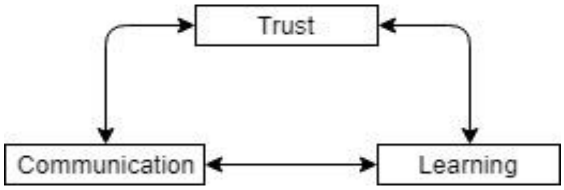

Figure 1. Three core principles for collaboration in water management and their interrelations.

The next challenge lies in finding ways to implement the core principles in water management practices at different scales. This starts with an awareness of the importance of these principles on the administrative level. Even though this importance might seem obvious to most people, actually working with the core principles and applying them proves to be challenging. Our recommendations to the Dutch national water authority are (1) to use case studies ('best practices') and (2) scenario exercises in training programmes for all employees working in collaborative programmes.

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Prototyping Virtual River

R.J. den Haan[1*], V.J. Cortes Arevalo[2], M.C. Van der Voort[1], S.J.M.H Hulscher[2]
[1] *University of Twente, Department of Design, Production and Management, Faculty of Engineering Technology, P.O. Box 217, 7500 AE, Enschede, the Netherlands* [2] *University of Twente, Department of Water Engineering and Management, Faculty of Engineering Technology, P.O. Box 217, 7500 AE, Enschede, the Netherlands*

Keywords — River management, Serious gaming, Design

Introduction

Serious games are increasingly used as facilitation tools in learning environments. In such learning environments, individuals meet, interact and exchange perspectives to resolve conflicts and determine collective actions (Keen et al., 2005; Pahl-Wostl et al., 2007). In the river management context, there are some examples of serious gaming environments; learning environments based around serious games (i.e. Lankford and Watson, 2007; Valkering et al., 2009; Stefanska et al., 2011; Savic et al., 2016). While these all have different goals and approaches, they have in common that players manage a river – from a stretch to a complete basin – from different roles or perspectives, either cooperatively or competitively. As part of the RiverCare research programme, we are developing a serious gaming environment titled Virtual River (VR). Here, we report on the challenges that the VR targets, the implications the targets have for VR and prototyping efforts.

Targeted river management challenges

For the development of VR, an interview study focused on identifying current challenges in Dutch river management (Den Haan et al., 2017). Three challenges were identified: (1) creating flexibility in a controlled river system; (2) sustaining the integrated approach in the maintenance of floodplains; and (3) formulating future river basin management policies to adapt to climate change. Interview respondents displayed diverging perspectives towards the first two challenges (Den Haan et al., 2017). It is therefore interesting to facilitate the exchange of these perspectives in the VR.
The first challenge, creating flexibility in a controlled river system, relates on one hand to water managers who showed a preference for controllability and therefore approached the floodplains from a fixation point of view while permitting change. On the other hand, nature managers approached the floodplains from a development point of view following natural processes. These two approaches seem incompatible. However, both acknowledged that floodplains require regulation in relation to for example vegetation development to safeguard flood safety, the challenge therefore relates to its execution, not to its necessity.
The second challenge, sustaining the integrated approach in the maintenance of floodplains, relates to maintenance hardly being included during the planning of Room for the River projects. Now that Room for the River projects are (nearly) completed, floodplain maintenance is mostly executed sectorally whereas project planning was integrated across sectors. Consequently, river management actors are concerned that floodplain areas might not develop as planned.

Implications

Targeting these two challenges in the VR has some implications for its design. First of all, when playing the VR, we want players to experience how plan-making and maintenance affect each other. This way, players would experience how – and if – objectives set in a project's plan-making phase are reached in its maintenance phase. To achieve this, players in the VR are, collaboratively, responsible for managing a riverine area for thirty years, where they pursue specified goals, are able to apply spatial riverine measures and plan for maintenance. Secondly, we want players to experience the need for control and stability – e.g. comply with the flood safety norms, reduce uncertainty – as well as the need for development and flexibility – e.g. reach floodplain target images, react to unforeseen events.

Prototyping

We are developing the VR in iterative cycles. At the time of writing, a cycle involving a first, playable prototype is completed. In this cycle, the VR was developed as a board game to test and evaluate some main elements and game rules we intend to implement and refine in further prototypes. Testing these elements and rules in a board game early on enabled us to see whether these could work as intended and what the perceived complexity of players on these are.
In the board game, players are asked to manage a riverine area for four turns,

* Corresponding author
Email address: r.j.denhaan@utwente.nl

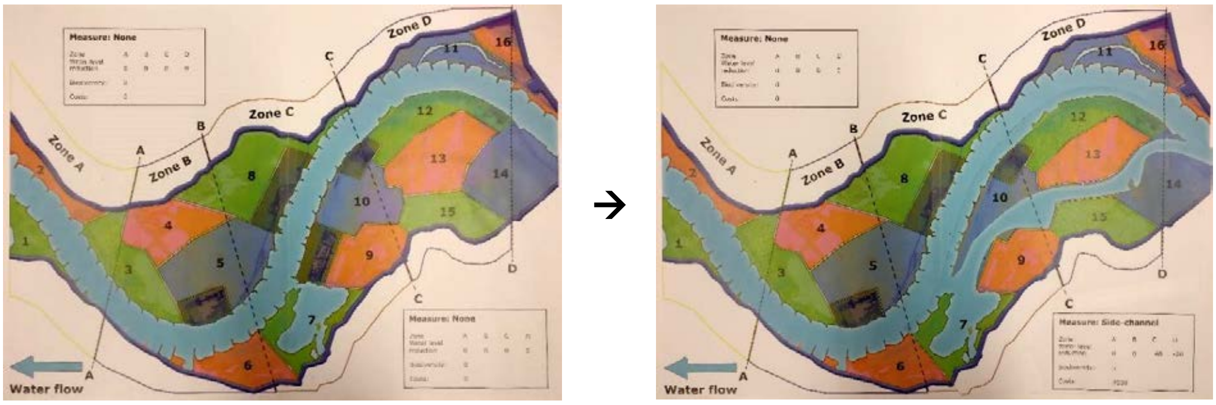

Figure 1. Virtual River's board game prototype with no measure implemented (left) and implemented side channel (right)

representing time steps of five years each. The area contains two major floodplains (see figure 1). Players have a specific role, each with its own budget and objective. At the start of the game, players collaboratively discuss whether or not they would like to apply spatial measures. Each major floodplain has the option of doing nothing or applying one of two possible spatial measures. Applying these measures may be valuable to increase flood safety, by lowering water levels, and ecological value. The area's arrangement is complete when players decide on which spatial measures to implement and how the costs are shared between players. Next, the four turns start. Each player now has to manage their management units: the floodplain areas that they own. To show the different ownerships, management units have different colours on the game board (see figure 1). Each management unit must have a management style, for example intensive nature management or half-natural maintenance management. In addition to setting or changing management styles, players may perform resets on management units. Depending on the management style or resets executed, the roughness of each maintenance unit might change between turns to reflect vegetation growth or succession. Similarly, this may result in more or less biodiversity between turns.

Test sessions and first results

Three test sessions were executed with the initial board prototype. Goal of the test sessions was to evaluate (1) the overall setup for the VR based around management units; (2) initial game indicators displaying player progress worked as intended and were understood by players; and (3) how giving players roles and individual objectives influenced the game play. One test session was executed with design researchers, one with game designers and one with researchers modelling river management measures. The test sessions revealed that the overall approach for the VR based around management units worked as intended. Players in all test sessions indicated that they learned how the river functions. However, players indicated that the complexity of the management units was high. The initial game indicators were understood by players, but were also experienced as a black box that they had trouble with relating to their actions. As for the player roles, during two test sessions these created some, at times tense, negotiations and conflicts. During the third session, the roles were mostly ignored.

Acknowledgements

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PlanSmart: a research group exploring approaches to planning and governing nature-based solutions

Christian Albert[1*], Barbara Schröter[2], Mario Brillinger[1], Jennifer Henze[1], Sarah Gottwald[1], Paulina Guerrero[1], and Claire Nicolas[2]
[1] *Leibniz Universität Hannover, Institute of Environmental Planning, Herrenhäuser Str. 2, 30419 Hannover, Germany*
[3] *Leibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg, Germany*

Keywords — Governance, Landscape Planning, Nature-based Solutions, Ecosystem Services, Geodesign

Introduction

River landscapes face increasing water-borne challenges such as securing water quality and provision, establishing appropriate urban water and wastewater management, and protecting against flooding. Nature-based solutions, interpreted as actions which make use of natural processes, are expected to help societies address ecological, social and economic challenges in sustainable ways (European Commission, 2015, Albert et al. 2017).

Fig. 1. Nature-based Solutions for Water-borne Challenges (Image: Westcountry Rivers Trust, altered)

This poster contribution introduces innovative scholarship currently undertaken by PlanSmart – an interdisciplinary research group co-hosted at Leibniz Universität Hannover and the Leibniz Centre for Agricultural Landscape Research – ZALF. For more information, see www.plansmart.info.

Research aim

PlanSmart's aim is to explore, develop and test innovative and transdisciplinary approaches to planning and implementing nature-based solutions for more resilient development of urban regions. The approaches considered are smart in that they consider social, ecological and economic targets, exploit synergies wherever appropriate, apply GeoDesign-technology for support decisions with the best available knowledge, and use SolutionLabs as platforms for transdisciplinary cooperation. This enhances the relevance of the planning outcomes for various actors and the likelihood of actual implementation in practice.

Research questions

PlanSmart investigates the following questions:

1. Which ecological, social and economic effects do nature-based solutions yield, also in comparison with technical solutions?
2. How can smart planning processes for nature-based solutions be successfully designed and implemented?, and
3. Which governance and business models and approaches to knowledge co-generation are suited for implementing smart planning for nature-based solutions in practice?

Research design

The research questions are addressed in a several research projects, organized in three clusters (Fig. 2).

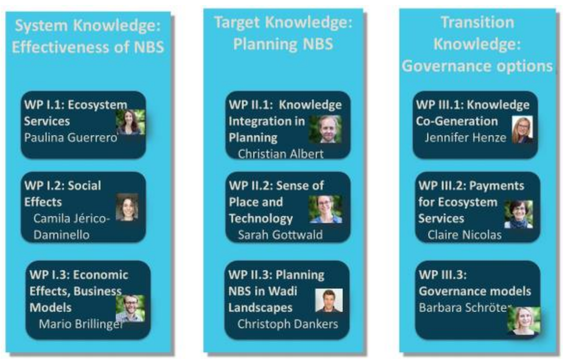

Fig. 2: PlanSmart's research clusters and projects

* Corresponding author
Email address: albert@umwelt.uni-hannover.de (CA)
URL: www.umwelt.uni-hannover.de/albert.html (CA)
www.plansmart.info

Case studies

PlanSmart considers three types of case studies:

- We are inspired from previous studies from Germany and the Netherlands that shed light on success factors and limitations of the context and design of planning and implementation processes for nature-based solutions.
- The Lahn river basin in Germany serves as a demonstration project for planning and implementing nature-based solutions. PlanSmart cooperates with “Living River Lahn”, a large project funded by the EU LIFE IP program to enhance the ecological status of the Lahn River and to simultaneously fulfill the interests of actors from various sectors.
- The generalizability of the findings will be explored in a transfer project in Europe or Central America.

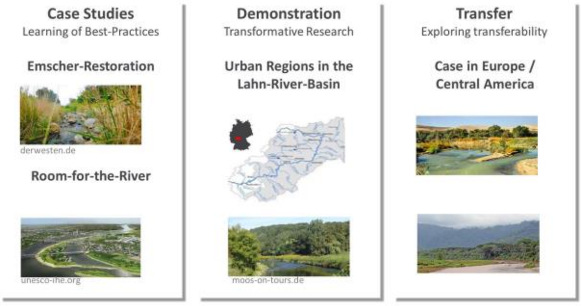

Fig. 3: PlanSmart’s case studies

Acknowledgement

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Session IIb
Advances in fundamental modelling and measuring

NCR

The Future River

Session IIb

Advances in fundamental modelling and measuring

Parametric model of wood-induced backwater in lowland streams

Tjitske J. Geertsema[a,*], Paul J.J.F. Torfs[a], Ryan J. Teuling[a], Joris P.C. Eekhout[a], Ton J.F. Hoitink[a]
[a]*Wageningen University, Hydrology and Quantitative Water Management Group, 6700 AA Wageningen, the Netherlands*
[b]*Soil and Water Conservation Research Group, CEBAS-CSIC, Murcia, Spain*

Keywords — Wood in streams, backwater, parametric model

Introduction

Placement of wood is a common method for increasing ecological values in river and stream restoration projects, which is already widely used in natural environments (1). Because of potential problems of inundation, the use in agricultural and urban environments is still limited. The complexity of hydraulic modelling of streams with vegetation (2; 3) hampers the precise prediction of the effects. The main challenges of hydraulic modelling include the irregular permeability and geometry of the wood, and the difficulty of accurately establish the underwater wood geometry. In addition, morphological activity triggered by the presence of wood and weathering of wood occur, which are both time dependent. To deal with these challenges, we develop a simple approach to parameterize wood in a one-dimensional flow model, representing on field observations from various sites. The initial conditions are particularly important because those result in the largest backwater effects (next section). The purpose of this study is to predict initial backwater effects caused by wood using a parametric model.

Experimental results

Hourly water levels gauged upstream and downstream of wood patches and discharge were collected for four streams in the Netherlands. The water level drop over the wood patch relates to discharge in the streams (Fig. 1). This relation is characterized by an increasing water level difference for an increasing discharge, up to a maximum. If the discharge increases beyond this level, the water level difference reduces to the value that may represent the situation without wood (Fig. 1). This reduction depends primarily on the obstruction ratio of the wood in the channel cross-section. Morphologic adjustments in the stream and reorientation of the woody material reduces the water level drop over the patches in time. These adjustments are visible within two to five years after the placement of the wood patches.

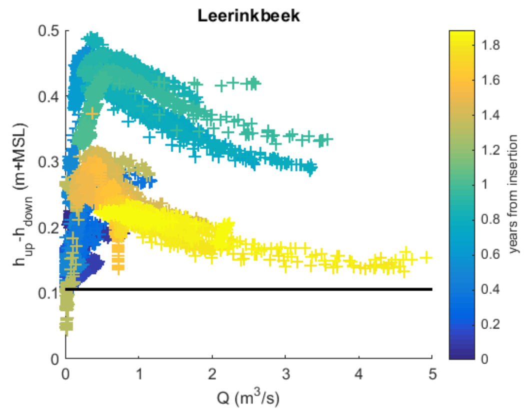

Figure 1: Relation between water level difference and discharge at Leerinkbeek. The black line indicates the water level difference before the insertion of wood.

Model results

To compare the results with the measurements and to extrapolate the results to other areas, a stationary one-dimensional hydraulic grade line model was constructed. In the model, wood patches were schematized as a local obstruction area where roughness was increased. The local roughness at the wood patches was related to the ratio between wetted perimeter of the wood and the wetted perimeter of the cross section. Hence, the roughness decreases when water levels increase above the crest of the wood, similar to what was observed in step-pool streams (4). The schematic wood patches influence the grade line locally by changes in Froude number and friction slope. Fig. 2 shows the cross sections and wood patches of the streams, which are used in the model calibration. Below the cross sections, Fig. 2 shows the experimental data for the first year after placement of the wood and the calibration results. The calibration results show good agreement with the experimental results. For Tongelreep and Ramsbeek, the calibrations show sharper edges than the measurements, which originate from the gross simplification of the wood patches and stream bed. In addition, the water

*Corresponding author
Email address: tjitske.geertsema@wur.nl (Tjitske J. Geertsema)
URL: www.hwm.wur.nl (Tjitske J. Geertsema)

level drops of Leerinkbeek were smaller in the first two weeks than in the rest of the year. The smaller water level drop could be the result of clogging of the wood patch in the first week. After the calibration, a sensitivity analysis is performed, which shows that the wood-induced backwater is more sensitive to the obstruction area than to roughness of the obstruction area. The geometry of the wood and the river influence the characteristics of relation between discharge and water level drop over the wood patches. The height of the obstruction area, for example, influences the discharge at which the maximum water level drop occurs (not shown).

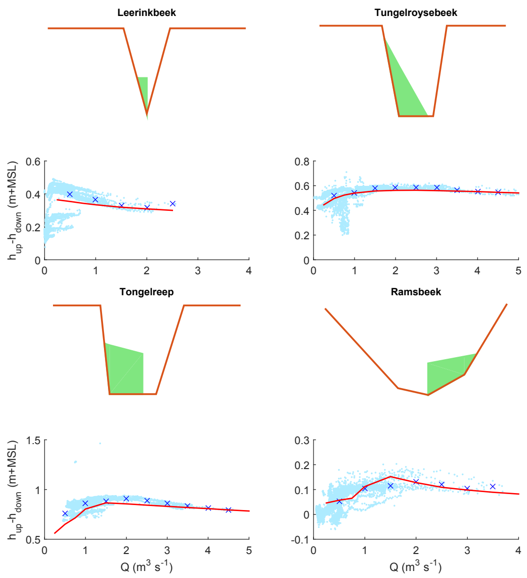

Figure 2: Calibration of the water level drop over wood patches at four experimental streams. The dots indicate the measurements after placement of the patches. The crosses are the average of the measurements and the red lines are the best fi s through the crosses.

Discussion and Conclusions

The experimental results show a relation between discharge and water level drop over the wood patches. The parametric model is able to reproduce this relation and to extrapolate the results to other areas with different river and wood geometries. The stationary model predicts the initial backwater effects, which is the upper limit of backwater effects due to reduction over time by morphological changes, and therefore, most relevant from a management perspective. In addition, the model shows that backwater effects can be reduced with increasing discharge by manipulating the obstruction ratio and by optimizing the location in the cross section, where wood patches are placed. The parametric model has several limitations. The upstream and downstream water levels should be connected, which mostly occurs in lowland streams. The most predominant limitation is the non-physical based Manning coefficient. The friction terms as form, drag, grain and spill are physically based, but these terms are very complex to measure in the field and will, besides, increase the parameters in the model. The above-described limitations should be considered in extending the model to other areas, but the model is suited for lowland streams with ordinary measurements of water levels and discharge. Despite these limitations, the model offers a simple tool to design and control wood in streams. It allows the user to estimate the maximum allowable backwater level for a certain area and can be used to design the wood patches. The maximum obstruction area of wood jams or beaver dams can be determined using the maximum allowable backwater level. The model can therefore be applied to (lowland) streams to prevent unnecessary removal of wood.

Acknowledgements

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Secondary Flow and Bed Slope Effects Contributing to Ill-posedness in River Modelling

Víctor Chavarrías[a,*], Willem Ottevanger[d], Ralph M.J. Schielen[b,c], Astrid Blom[a]
[a] *Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands.*
[b] *Rijkswaterstaat, Lelystad, The Netherlands.*
[c] *University of Twente, Enschede, The Netherlands.*
[d] *Deltares, Delft, The Netherlands.*

Keywords — 2D morphodynamics, ill-posed problems

Introduction

Two-dimensional flow models are widely used and necessary to predict phenomena such as the dynamics of bars. In these problems the effect of the bed slope in the direction of the sediment transport rate needs to be accounted for to obtain physically realistic results. This effect is included using an empirical closure relation. Even including bed slope effects, 2D models do not capture 3D phenomena such as secondary flow which occurs when the flow curvature is large. This process is accounted for in a parameterized manner including one equation to model the advection and diffusion of the secondary flow intensity.

A model needs to be well-posed to be representative of the physical phenomenon under study. That is, the resulting system of equations must have a unique solution which does not infinitely diverge for infinitesimal perturbations in the problem data (Hadamard, 1923). Otherwise, the model loses its predictive capabilities exemplified in spurious oscillations that appear in numerical solutions of ill-posed problems.

Previously we have studied the conditions in which the active layer model, used to account for mixed-size sediment in river morphodynamics, becomes ill-posed (Chavarrías et al.). We found that this model may be ill-posed under a larger range of conditions than previously known. In particular we studied the effect of the empirical closure relations to account for hiding in the sediment transport rate and the sediment transfer from the bed surface to the substrate in aggradational conditions and we found that they play a major role, limiting or extending the possibility of obtaining an ill-posed model.

Here we extend the previous analysis including 2D effects. We study the conditions in which the parametrization of secondary flow and bed slope effects yield a well-posed model.

*Corresponding author
Email address: `v.chavarriasborras@tudelft.nl` (Víctor Chavarrías)

Perturbation Analysis

We study the conditions in which secondary flow and bed slope effects yield a well-posed model by means of a perturbation analysis of the model equations. The flow is modelled by the Shallow Water Equations including the effects of secondary flow and an advection-diffusion equation that models the transport of the secondary flow intensity. The Exner equation accounts for the mass conservation of the bed sediment. The active layer model accounts for the conservation of sediment per size fraction. The system is closed with relations for the sediment transport rate, the bed slope effect, and the equilibrium secondary flow intensity. We refer to Chavarrías et al. (2018) for details on the model equations.

The equations are perturbed around the steady and uniform solution of flow on a flat sloping bed without transverse slope. We linearize the system and assume a plane wave solution to obtain an eigenvalue problem. The real part of the eigenvalues represent the growth rate of perturbations as a function of the wave length. A model can only be representative of a physical process if infinitely short perturbation do not grow. Otherwise the solution is dominated by the smallest scale in the model which is nonsense in the continuous limit. Thus, if the real part of at least one eigenvalue is not negative or does not tend to 0 for increasing wave number, the problem is ill-posed.

Results

We first consider a reference state without morphology (i.e., fixed bed). We numerically compute the eigenvalues as a function of the wave numbers and we find that when the diffusion coefficient of the secondary flow intensity equation is equal to 0, the model is ill-posed. We run a numerical simulation in these conditions using Delft3D and we find that the solution presents unphysical growth of truncation errors in the initial and boundary conditions which supports the finding that it is ill-posed.

It is physically unrealistic to assume that the diffusion coefficient is equal to 0. We numeri-

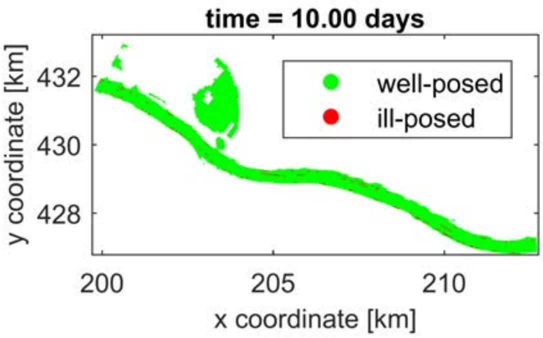

Figure 1: Ill-posedness in the DVR simulation.

cally reproduce the large curvature laboratory experiments conducted by Ashida et al. (1990) using a physically realistic value of the diffusion coefficient and we find that it is insufficient to guarantee a well-posed model. When we use a diffusion coefficient large enough to yield a well-posed model, the flow velocity pattern is unrealistic.

Following a similar procedure we study the role of bed slope effects without secondary flow. We observe that the consideration of bed slope effects is not only necessary to reproduce bar and bend morphology but it is also necessary to obtain a well-posed model. A unisize case is ill-posed when bed slope effects are not accounted for and it is well-posed otherwise. Under mixed-size sediment conditions the kind of closure relation plays an important role. We see that, for a simplified case with two sediment size fractions, the simplest closure relation only dependent on the bed slope yields a well-posed model but a more complex one including a dependence on the bed shear stress turns it to be ill-posed.

Ill-posedness Routine

We have implemented a routine in Delft3D to check whether simulations suffer from ill-posedness. The current version focuses on ill-posedness caused by the active layer model and neglects the other origins (i.e., secondary flow and bed slope effects). We run a subdomain of the DVR model used to predict dredging and dumping operation in the Dutch Rhine and we find that it suffers from ill-posedness (Figure 1). This stresses the necessity of pursuing a better description of mixed-size sediment processes.

Discussion and Conclusions

Our analysis of the system of equations modelling 2D morphodynamics in curved channels shows that the diffusion coefficient of the secondary flow equation is vital to obtain a well-posed model. The necessary diffusion to obtain a well-posed model may be larger than what is physically realistic. This implies that the secondary flow model is not always valid. Bed slope effects are a necessary mechanism to obtain physically realistic solutions but not all closure relations provide a physically sound model. In our analysis we have neglected diffusion in the momentum equations which may have a regularizing effect. Yet, numerical solutions suggest that it is insufficient to provide a well-posed model. We have linearized the model around a state characterized by straight flow. Thus, the ability to predict the mathematical character of the model is restricted to situations with small curvature. Yet, we have shown that it can be used in situations with a reasonably large curvature.

Acknowledgements

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The influence of transverse slope effects on large-scale morphology in morphodynamic models

Anne W. Baar[a,*], Marcio Boechat Albernaz[a], Maarten G. Kleinhans[a]
[a] Utrecht Universiy, Department of Physical Geography, Faculty of Geosciences, Heidelberglaan 2, 3584CS, Utrecht, the Netherlands

Keywords — Transverse slope effect, Morphodynamic modelling, Delft3D

Problem definition

All morphodynamic models are sensitive to a calibration of the transverse bed slope parameter, which determines the length of fluvial bars and active channel width (*Schuurman et al.*, 2013), braiding index (*Struiksma et al.*, 1985), stability of river bifurcations (*Bolla Pittaluga et al.*, 2015), and wave lengths of coastal sandbanks and sandwaves (*Hulscher*, 1996; *Blondeaux and Vittori*, 2016). The transverse slope parameter determines the amount of downslope sediment transport due to gravity on slopes transverse to the main flow direction. When secondary currents are present, downslope sediment transport due to gravity is balanced by helical flows dragging the sediment upslope, and thereby also controls the adaptation of the bed to perturbations in the flow. An incorrect setting thus has major consequences for the predicted large-scale morphology, bank protection works and dredging volumes for fairway maintenance.

However, current morphodynamic models tend to underestimate slope effects, and thereby over-predict channel depth and braiding index, and therefore slope effects are often artificially increased when calibrating on existing morphology (*Van der Wegen and Roelvink*, 2012; *Schuurman et al.*, 2013). However, Baar et al. (conditionally accepted) showed that the realistic calibration range of the slope parameters is much smaller than current model studies imply, and suggest that such calibration is necessary to compensate for other, yet unidentified, model weaknesses such as issues with numerical schemes or missing processes. Furthermore, in the morphodynamic model Delft3D there are two commonly used options to calculate the deflection of sediment transport on transverse slope: the method by *Ikeda* (1984) (Islope $= 2$) and the method by *Koch and Flokstra* (1981) (Islope $= 3$). The difference in effect of both options on the long-term morphology is unknown.

*Corresponding author
Email address: a.w.baar@uu.nl (Anne W. Baar)

Objective and methodology

The objective of this study is to identify possible causes of the overdeepening of channels in Delft3D, and to quantify the sensitivity of predicted long-term morphology to the transverse bed slope parameters, even when a measured bathymetry is used for calibration. To this end, three different model studies are conducted. Firstly, a simple straight river channel of 5 grid cells wide is used to test several parameter settings and their effect on the balance of downslope sediment transport and channel incision. Then, the difference in effect of the two main transverse slope options is tested in an existing large-scale river model and in an existing large-scale estuary model.

Slope effects in Delft3D

The main difference between both slope options in Delft3D, is that the predictor of *Ikeda* (1984) uses a critical shear stress, which is absent in the predictor of *Koch and Flokstra* (1981). However, also the resulting transport vector is calculated differently. Firstly, the magnitude of sediment transport is predicted, based on a situation of a flat bed with a single grainsize. Secondly, for *Koch and Flokstra* (1981) the direction of sediment transport is corrected for transverse gradients by rotating the transport vector based on the user-defined factor A_{sh}, while for *Ikeda* (1984) an additional transport vector is calculated perpendicular to the flow direction, based on the input parameter α_{bn}. This means that for the predictor of *Ikeda* (1984) the total magnitude of sediment transport also increases when slope effects are increased on calibration, while for *Koch and Flokstra* (1981) this is not influenced directly. The relation between α_{bn} and A_{sh} is plotted in Fig. 1. The default value of α_{bn} in Delft3D is set to 1.5, while the parameter A_{sh} is not defined in the model, but should be 1.5 according to *Koch and Flokstra* (1981).

Large scale morphology

Schuurman et al. (2013) varied the A_{sh} between 0.35 and 1.5 for a Brahmaputra-sized braided sand-bed river with the sediment transport predictor of *Engelund and Hansen*

(1967), and concluded that an A_{sh} of 0.7 is the optimal value for this system. This corresponds with an α_{bn} of 7 (Fig. 1). However, when we used this slope option in the same model, the increase in total sediment transport results in a significant decrease in channel depth and braiding index compared to the original model runs (Fig. 2).

When modelling a river delta influenced by tides, and with the sediment transport predictor of *Van Rijn* (1984), results are less different (Fig. 3). The river with the predictor of *Koch and Flokstra* (1981) has a slightly deeper channel and a higher braiding index downstream than the model with the predictor of *Ikeda* (1984). However, in both models, unrealistically deep channels are formed.

These results suggest there is a large difference in slope effects when combining it with either the sediment transport predictor of *Engelund and Hansen* (1967) or *Van Rijn* (1984). Furthermore, these two model results show that differences in predicted long-term morphology are larger when channel dimensions are more realistic,and thus suggest that the calibrated models are more sensitive to changes in slope effects.

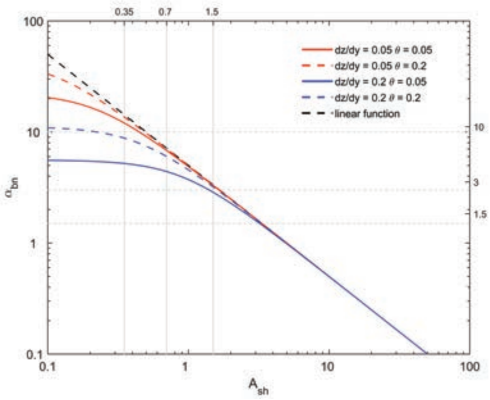
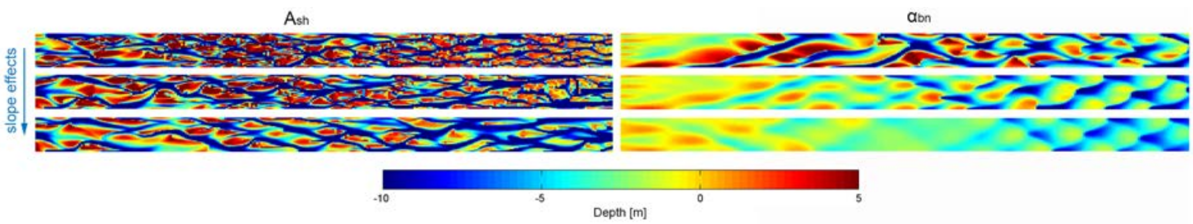


Figure 1: Relation between α_{bn} and A_{sh} (Baar et al., conditionally accepted).

Figure 2: braided river model of Schuurman et al. (2013) with varying slope effects. The middle panels represent the runs with default slope parameters.The width of the river is 3600m.



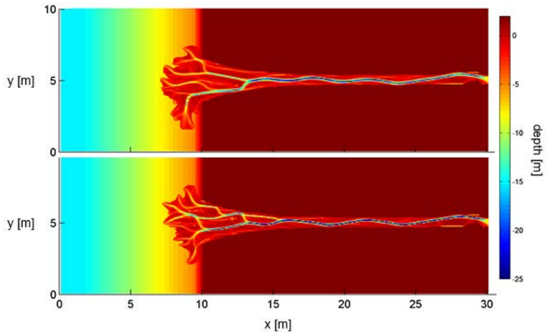


Figure 3: River delta with tidal influences. top panel: $\alpha_{bn} = 5$, bottom panel: $A_{sh} = 1$

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Using a lightweight polystyrene sediment to resolve dynamic scaling issues in fluvial dune modelling

Bas Wullems[a,*], Suleyman Naqshband[a], Ton Hoitink[a]
[a] *Wageningen University, Hydrology and quantitative Water Management group, P.O. Box 47, 6700 AA, Wageningen, the Netherlands*

Keywords — River Dunes, Upper Stage Plane Beds, Polystyrene sediment,

Introduction

River dunes have important consequences in terms of navigability, so a proper prediction of their dimensions and development is valuable. Numerical modelling of fluvial processes with a dynamic bed remains difficult, so that for many studies a flume setup is used. However, there are still some dynamic scaling issues that make it hard to compare results achieved in such a laboratory setup to a natural situation. Recently, Vermeulen et al. (2014) have proven that a bed-load dominated situation can be better approximated when lightweight polystyrene granulates are used as sediment, rather than sand grains. In this research, dunes are simulated with polystyrene in a suspension-dominated situation.

Dune dimensions

Dunes created in a sand-bedded flume typically have a relative dune height (height normalized by the water depth) that is up to two times as high as the average relative dune height in rivers. It is hypothesized that this is due to the high Froude number used in most flume studies, which induces a greater interaction between the bed and the free surface Naqshband et al. (2014). In addition, the typical laboratory dune has a very steep leeside that approaches the angle of repose of sand, while more symmetric dunes with a lower angle are more common in nature (figure 1).

Transition to upper stage plane bed

It has often been observed that as a larger fraction of the sediment is transported in suspension, dunes start to flatten out and eventually transition into an upper stage plane bed. However, Naqshband et al. (2014) show that this transiton does not only depend on the suspension number u_*/w_s, in which $u*$ is the friction velocity and w_s is the settling velocity, but also on the Froude number Fr. It is therefore expected that dunes can be created in a suspension-dominated environment, provided that the Froude number remains low.

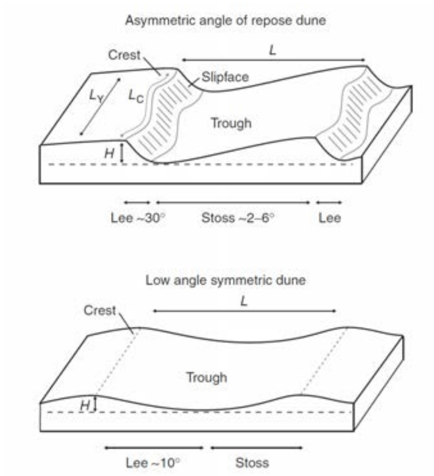

Figure 1: Schematic representation of high angle dunes (top) and low angle dunes (bottom). Image courtesy of Venditti (2013).

Methods

A tilting flume was used to investigate dunes' behaviour under a range of suspension numbers ($0.5 < u_*/w_s < 2.5$) and a low Froude number (0.15). In this flume, discharge, bottom slope, sediment discharge and downstream water height can be adjusted to obtain the desired values for u_*/w_s and Fr. The flume was filled with a 15 cm thick layer of polystyrene grains with a D_{50} of 2.1 mm. The material has a relative density Δ with respect to water of 1.055. This causes a lower settling velocity, so a large amount of suspended sediment can be achieved, while the friction velocity u_* can be kept lower. This way, a low Froude number can be ensured.

During each run, dunes started to form and migrate downstream. Once the dune field between 3 and 8 m from the inlet point showed similar dune dimensions, measurements were started. The dune field was scanned with a laser that is reflected by the polystyrene grains. This way, the bed height could be determined at every downstream and lateral coordinate. Water heights and discharges were recorded using stilling wills with linear position sensors and electromagnetic flow meters, respectively.

*Corresponding author
Email address: bas.wullems@wur.nl (Bas Wullems)

Results and discussion

Dunes in a suspension-dominated flume migrate more rapidly than in a bedload-dominated situation. They frequently break up into multiple dunes or overtake one another. Most striking, though, is that dunes are still observed at $u_*/w_s = 2.5$, where most sand-bedded flume studies would suggest the presence of an upper stage plane bed (figure 2).

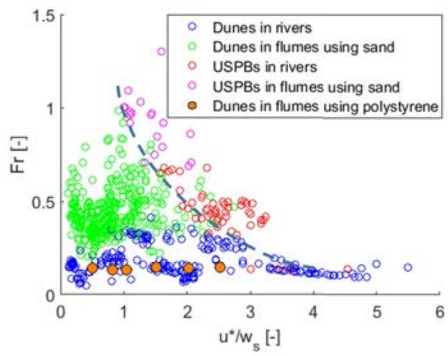

Figure 2: Froude and suspension numbers of dunes and upper stage plane beds observed in rivers and in fl mes using either sand or polystyrene. The dashed line indicates the approximate transition between the dune and USPB regimes.

As can be seen in figure 3, relative dune heights simulated with a polystyrene-bedded flume are within the range that commonly occurs in rivers and are lower than dune heights simulated with a sand-bedded flume. The abrupt flattening that is often observed with a rising suspension number is not observed in this case. This can be explained by the greater interaction between the bed and the free surface at high Froude numbers, which increases the magnitude of undulations at the surface (Niemann et al. (2010)). These undulations increase flow convergence over the crests and promote crest erosion and therefore flattening. Finally, leeside angles are significantly lower than those observed in a sand-bedded flume. They are not quite as symmetrical as the most common river dunes (figure 1), but are sufficiently different to cause a different turbulence field around the dune (Hendershot et al. (2016)).

Conclusion

So far, experiments in sand-bedded flumes have captured the bedload-dominated regime better than the suspension-dominated regime. Typically, these experiments simulate too large dunes with a leeside angle that approaches the angle of repose of sand. Often, Froude numbers used in such experiments are unrealistically high. When lightweight polystyrene grains are used, Fr can be kept quite low. With this material, the dune height and angle of repose resemble the values found in natural rivers more closely. Contrary to experiments in sand-bedded flumes, where dunes flatten out to upper stage plane beds at higher suspension numbers, the experiments with polystyrene show that dunes can persist even at high suspension numbers, provided that the Froude number is sufficiently low.

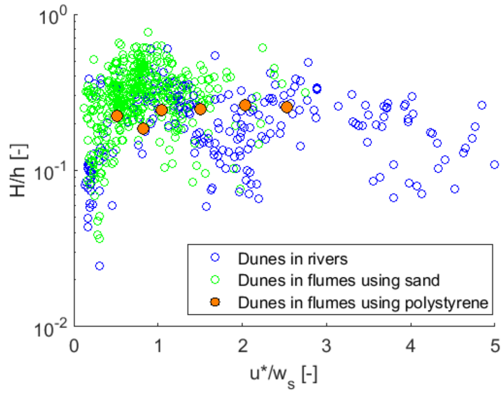

Figure 3: Relative dune height plotted against suspension number for all dunes observed in rivers and in flumes using either sand or polystyrene.

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Deriving Grain Size Distributions From UAVs Images

Alessandro Cattapan[a], Paolo Paron[a] and Mário J. Franca[a]
[a]*IHE Delft Institute for Water Education, Water Science and Engineering Department Westvest 7, 2611 AX Delft, The Netherlands*

Keywords — grain size, UAV, remote sensing

Introduction

The Grain Size Distribution (GSD) of a river's bed, bars and banks is a determinant property that influences many physical, chemical and ecological processes occurring along riverscapes. For long time sensing GSDs has been a lengthy, laborious, expensive and quite inaccurate process. In recent years photosieving techniques allowed a faster, non-intrusive and semi-automated way to measure GSDs of the surface layer of sediment of a river from images (Buscombe, 2008; Buscombe and Masselink, 2009). These measures were usually limited in spatial and time extension. Recently the introduction of Unmanned Aircraft Vehicles (UAVs) and the opportunity that they provide to capture hyperspatial images opened a whole new list of possibilities for high resolution data acquisition (Dugdale et al., 2010). This research focuses on investigating the applicability of the combination of these technologies to the derivation of GSD in river's gravel bars.

Method

The dataset analyzed in this research comes from a series of flights performed in September 2017 on an exposed gravel bar of the Brenta River, Italy. Fig. 1 shows the locations of the Brenta River basin and of study site where the flights were performed. The UAV used is a DJI Phantom 4 PRO, the flight height has been kept constant at 5.0 m above the take-off point, which allowed a resolution of 1.51 mm/px. The area covered in flight 1 and 2 was of around 377 m^2 and 36 m^2 respectively. A series of ground control points have been collected using a smartphone and the freely available application Mobile Topographer. The Pictures collected have been merged and georeferenced using the Dronedeploy online service. Fig. 2 shows an example of the resulting ortophoto obtained with this procedure. In order to test the applicability of UAVs in capturing images useful for GSD analysis, we used the BASEGRAIN software to detect single sediment sizes from one of these pictures (Fig.3).

* Corresponding author
Email address: a.cattapan@un-ihe.org (A. Cattapan)
URL: https://www.un-ihe.org/alessandro-cattapan (A. Cattapan)

Figure 1. Location of the Brenta river basin and of the flights performed.

Figure 2. Example of an ortophoto obtained from a flight

Figure 3. Image detection of grain size using BASEGRAIN

This software allows the definition of the major and minor axis of each individual grain detected from an image (7.3m x 5.5m) of the surface layer. Moreover, the analysis of Stähly et. al. (2017) suggest that GSDs obtained from image-detection and square-hole sieving are in general characterized by comparable accuracy, therefore opening the ground to a widespread use of the suggested methodology for detailed and extensive GSD analysis at river basins scale.

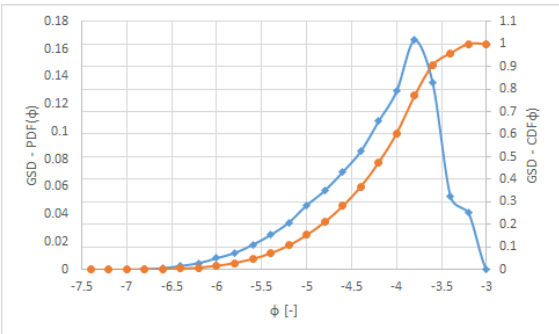

Figure 4. Example of grain size distribution (blue) and cumulative grain size distribution (orange) obtained applying the image analysis software BASEGRAIN to an UAV's captured image.

Results

The application of BASEGRAIN to the selected image allowed the detection of 27903 individual grains; providing a sample whose size could not be otherwise achieved. The sediment size has been transformed from mm to the classical φ scale (Krumbein et. al., 1963), defined as:

$$\phi = -(D/D_0) \qquad (1)$$

where D_0 =1 mm, and the grain size distribution have then been computed.
The results are summarized in Fig. 4 and in the following Table1.

Table 1. Results from photosieving the image of an exposed bar captured using an UAV.

Parameter	Value
D_{50}	-4.15
D_m	-4.30
St. Dev	0.65

Conclusions

The methodology adopted in this research, and herein described, was applied to a gravel bar composed of sediment sizes ranging from gravel to boulders. The accurate detection of material finer than coarse sand (around 0.5 mm) is still an open problem mostly due to the technological limits imposed: the available computational power and the accuracy of the ground control points, which must be in the same order of magnitude. This method will be further used by the authors in a larger study aiming at analysing the morphological changes at reach and basin scale deriving from impulsive sediment inputs in the river network due for example to landslides or debris flow, with particular focus on the interplay of spatial and temporal scale of the transport phenomena involved.

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Numerical Modelling of Erosion of Sediment from Reservoirs

Sudesh Dahal[a*]
[a] IHE-Delft, Institute for Water Education, Department of Water Science and Engineering, Specialization in Hydraulic Engineering and River Basin Development, P.O. Box 3015, 2601 DA, Delft, the Netherlands

Keywords — Sediment, Reservoir, Delft3D

Introduction

Sediment deposited in the reservoir upstream of dam is subjected to erosion during flushing operations or after the removal of dam. The practice of dam removal is increasing worldwide, due to ecological and environmental considerations. But the major concern in dam removal is how the sediments stored in the reservoir are eroded after the removal of dam. Also sediment flushing operations have become more common to release part of the sediment stored in the reservoirs. It is important to establish the efficiency of these practices in removing stored sediment from reservoirs. Dam removal exposes all the stored sediments in the reservoir, which can be seen as an extreme case of sediment flushing from reservoirs. A careful study is necessary to predict the erosion of sediments from the reservoir and to optimize the sediment removal process to cause minimum negative effects. Numerical models could be an effective tool for simulating sediment erosion process but their performance has not been verified yet.

Problem Statement / Research Gaps

Prediction of the removal of sediment from the reservoir is challenging. Very few similar studies have been done in the past. There is no any clear methodology to study sediment removal by flow in reservoirs. The prediction of the morphological processes after dam removal is necessary to adopt the removal strategy to cause minimal impacts on the river system and ecosystem. But lack of sufficient information is a major problem in predicting future consequences.

Some recent dam removal studies have employed one-dimensional numerical modelling to predict long term morphological response (Stillwater Sciences, 2000a). But 1D numerical models are not sufficiently capable to predict the changes in river system at the cross-sectional scale. Hence a two-dimensional model is necessary to study the erosion of sediment stored in the reservoir upstream of dam.

The applicability of the two-dimensional numerical models in sediment erosion process have not been tested yet. The process of sediment flushing from reservoir and sediment erosion after dam removal are very similar. So a numerical modelling study should be carried out to investigate the ability of model to reproduce the morphodynamic processes after dam removal and interpret it with the sediment flushing operations.

Case Study

This research is based on the case study of removal of Marmot Dam which was located in Oregon, USA. This event of Marmot Dam Removal is an attractive study topic for researchers due to the availability of monitoring data before, during and after the removal of dam (Podolak and Pittman, 2011).

The 15m high Marmot Dam was located across the Sandy River, a tributary of Columbia River. It was a component of the Bull Run Hydropower Project owned by Portland General Electric (PGE). The Marmot Dam was removed in October 2007 due to decommissioning of the Bull Run Hydropower Project. At that time the reservoir upstream of the dam was almost completely filled by sediment. The sediment volume deposited in the reservoir was estimated to be 750,000 m^3 of sand and gravel (Squier and Associates, 2000), which is equivalent to about 5 to 10 years of average annual sediment load. The breaching of the temporary cofferdam and initiation of reservoir erosion is shown in Fig. 1.

Figure 1. Breaching of the Cofferdam and initiation of Reservoir Erosion, 19 Oct. 2007, (Major et al., 2012)

* Corresponding author
Email address: dahal6@unesco-ihe.org (Sudesh Dahal)

Research Methodology

The erosion process of the reservoir sediment after removal of Marmot Dam is studied using a two-dimensional morphodynamic model built in modelling software Delft3D. Delft3D-Flow is a simulation program for multi-dimensional hydrodynamic flows and transport phenomena, including sediments (Deltares, 2017). The objective is to develop a model to reproduce the erosion process that occurred in the reservoir after dam removal. The morphological processes occurring in the reservoir are observed as change in bed topography, sediment transport rates and sediment composition. The calibrated and validated model can then be used to simulate similar process under various scenarios. The conclusions about the capability of model in reproducing the sediment removal process are then analyzed in view of optimizing the sediment flushing operations.

This research focuses on the simulation of the erosion process of the sediment stored in Marmot Dam Reservoir after the dam removal. A two-dimensional (2D) morphodynamic model built in Delft3D is used to simulate the processes involved. The subsequent process of modelling work are briefly described below:

Model Development

The data necessary for the development of the model are the computational grid along the river and reservoir, bathymetry of river and reservoir, discharge time series, sediment inflow time series, sediment composition and rating curve of gage stations. The river boundary line is obtained from the google earth images just before the removal of Marmot Dam. This boundary is used to create the computational grid cells along and across the river and reservoir. The bathymetry of the river and reservoir is generated from the 2007 LIDAR survey data combined with other topographic surveys. The inflow discharge and inflow sediment time series is obtained from the USGS gage stations located nearby.

Model Calibration and Validation

The Manning's roughness coefficient "n" is used as a parameter for the hydrodynamic calibration of the model. The roughness may vary throughout the reach but a uniform value is assumed because of uncertainty. The calibration is done by altering the roughness value until the simulated water levels are similar to the measured water levels in the calibration points.

The Morphodynamic Calibration of the Model is done with the monitored data after dam removal such as sediment load and bed topography. The parameters used for the calibration process are sediment transport formula, sediment composition, sediment size etc.

The calibrated model is then validated by comparing some other monitored data with the simulated results. The results of model validation allow assessing model performance in reproducing sediment erosion from reservoirs.

Scenario Analysis

Once the model is calibrated and validated, it can be trusted to get proper results for further simulations. The result of the reservoir erosion can be predicted at various locations at various times. Also various scenario of sediment removal can be modelled to observe the effect of each scenario. Flushing of sediment through the dam is one of the scenario. Other scenarios could be removal of dam in stages rather than one actual case of removal at one stage.

Result Analysis / Integration

The result obtained in this research is the development of a 2D model to reproduce sediment erosion process in reservoirs. The model so developed is assessed for its capability to reproduce the physical processes occurring during sediment erosion from reservoirs. The model is used to simulate some other scenarios of reservoir erosion, in view of getting some idea about optimizing the dam removal strategies in similar conditions. Also the results can be analysed in view of sediment flushing from reservoirs considering dam removal as an extreme case of reservoir flushing. The results obtained from all the scenarios and simulations can be integrated to get a general idea of the modelling of reservoir sediment erosion due to dam operations.

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Session IIIa

Towards multifunctional Self-Sustaining Rivers

Residual biomass from riverine areas – transition from waste to ecosystem service

Astrid E. Bout[a*], Swinda F. Pfau[a], Erwin van der Krabben[b], Antoine J.M. Smits[a], Ben Dankbaar[a,b]
[a]*Institute for Science, Innovation and Society, Faculty of Science, Radboud University Nijmegen, P.O. Box 9010, Nijmegen 6500 GL, The Netherlands*
[b]*Institute for Management Research, Radboud University Nijmegen, P.O. Box 9108, Nijmegen 6500HK, The Netherlands*

Keywords — Vegetation management, Biomass use, Ecosystem Service

Introduction

In recent years, the use of biomass for various uses, such as energy and materials, has received increasing attention. The upcoming bio-economy is stimulated by various drivers, such as the need to reduce our dependence on fossil resources, the goal to reduce greenhouse gas (GHG) emissions, environmental concerns and an increasing demand for sustainable products (Pfau et al. 2014). Replacing fossil resources with biomass in the production of energy and materials is expected to improve the sustainability of these products, but the contribution is not self-evident (ibid.). One strategy that is often suggested to increase sustainability, is the use of residual biomass (van Dam et al. 2005; Jenkins 2008; Osseweijer et al. 2010; Hatti-Kaul 2010; Landeweerd et al. 2011; Centi et al. 2011; Voll and Marquardt 2012; Keijsers et al. 2013). The use of such residues makes it possible to re-use materials, that would otherwise be waste, as input for new production chains. Four types if residual biomass can be distinguished: agricultural residues, animal manure, organic waste and landscape residues (Hoogwijk 2004; Pfau 2015). Landscape residues may include biomass released during landscape maintenance activities in various types of landscapes, such as forests, roadside vegetation, pastures and half-natural landscapes such as floodplains (Pfau 2015). Recently, there is a change in the perception of landscape residues, from a waste product towards a useful, natural resource. Especially in the case of necessary vegetation management in landscapes, such as roadside vegetation and floodplains, the provision of biomass is now often viewed as an ecosystem service.

An interesting case for the change of perception of residual biomass is the vegetation management in riverine areas in the Netherlands. Large parts of the Netherlands are located in the delta of three major rivers (the Rhine, the Meuse, and the Scheldt). This delta area is densely populated and especially vulnerable to peak discharges, which are predicted to occur more frequently in the future due to climate change, causing an increased flood risk (Middelkoop et al. 2001; Kabat et al. 2005; Albers et al. 2015). One important measure to manage flood risks is vegetation management. Since 2014, a new vegetation norm determines the permitted vegetation height per area, based on water safety considerations (Rijkswaterstaat 2014). Vegetation has to be removed regularly to achieve the envisioned safety standard, which requires costly maintenance measures. This has given rise to the idea of using biomass released during maintenance measures, thereby (partly) re-paying the management costs and at the same time providing a valuable resource. Perception of landscape residues thus changed from a waste stream towards a potential ecosystem service.

In this paper, we explore the transition from waste to ecosystem service of residual biomass in Dutch water management organisations and the potential new market for residual biomass. We focus especially on the drivers of the water management organisations to engage in such a market environment, adapting vegetation management practices and engaging in the use of biomass as ecosystem service.

The research questions to be answered in this paper are:

1. What is the current practice regarding vegetation management and the provision of residual biomass in Dutch water management?
2. What are the drivers for biomass use and a change of perception of biomass as ecosystem service?

Method

To achieve the goal of this study, we evaluated the use of biomass in current water management practices. We contacted various people engaged in vegetation management at

* Corresponding author
Email address: astrid.bout@ru.nl (A.E. Bout)

all water boards in the Netherlands, Rijkswaterstaat and the State Forestry Service and created a database of vegetation management practices in these organisations, containing details about the organisation of vegetation management and biomass use. We were able to gather information from 19 water boards, three units of Rijkswaterstaat and five units of the State Forestry Service. We then analysed the organisational structures of vegetation management in these practices. To enable a closer look at both the organisation and the drivers behind biomass use, we conducted in-depth analyses of exemplary cases. We conducted 13 semi-structured interviews with employees responsible for vegetation management within their organisation. During the interviews, we gathered information on the current uses of residual biomass from riverine areas and details on the organisation of both vegetation management and biomass use. We furthermore discussed the objectives, considerations, drivers and outcomes of vegetation management and biomass use. We analysed the interviews using qualitative data assessment (QDA) software atlas.ti to allow for a structured analysis of the respondents comments.

Results

We describe 13 applications of biomass that are currently realised. Furthermore, we identified and describe six ‘organisation mechanisms’ based on the organisation of both the execution of vegetation management and the use of residual biomass. Most importantly, we found nine different drivers for biomass use of the water management organisations. Examples are:

1. Nature / Ecology: extraction of biomass from system to reduce nutrients
2. Tradition: “we have always done it this way”
3. Value of biomass: use biomass for something “valuable” or “useful”

Discussion

In several instances, costs and value of biomass uses are confused in the approaches of the water management organisations. While the driver for certain uses is to achieve a higher societal value, the choice is in practice made based on lower costs. A lack of scientific consensus on sustainable uses of biomass becomes evident, which results in vague and uniformalised decision criteria applied to decide between different uses of biomass.

Extraction of biomass seems to be preferred by most, but is often hindered by a discrepancy between the benefits of current biomass uses and the negative impacts of collecting and transporting biomass. However, extraction could provide additional functions next to the provision of biomass: several interviewees describe that it is better for ecosystem functioning and water management goals, such as water discharge.

Our initial assumption was that the main driver behind the transition from regarding biomass as a waste product to seeing it as an ecosystem service is an expected win-win situation for public organisations: using biomass for something useful and getting some money for it. We found, however, that this win-win is not necessarily the most important driver. Multiple drivers were observed; money is currently not very influential, though an increase in value is expected in the future. Using biomass for something “valuable” or “societally responsible” is, however, observed as driver.

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Quantifying biomass production in floodplains along the Rhine river distributaries

K.R. Koopman[a,e]*, M.W. Straatsma[b], D.C.M. Augustijn[c], A.M. Breure[a,d,] H.J.R. Lenders[a], S.J. Stax[a], & R.S.E.W. Leuven[e]

[a] *Department of Environmental Science, Institute for Water and Wetland Research, Radboud University, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands*

[b] *Department of Physical Geography, Utrecht University, P.O. Box 80115, 3508 TC Utrecht, The Netherlands*

[c] *Twente Water Centre, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands*

[d] *Centre for Sustainability, Environment and Health, National Institute for Public Health and the Environment (RIVM), P.O. Box 1, 3720 BA Bilthoven, The Netherlands*

[e] *Department of Animal Ecology and Physiology, Institute for Water and Wetland Research, Radboud University, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands*

Keywords — Room for the Rivers, Riverine management, Ecosystem services

Introduction

River systems provide valuable functions and services to mankind, such as: water supply, transport capacity, sediment and biomass. As fossil resources are depleted fast, the need for alternatives increases. Biomass produced by riparian vegetation is a valuable riverine ecosystem service and has various applications, for example bioenergy production. In order to quantify how much biomass can be harvested, the river systems' potential for biomass production needs to be determined. We developed an approach for quantifying annual above-ground biomass production of river floodplains systems (Koopman et al., 2018). Next, our approach was applied to calculate spatiotemporal development of biomass production in floodplains along the Rhine river distributaries in the Netherlands (the rivers Waal, Nederrijn-Lek and IJssel). Biomass production was calculated for the years 1997, 2005, 2008 and 2012. During this period these river distributaries underwent different management measures, natural succession and land use change, which potentially affected the biomass production.

Method

Study area and mapping

The Rhine river distributaries and their floodplains have been regularly mapped over the period 1997-2012 using the Ecotope System for National Waterways (Van der Molen, 2003). The ESN classifies the riverscape into ecotopes, which are homogeneous landscape units based on hydromorphological, geo-morphological, ecological and land use characteristics. The maps are available for the years 1997, 2005, 2008 and 2012. The riverscape underwent many changes due to natural vegetation succession, land use changes and measures of the Room for the River programme (e.g., side channel construction, floodplain lowering and removal of summer dikes; Silva et al., 2001; Van Stokkom et al., 2005; Straatsma et al., 2017).

* Corresponding author
Email address: kkoopman@science.ru.nl (K.R. Koopman)

Biomass production of floodplains

Biomass production rates (ton_{dm} ha^{-1} yr^{-1}) for woody and non-woody biomass were linked to nine corresponding vegetation classes present in floodplains along the three distributaries. These vegetation classes were retrieved by aggregating ecotopes of the ESN based on vegetation with similar roughness values (Van Velzen et al., 2002). Next, biomass production of floodplains was calculated by multiplying the biomass production rates with the surface area of corresponding vegetation classes. The biomass production values were aggregated at floodplain scale (177 sections) and distributary scale.

Results

Total biomass production decreased most in floodplains along the IJssel river, followed by the Waal and Nederrijn-Lek rivers, respectively (Table 1). Annual biomass production decreased in most floodplains (Fig. 1). Decreases ranged up to $10.1 \cdot 10^3$ $tons_{dm}$,

Table 1: The annual above-ground biomass production of the Rhine river distributaries for the years 1997, 2005, 2008 and 2012. Biomass is given in tons dry mass.

Distributary	1997	2005	2008	2012
Waal river	7.2E+04	7.2E+04	6.3E+04	6.1E+04
Nederrijn-Lek river	7.1E+04	6.6E+04	6.4E+04	6.2E+04
IJssel river	9.9E+04	9.3E+04	9.1E+04	8.6E+04

while increases only ranged up to $2.8 \cdot 10^2$ $tons_{dm}$.

Discussion

This study shows the cumulative effect of 15 years of riverine management, vegetation succession and land-use change on annual biomass production of floodplains. Above-ground biomass production decreased along all three distributaries. This can likely be contributed to several factors. First, Room for the River measures were implemented to give the river more space and improve spatial quality (Silva et al., 2001; Van Stokkom et al., 2005, Straatsma et al., 2017). Several vegetation classes were converted into aquatic classes (e.g. side channels) or vegetation was removed and set back to the pioneer stage (floodplain lowering, obstruction removal). In other instances management of the vegetation was altered. During the 15 year period many intensively managed production grasslands were sold to various nature conservation organisations which abandoned agricultural management and allowed natural grassland to develop (Nienhuis et al., 2002). The production rate of natural grasslands is two times lower than that of production grasslands. Succession allowed biomass to develop in some floodplains, however, this was not sufficient to counter the decreases in production in other floodplains. In conclusion, the implementation of river management measures improved flood safety and spatial quality, but coincided with a decrease in biomass production.

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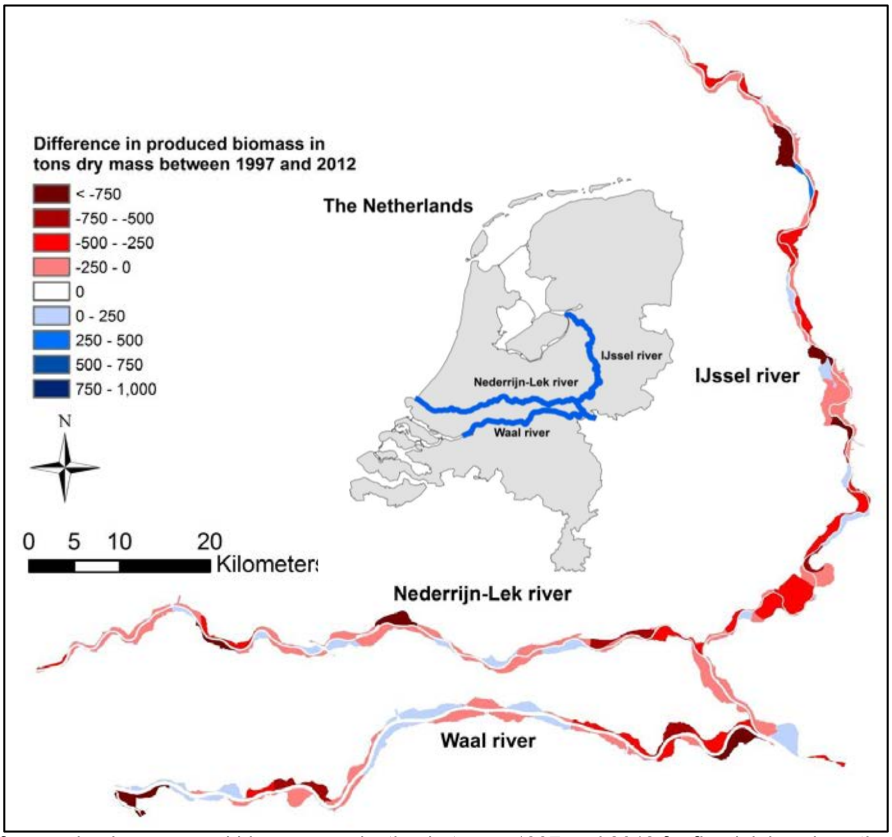

Figure 1: The difference in above-ground biomass production between 1997 and 2012 for floodplains along the Rhine river distributaries.

Drivers and challenges for river management in the circular economy

Jeroen Rijke[a,b]*, Jacomien den Boer[a], Toine Smits[b,c]
[a]HAN University of Applied Sciences, Ruitenberglaan 26, 6826 CC, Arnhem, Netherlands
[b]VHL University of Applied Sciences, Larensteinselaan 26a, 6882 CT, Velp, Netherlands
[c]Radboud University, Heyendaalseweg 135, 6525 AJ, Nijmegen, Netherlands

Keywords — River management, circular economy, sediment, biomass, plastic

Introduction

Driven by the premises that the circular economy (CE) provides economic and business value without compromising the finite stock of natural resources, it is rapidly gaining popularity in various domains such as consumer goods, construction and logistics. Based on a review of a variety of emerging theories such as cradle to cradle, the performance economy and biomimicry, the Ellen Macarthur Foundation (2015) has developed three principles for the CE as a basis for sustainable development:

1. Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows.
2. Optimise resource yields by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles.
3. Foster system effectiveness by revealing and designing out negative externalities.

Building on insights from the Netherlands, Indonesia and Vietnam, we explore in this contribution how the principles of the CE can be applied to river management and examine what are currently the key drivers and challenges to do so.

Method

This work presents preliminary findings that are drawn from four cases:

Case NL1: the development of a vision for sustainable development in the Rivierklimaatpark IJsselpoort, the Netherlands. This vision is currently under construction. Three workshops were organised with key stakeholders (Rijkswaterstaat, Province of Gelderland, Natuurmonumenten, municipality of Rheden) to discuss how the CE principles could be used to contribute to sustainable development of the project area on the short, medium and long term and what needs to be resolved in order to achieve this.

Case NL2: an inventory of technologies that are applied for using dredging materials as a resource for building flood protection works in the Netherlands. One workshop and 11 interviews were held to examine what technologies are currently being applied in the Netherlands and what are the strengths, weaknesses, opportunities and threats for these.

Case IN: the development of a 'sediment recycling factory' near Bandung, Indonesia. Two workshops were organised in Indonesia and one in the Netherlands to discuss the challenges related to sediment management in the 'Bandung' Basin, the potential added value of sediment recycling and related challenges for doing so.

Case VN: the development of amphibious housing from recycled plastic in the Mekong Delta, Vietnam. Four meetings were organised with academics and the private sector to explore the added value and feasibility of low cost amphibious houses with a floating platform from recycled plastic in areas in the Mekong Delta that are prone to seasonal flooding.

The drivers and challenges that have emerged during the workshops and meetings are summed up for each individual case. Subsequently, we have categorised the barriers using a transition governance framework that was developed (Farrelly et al., 2012) and tested in the context of urban water cycle management and that was later also applied to river management in the Netherlands (Rijke, 2014). This framework has proven to function as a checklist for identifying whether the required enabling factors for a transition are available in a certain context (ibid). As such, we have used it to determine what is needed to make progress for applying the CE principles to river management.

Results

Drivers

Five types of drivers were identified to adopt the CE principles to river management (Table 1).

1. Societal value creation (NL1, IN, VN)
2. Reduced life cycle cost (NL1, NL2, VN)
3. Superior strength/durability of construction materials (NL2, VN)
4. Pollution control (IN, VN)

* Corresponding author
Email address: j.rijke@han.nl (Jeroen Rijke)

5. Community ownership of sustainable development (NL1, IN, VN)

Challenges

Table 1 provides an overview of the availability of the enabling transition governance factors for adopting the CE principles in each of the cases. For this, eight enabling transition factors as proposed by Farrelly et al (2012) are used: 1) Vision (narrative, metaphor, images), 2) Policy framework and institutional design, 3) Economic incentives and justification, 4) Regulation and compliance, 5) Leadership, 6) Capacity building and demonstration, 7) Public engagement, 8) Research partnerships with policy and practice. Three cases (NL2, IN and VN) clearly revealed technology readiness as a ninth factor. Table 1 refers to these factors as 1-9.

Table 1. Overview of the availability of enabling transition governance factors

	NL1	NL2	IN	VN
1	Area centred, is developing	Material focused, is developing	No	Material fo-cused, refers to 'plastic soup'
2	Not actively supportive	Not actively supportive,	Not actively supportive	Not actively supportive
3	Yes, but value chain disconnect ed	Yes, but value chain disconnect ed	Unclear	Financial mechanism needed to support upfront investment
4	At times impeding	At times impeding	Disfunctio-nal	Unknown
5	Driven by public sector	Driven by private sector	Driven by internationa l research partnership	Driven by private sector
6	Ongoing	Ongoing	Ongoing	Ongoing
7	Not yet	No	Not yet	Not yet
8	Living Lab	Project based	Living Lab	Project based
9	N/A	Pilot stage	Ideation stage	Feasibility study stage

Table 1 indicates that there are many challenges to adopt the CE principles to river management. Three key challenges stand out:

1. A clear vision of what it means and how to adopt CE to river management is at best under construction from a single material point of view (e.g. plastic in VN, sediment in NL2). The challenge to develop a clear vision is affected by a discrepancy between the systems that are central to the CE (value chains) and those to river management (e.g. watersheds, floodplains, dike rings and jurisdictions). Although this is acknowledged in NL1, this has not yet resulted in an integrated vision.
2. Implementation of CE in river management requires new policy and regulatory frameworks that are better equipped to support recycling and reuse of natural resources and waste (all cases). Accordingly, there needs to be a rethink of roles and responsibilities of actors involved in the management natural resources, waste, infrastructure and floodplains. In all cases it was suggested that experimentation and collaborative learning are important for this.
3. Finally, it should be noted that adopting the CE for river management is not a governance issue alone. Lack of technology readiness is explicitly mentioned in three cases

Conclusion

Although the CE principles are more widely adopted in other domains of water management (e.g. stormwater harvesting and reuse, wastewater recycling, wastewater nutrient mining), the CE provides a relatively new perspective on river management. The cases highlight that CE thinking may provide a variety of benefits for communities, asset managers and pubic authorities in river areas. However, the implementation of this concept is not without challenges and further work needs to be done to remove these challenges and take stock of the looming benefits of the CE. Based on our study, we conclude that there is a need for experimentation space in order to support the development of a vision for how to adopt the CE in river management.

Acknowledgements

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PRIMA: A method for performance based asset management of the rivers

Wouter Rozier[a*], Bram de Groot[a], Nathalie Asselman[b], Otto Levelt[b]
[a] Rijkswaterstaat WVL, Postbus 2232, 3500 GE Utrecht, The Netherlands
[b]Deltares, Postbus 177, 2600 MH Delft, The Netherlands

Keywords — Performance management, Rivers, Flood risk, Rijkswaterstaat

Introduction

This paper provides insight into how Rijkswaterstaat improves the asset management of the Dutch rivers to the future.

Rijkswaterstaat develops, manages and maintains three main infrastructure networks in the Netherlands in behalf of the Ministry of Infrastructure and Water Management.
These three networks (the main road network, the main waterways network and the main water system) maintained by Rijkswaterstaat have the status of 'primary system'. A system is a coherent aggregate of (physical) parts intended to fulfil a certain function like the discharge of rivers. The components that make up the main systems, such as the rivers, consist of even smaller system elements, such as flood plains, weirs or floodgates.

The Ministry of Infrastructure and the Water Management establishes policy objectives for the networks managed by Rijkswaterstaat. Every 4 years agreements on the management and maintenance are made in Service Level Agreements (SLA).
In these agreements, the Ministry and Rijkswaterstaat set out the performance Rijkswaterstaat must provide and the related costs.

In the past, the budget for maintenance of the networks of Rijkswaterstaat was settled by taking the average maintenance cost of an object times the number of objects. Thereby the performance of the object was known and not the performance of (the function of) the system.
Budgets for maintenance are under pressure, and the Ministry wants to know which performance Rijkswaterstaat can deliver for a certain budget in order to fulfil the policy objective and which risk we take for the function.

* Corresponding author
Email address: wouter.rozier@rws.nl
URL: www.Rijkswaterstaat.nl

A change is needed from assessment of the objects to an assessment of the contribution of the objects to the function of the network. The management of this process is called performance management or risk based asset management (PROBO, 2016).

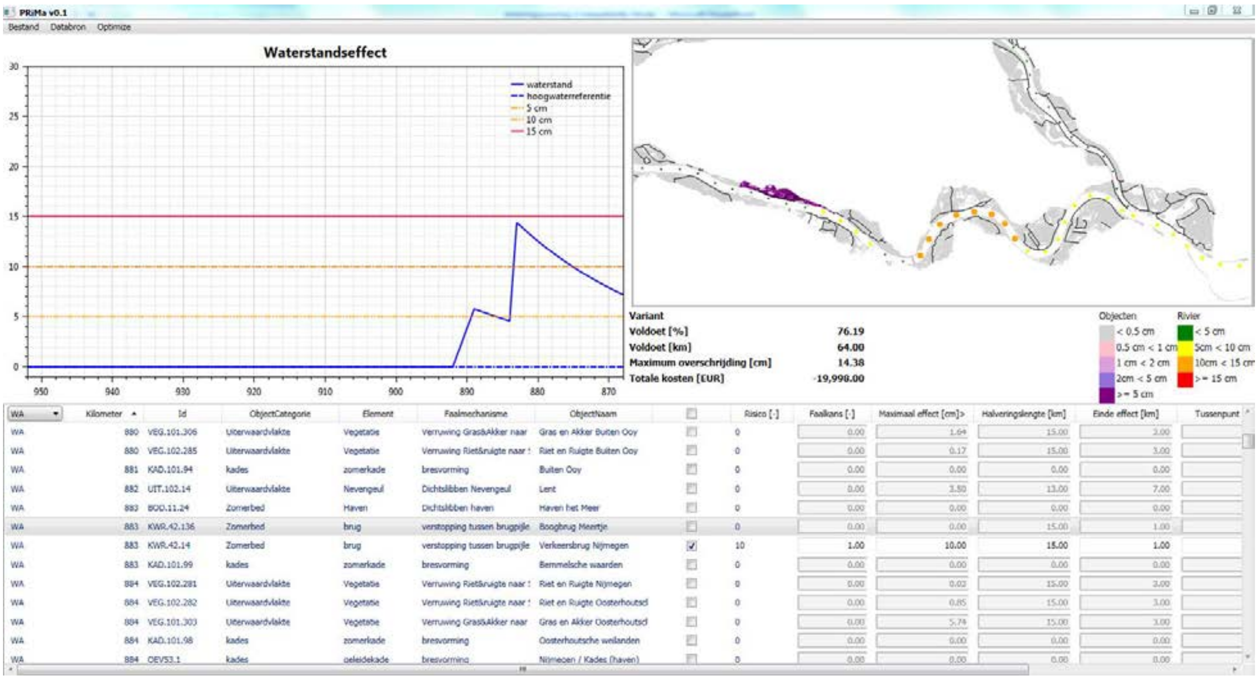
We developed a method to make this change possible for the function: accommodate the design discharge of the Dutch river system.

Method

We developed a line of reasoning, to come to a prioritisation of the objects and areas with a high risk regarding the exceeding of the design water levels. Based on an expectation (calculated or estimated by expert judgement) that objects will satisfy set requirements in terms of performance:

1. Determine/update the area and objects in the floodplains of the Dutch rivers.
2. Determine the actual condition/ state of the objects (via monitoring programs).
3. Determine/ update the probability of failure and the effect of failure of the object regarding the design discharge.
4. Determine the cost of maintenance of the objects.
5. Couple the policy objective for the Netherlands (reduce the flood risk) via the objectives of the rivers (safe discharge of water, ice and sediments) to the performance of the system and the performance of the objects in the system (the floodplains).
6. Perform a risk analysis with the data collected in the previous steps.
7. Prioritise the objects regarding the risk, cost or demanded performance of the system.

The large amount of data collected of the river system (e.g. area: 110.000ha, 13.000 landowners, 8 weirs, 100+ side channels) and the information we added to this data, forced us to develop a tool in order to perform the risk analysis and make the prioritisation.



Tool to prioritize maintenance of assets

This tool was developed following the line of reasoning. The tool was based on the planning kit Room for the River (in Dutch: Blokkendoos Ruimte voor de Rivier). It consists of a large database of objects and assets that affect the flow and, in case of bad maintenance, would lead to increased water levels and/or changes in the discharge distribution. Types of objects in the database include different types of floodplain vegetation, side channels, groins, regulation works and weirs. For each object, the location, and the impact on flood water levels as well as discharge distribution are given. The asset manager needs to define the actual condition of the object (or failure probability). For instance, if no sedimentation has occurred in a side channel, failure is 0. If a side channel has silted up so that under average river discharges no water flows through it, then failure is 1. The impact is scaled in accordance with the failure probability to produce the actual impact on flood water levels. The increase in water levels is shown in a graph. Similar to the planning kit, it is assumed that the effect of different objects can be summed to get the total effect. This is also shown in a map. The asset manager can then work out different maintenance strategies. The present version of the tool does not include maintenance costs. But it is intended to include those in a future version of the tool, so that the asset manager also gets an impression of the costs that are related to the different maintenance strategies.

Figure 1. screen dump of prioritisation tool. Upper left: the graph indicating the increase in water level due to (partial) failure of different objects and assets. Upper right map showing the same information. Lower part: table showing all objects and assets that are located along the selected river reach.

The impact of failure of objects on flood water levels is based on model simulations. However, for many objects and assets, no model data were available. That means that impacts are based on expert judgement and need to be improved. Also, rules of thumb were applied to assess the impact of failure on the discharge distribution. In 2018 we plan to study this effect in more detail.
More insight also is needed in the way assets deteriorate over time. How do different types of vegetation develop? And how fast do different side channels silt up? This knowledge can be used to support asset managers in developing maintenance strategies for future years.

Future

This project finishes in the end of 2019, at the start of the process for the new SLA period. But the development of performance management by Rijkswaterstaat just started.

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Water quality management in Upper Citarum River: understanding and influencing policy to improve water quality

Lufiandi[a,b,*], G. Geerling[b,c], A.J. Effendi[a], D. Roosmini[a], A. Sudradjat[a], L.W.J. Knippenberg[b], A.J.M. Smits[b]

[a] *Environmental Engineering Graduate Program, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Bandung, Indonesia*
[b] *Institute for Science in Society, Radboud University, Nijmegen, The Netherlands*
[c] *Ecology and Water Quality Department, Deltares, Delft, The Netherlands*

Keywords — Upper Citarum River; Water Quality Management; Scenario Development; Stakeholders collaboration

Introduction

The Citarum River, the largest and longest river in West Java Province in Indonesia, remains an essential part of 25 million people's lives as a source of water. Over the past two decades, the river water quality has been severely degraded and its capacity to support the livelihood of the area's inhabitants has been significantly reduced.
Most studies in the field of water quality in Citarum River have only focused on specific technical issues. The development of a comprehensive framework needed in order to analyze the most important factors, and to assist in designing a policy for water quality improvement.
The main question addressed in this research is: How effective is the management of water quality in Upper Citarum River? The research is divided in four parts, as described below.

Methodologies

1. Compilation of all available water quality data over three decades; comparing and examining trends of monitoring results; accessing the long-term water quality and examining the use of the obtained monitoring data in relation with the response policies.
2. Identification of source of pollutant; identification and calculation of pollutant load; modelling scenarios of future changes in pollutant sources.
3. Identifying water quality management stakeholders, semi-structured interviews and participant observation, collaboration analysis in planning and implementation phase.
4. Developing an appropriate instrument to foster co-operation and joint decision making (serious game); creating an evaluation method for the game; and testing the effectiveness of the game.

* Corresponding author
Email address: lufiandi2002@yahoo.com

Results

1. River monitoring and state of water quality.
   The water quality monitoring activities and control of pollution sources are very limited, lacking in collaboration and data-sharing among the stakeholders, operating a water quality database, policy responses based on monitoring activities and law enforcement.
   A different method to calculate the state of river water quality is endorsed by the government (STORET and Water Pollution Index-WPI) and resulted in a different policy status of water quality as shown in Figure 1. WPI calculation method resulted in a better state and upwards trend of water quality while the STORET method always resulted in a "highly polluted river state" and downwards trend of water quality.

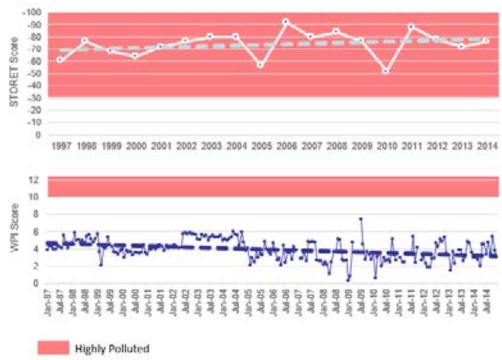

Figure 1. Comparison of the state of Citarum's river water quality based on STORET and WPI calculations.

2. Developing scenarios
   It is essential to develop scenarios in the Citarum's water quality improvement program to prepare for future demands and pollutant emissions. The previous and recent Citarum's water quality improvement programs are not effective, in part caused by a lack of systematic analysis of changing drivers, pressures and states of water quality in the Citarum basin (DPSIR approach).
   Preliminary scenario developed by using SOBEK software for six water quality parameters showed that the improvement of sanitation facilities (septic tanks) for the people should be priority since the domestic activity is the largest contributor to the water quality problem in Upper Citarum.

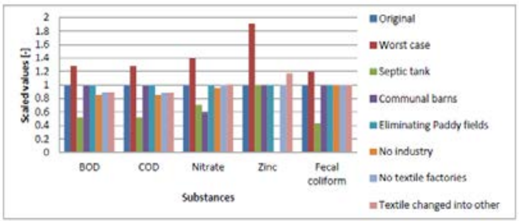

Figure 2. Preliminary development scenario in Upper Citarum River (the results are scaled to the original condition in 2015).

   Involving many stakeholders is necessary for river water quality improvement based on development scenarios, no single / monodisciplinary measure or scenario can solve the water quality problem.

3. Stakeholders Analysis
   Stakeholders collaborate but several issues make the collaboration not effective in improving water quality. Stated reasons based on interviews are: top down initiative of government programs; no clear autonomy of the river and transitional period of decentralization; and last also the nature of stakeholders' engagement which is mainly informed and consulted as shown in Figure 3 (not participative). As a result, there is no clear understanding among the stakeholders' of existing programs and each other's goals (essential for collaboration).

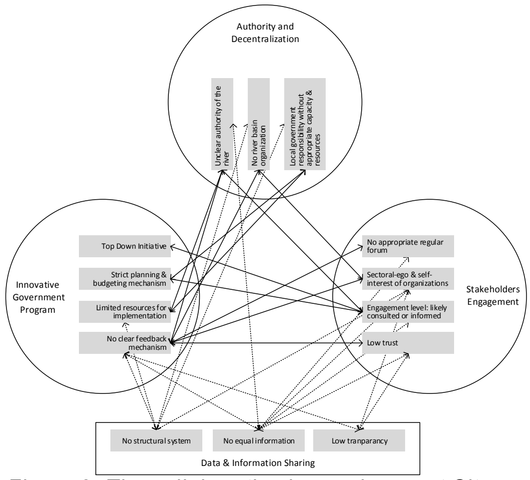

Figure 3. The collaboration issues in recent Citarum water quality improvement program

4. A tool for communication, education and policy making (serious game).
   There is a need for improving a clear understanding between all stakeholders before developing and implementing a water quality improvement programme. Common understanding should encompass: the condition of the river; possible measures and their impacts; a shared vision/goal, and clear roles and responsibilities.

   A serious game 'healthy rivers' is developed as a tool for water quality management training as a communication, education and policy-maker tool for Water Quality Management in Upper Citarum River.

Conclusions

Monitoring and data sharing in water quality is important to have a transparent and accurate state of the river water quality to be used in policy making process and to be used for law enforcement. No single institution can solve the pollution problem, stakeholder collaboration is essential to improve water quality in Upper Citarum River. A method or tool to improve stakeholders' collaboration is needed to be developed and implemented.

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The Rhine Meuse delta: an aspired UNESCO Global Geopark

Brendan F. McCarthy[a], Gepco M. de Kruijff[a], Emmie M. Nuijen[a], Kim M. Cohen[b]
[a] Rhine Meuse delta (aspiring) UNESCO Geopark, De Wetering 1, 4021 VZ Maurik, the Netherlands
[b] Universiteit Utrecht, Postbus 80.115, 3508 TC Utrecht, The Netherlands

Keywords — Geoparks, Rhine Meuse delta, international sustainable tourism, Geo Science, landscape, nature

Introduction

Since 2012, the Enterprise HollandDelta public-private partnership initiative has been working on launching the Rhine Meuse delta Geopark and on qualifying for a UNESCO Global Geopark status. The Rhine Meuse delta (aspiring) UNESCO Global Geopark consists of three elements:

- Delta: a dynamic area where major global issues are changing the landscape and the life of communities
- Geo: a region with a common history and specific qualities on landscape, geology, geomorphology, ecology and heritage
- Park: an open space where people are engaging with the landscape and learning about the region and the impact it has on human activities. Local communities grant global visitors journey experiences through the park.

This geopark unites river, polder and estuary landscape zones (Fig. 1). It covers the Rhine Meuse delta as a living delta with a long history of human involvement, that brought the country trade and wealth, polders and windmills, dikes and groynes, identity and reputation.

UNESCO Global Geoparks

UNESCO describes Global Geoparks as follows: *'single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development. Their bottom-up approach of combining conservation with sustainable development while involving local communities is becoming increasingly popular'*. UNESCO in its recognition of geoparks strives for areas where besides natural history interests, also i.e. cultural heritage and modern economic vitality (notably tourism) play part in the geopark. At present, there are 127 UNESCO Global Geoparks in 35 countries. Modern deltaic environments are hardly represented in that list.

* Corresponding author
Email address: info@wwic18.nl (Brendan F. McCarthy)
URL: www.wwic18.nl (Brendan F. McCarthy)

Figure 1. Area of Interest (dd 2017): Various landscapes of The Netherlands joined by Rhine Meuse delta branches

Delta: facing global change

High river water levels in 1993 and 1995 made people in The Netherlands aware that climatic change is affecting their delta. The Netherlands is no exception: low deltas around the world are struggling with comparable issues. The Dutch government via their Delta Programme is investing 50 billion Euro up to 2050, to allow the delta and its inhabitants to adapt to climatic change.

Experts, government and local communities agree that adaptation needs are not restricted to climate change alone because societies are changing nationally and internationally. Facing the pressures of change that are unleashed over deltaic regions requires integrated activity. Approaches are necessary to fundamentally deal with the issues at hand. The launch of the Rhine Meuse delta (aspiring) UNESCO Global Geopark echoes this in striving for:

- Involvement of local communities in coping with climatic change in the delta
- Broadened comprehension of the delta as a geo-system, and learning about ways to deal with current challenges of global change.
- Raising awareness of the qualities of the delta and the contribution it can have to coping with climatic change, worldwide.
- Finding new ways for making a living for local communities in a way that enhances the qualities of the delta, i.e. delta-oriented sustainable tourism.

Geo: Rhine Meuse delta

As a major delta, with a long history of humans living with rivers, tides and coasts, The Netherlands is world famous. The system has received abundant sediment from the European hinterland and distributed this into the North Sea Basin, building land into the sea. Helped by glaciations in the last million years, by sea level rise since the end of the last ice age, and by human activities of the last few millennia, especially the central Netherlands hosts an exceptionally diverse Pleistocene, Holocene and 'Anthropocene' geoheritage.

Through the influence of human factors, the lowland delta of Rhine and Meuse has changed considerably, especially in the last 1,000 years. The pre-historic dynamic river landscape with sand, clay- and peat deposition, morphed into one where river migration was more controlled and people installed dikes, polders, towns and villages and flow control structures. The long history interaction of riverine and human dynamics in the densely populated country, make it an internationally, unique delta.

The history of human impact at full-delta scale, i.e. the combination of deforestation in the hinterland and dense occupation and engineering responses in the lowland, in The Netherlands begins earlier than in most other deltas. To substantiate the geopark, we work towards listing approximately 100 geo-sites (and as many natural and cultural heritage sites) in the geopark area, of which a considerable number (say 25) of internationally acclaimed value, with a good geographical and functional spread.

Park: visitor journeys through the delta

The impact we aim to accomplish is a change in the level of knowledge or state of mind (a mental shift) of its 'visitors' (i.e. inhabitants, tourists, students, scholars, researchers, etc.). The visitor's knowledge of the delta will be enhanced through his delta experience and he will be better equipped in coping with the challenges. This journey can take different kinds of forms. What visitors have in common is a true experience of the delta as a destination and a third space where they share experiences and learn about dealing with issues in a dynamic delta. This journey is customised to the needs of the specific visitor and catered for by local communities and/or businesses.

The Destination Management Organisation (DMO) of the Rhine Meuse delta (aspiring) UNESCO Global Geopark will be a compact platform organisation aimed at enabling the exchange of experiences and knowledge and the connection of communities (local communities, scientists, visitors, policy makers, etc.). The DMO will connect:

- Knowledge of the Rhine Meuse delta and educational programs for primary/secondary education, interest groups, broad audience
- Knowledge about the Rhine Meuse delta as a tourism destination, hosted by a large variety of tourism actors
- Scholarly knowledge and scientific research (geology, geomorphology, ecology, history, engineering, geography, economy, etc.
- Management and governance knowledge, economically, politically, stakeholder interests (nature, culture, business), creative innovation and commerce

We bring these groups together, annually, at the HollandDelta WWIC18 conference. The fifth edition of the conference WWIC18 is scheduled for March 12-16 2018, at Tiel. Suggestions for contributions to this conference are most welcome. The Rhine Meuse Geopark DMO already receives strong support from many local organisations, entrepreneurs, and from government. The (aspiring) UNESCO Geopark engages the scientific community, represented in a vision & leadership team. It is to consist of representants of a wide variety of disciplines.

For the Dutch professional community on river engineering and geomorphology, the (aspiring) UNESCO Global Geopark would be a next platform and open livinglab to co-create new knowledge and helping to build out international visibility of their scientific research and leadership in knowledge development on river delta's worldwide.

Conclusion

The international geological and geomorphological value of the Rhine Meuse delta is unmistakeably high, and hence the UNESCO Global Geopark status will be a strong international recognition of its qualities. With this status, we aim at increasing the perception of the different aspects of the delta, not in the least by causing a visitors' mental shift regarding the important position of deltas as driving forces in transforming our big world on a small planet within its planetary boundaries.

We also aim to transform a significant part of the € 75 billion annual spendings in tourism in so-called 'geo-tourism' or sustainable tourism that reconnects humanity with abiotic (delta landscape), biotic (nature), culture and communities. We aim to increase awareness, knowledge and preference of the Rhine Meuse delta on a global scale. A growing movement of people is already making effort in establishing this result.

Interorganizational Collaboration and innovation: towards Self-Supporting River Systems

Astrid E. Bout [a,b*], Heleen Vreugdenhil [c]
[a] *Institute for Science, Innovation and Society, Faculty of Science, Radboud University Nijmegen, P.O. Box 9010, Nijmegen 6500 GL, The Netherlands,* [b]*Rijkswaterstaat, Eusebiusbuitensingel 66 Arnhem, P.O. Box 25, Maastricht 6200 MA, The Netherlands,* [c]*Deltares, Boussinesqweg 1, 2629HV Delft, The Netherlands*

Keywords — Innovation procurement, Sediment management, Riverine Biomass, Plastic Free Rivers, hydropower

Introduction

Self Supporting River Systems (SSRS) is a program initiated by Rijkswaterstaat (RWS). The program strives after a changing river management from a classic artificial style towards using the rivers' natural dynamics in order to increase quality and reduce maintenance costs. Secondly this approach aims to create added value by and for various stakeholders**.

One specific example of the program SSRS is the installation of the so-called 'Leerteam' (Innovation Team). This team is part of the maintenance contract of the IJssel and Twentecanals and has as aim to further innovations and improvements for river management. The addition of the Innovation Team into the standard contract seeks to not only make it easier to innovate in river management, but also to accelerate the process.

In this paper we present some of the innovations the Innovation Team has been involved in and discuss how the team has contributed to the innovation process and indicate opportunities for the future.

The Innovation Team

The learning space and the innovation team have been established since the start of the contract IJssel/Twentekanalen in 2015. It consists of a core team of parties within the so-called 'golden triangle' – in this case the contractor BAM/vd Herik as market party, RWS as public party, and Deltares as knowledge institute. It is an open consortium, meaning that any interested party can join the team.

During the initial stages of the innovation team the focus was on identifying and selecting potentially interesting innovations. The sources of the innovation were primarily from the three organizations involved (so the contractor, Deltares and RWS), but over time innovations coming from other sources have been embraced as well. The themes that are being focused on include:

- Sediment management
- Biomass
- Energy from water
- Plastic

The rationale behind adopting innovations were that they had the potential to:

- Increase sustainability
- Reduce maintenance costs
- Generate benefits; in particular for the innovation owner so that they would be intrinsically motivated to act as ambassador and invest resources.
- Develop a business chain on the long-term

The eventual objective is to develop a closed 'business case' meaning that the innovation is worth investing in and has the potential to be widely applied nationally and internationally. To achieve this, the first contours of a societal costs benefit analysis (SCBA) are drawn and research gaps identified. In combination with a communication strategy, a pilot can be developed for the IJssel or Twentecanals which serve as test-grounds. The innovation team can support the innovations in different ways depending on the needs of the innovation. Some innovation were low-tech others more high-tech. Also, the technology readiness level (TRL) varied greatly. So were some of the innovation just mere ideas whilst others had already tested prototypes. The innovation-team helps innovation towards their next phase by generating funds, co-developing the innovation, designing the pilot, implementation, permitting processes, monitoring, evaluation and communication.

Ongoing innovations

Examples of innovations that are currently under development include:

- **Flexible Groynes**

The idea of the Flexible Groynes is to make groynes of the so-called X-stream blocks, developed by BAM (Figure 1). The material is relatively porous and so provide advantages

* Corresponding author
Email address: astrid.bout@ru.nl (A.E. Bout)
**www.ssrs.info

over traditional groynes due to less material use, relatively easy repair, and reduction of erosion around the groyne. It is expected that a pilot will take place in 2018.

Figure 1 X-stream blocks and pilot location close to Kampen (Deltares 2017)

- **Herded Sheep**

The common method to keep vegetation low and so to maintain visibility and a certain safety level is to mow embankments mechanically. In this trajectory, it is studied whether and how herded sheep can make a difference for biodiversity, cultural heritage and work safety while costs remain comparable (Boon and Vreugdenhil, 2017). Currently, three pilots have been implemented, in which a SCBA has been designed and vegetation studies performed.

- **Bubble Barrier**

The Great Bubble barrier is a long tube with small holes placed at the bottom of a river through which air is sent (Figure 2). As such a bubble screen is developed that should guide plastic waste to the side of the river where it can be removed from the water. A bubble screen in itself is not new, but the application for waste removal is. Autumn 2017 a pilot has been implemented near Kampen.

Figure 2 *Testing the Great Bubble Barrier in the lab and in the IJssel (picture: TGBB)*

- **Energy from water**

Flowing water provides the potential to generate power. However, slow flowing rivers in deltas can usually generate too little power for a system to become profitable. The innovation team is currently facilitating two systems (EQA and Lintur) that are being developed for application in the river (eg attached to groynes or bridges).

Innovations: Strengths and challenges

The selected innovations are all in different TRL stages, have different primary problem owners, range from highly technological to low technological, different unknowns, and different potentials. Table 1 compares the different innovations, and indicates where the potential and challenges are.

Table 1 The different innovations and their characteristics

	Flexible Groynes	**Herded Sheep**	**Bubble Barrier**	**Energy**
Interests for 'owner'	Testing + Showcase	Large, new client (more work)	Technological development + Showcase	Testing + Showcase
Barriers/ Challenges	Limited application in NL Effect on shipping unknown	Costs still significantly higher	Plastic still limited on the agenda; Focus on macro plastic	Profitability
Potential	Relatively pristine rivers (abroad)	Easily accessible areas for grazing	All rivers, canals in NL and abroad	All riverdeltas
Strengths	Permeability; easy repair	Biodiversity; cultural heritage	PR, widely acknowledged problem	Interesting for individual clients (eg. water authorities)
Steps to be taken	Develop SCBA	Track biodiversity change. Further develop business model	Reduce energy consumption; develop full chain	Design optimization

Role of the innovation team:

The added value the innovation team include:

- Have dedicated energy on innovations
- Facilitating innovation process
- Combined access to different types of parties with different resources, interests and capabilities.
- Enable innovation during a contract period, including testing locations

The take-off of an innovation

Critical for the innovations to really take off, are ownership and the development of SCBAs diversified for different stakeholders. Only when each stakeholder can see the benefits most relevant to him, they will be willing to invest in the innovation or become client. This does not all pivot around money issues. Gaining knowledge and more sustainable river management are high on the agenda. To achieve this, pilots are usually necessary, but even then, many questions remain or can only be answered in the long term. Scale is usually also an issue in taking off: the IJssel in itself cannot generate sufficient benefits for all innovations, but when taking other rivers, in NL and abroad into account, more opportunities arise. Lastly, it is often worth broadening the concept of the innovation (e.g. not only collecting waste or herding, but building a business chain) to increase the attractiveness or reduce primary costs.

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Integral development and new combinations of functions at stone factory terrains in the floodplains

Sara Eeman[a*], Jeroen Rijke[a,b], Jacomien den Boer[b]
[a]*Applied University Van Hall Larenstein, Larensteinselaan 26a, Velp*
[b]*Applied University HAN, Ruitenberglaan 26, Arnhem*

Keywords — adaptive strategy, floodplain development, co-creation

Introduction

In the floodplains of the Rhine branches in the Netherlands, a lot of so-called 'flood-free' areas can be found. These areas remain dry during extreme river discharges. They are either natural elevations or they have been elevated for e.g. industrial activities, mainly stone factories. In the province of Gelderland alone, over 80 of such areas exist, of which many have lost their function and start to deteriorate (e.g. Fig. 1). The province of Gelderland and Rijkswaterstaat have formally agreed to investigate the possibilities to redevelop these former stone factory terrains in order to achieve more space for the river and enhancing the spatial quality of the river region (BO-MIRT 2015).

In this project, different stakeholders combine their views on the redevelopment of stone factory areas: economy (KNB, for the ceramic industry), nature and maintenance (Staatsbosbeheer, owner of several areas), cultural heritage (RCE, government institution for cultural heritage) and three educational institutes (VHL and HAN Universities of Applied Sciences, MBO Helicon Velp).

Figure 1: Former stone factory near Maurik. © Jean Paul Opperman

Urgence

This research is closely related to the actual national policy developments of the Dutch Delta Program and associated river programs. Besides, regional programs aimed at increasing the spatial value of rivers in a wide social and natural context (e.g. WaalWeelde and River Climate Parc IJsselpoort) need perspectives for integral spatial development in the region of the Rhine branches in The Netherlands. Even though the program 'Room for the River' is completed, creation of more buffer zones during high water remains necessary given the expected effects of climate change and sea level rise. Areas where former stone factories have lost their function could form one of the solutions in this search for water buffering in multifunctional areas. The desirability of redevelopment is therefore currently explored by Rijkswaterstaat and Staatsbosbeheer, and actualisation of the Delta Program for the Rhine branches is in progress. Both the exploration and actualization identify lowering of the 'flood-free' areas as an option that increases flood safety around the river branches. However, methods to define the optimal (re)destination of such areas within the larger context of regional flood safety and spatial development (including ecology, economy and cultural heritage) do not currently exist.

Goal

The goal of this project is to provide development perspectives to policy makers, land owners and water managers responsible for the 'flood-free' areas in the Province of Gelderland. These perspectives enable making sustainable choices on the short, middle and long term with respect to integral re-destination and development of the areas. An integral approach is used to combine flood safety, natural values, economic perspectives and cultural heritage, which should result in a widely supported development strategy.

Besides, this project aims to evaluate the added value and restrictions of different decision tools (like serious games and interactive dashboards) in different parts of the decision process around integral spatial development, and to make these tools suitable for education purposes.

* Corresponding author
Email address: sara.eeman@hvhl.nl (Sara Eeman)

Research question

The question formulated by the parties involved is:

"How can directors, administrators and managers of the branches of the river Rhine be enabled to make considered choices for the development of 'flood-free' areas in the floodplains, aiming at long term integral solutions for both the local perspective and the regional coherence? "

This will be investigated in a wider perspective to test, evaluate and develop the methods used to answer this question, offering tools for different complex spatial issues.

Method

The research question is approached using the ABCD-method developed by The Natural Step (2011), illustrated in Fig. 2.

The phase plan is divided in four phases (ABCD) where each step is logically based on the previous step. The final phase will result in an adaptive strategy for sustainable development of the 'flood-free' areas of the Rhine branches region. The scientific character of this project has led to the extra step E: evaluation.

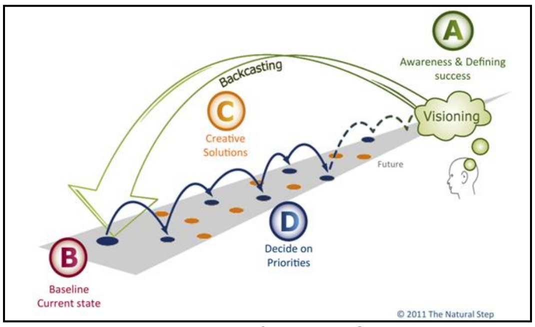

Figure 2: Visualisation of the ABCD-method that will be adopted during this research.

A. Visioning: stakeholders determine common goals and guiding principles for redevelopment.
B. Baseline current state: Gather data of the current status of the areas and identify the differences with the vision developed under A.
C. Creative solutions: joint identification of possible development pathways of the 'flood-free' areas and their effects on flood safety, nature, economy and cultural heritage. Pilot locations will be used to develop and apply decision support tools.
D. Decide on priorities: jointly decide on financial and political feasibility of different pathways followed by identification of the needed interventions and their sequence for the most feasible pathways.
E. Evaluation: joint evaluation of the approach followed and the decision tools used in steps C and D, as well as the suitability of these tools for educational purposes.

Deliverables

- An adaptive strategy for a coherent redevelopment of 'flood-free' areas.
- Connection between national (flood safety) and regional (spatial quality) issues and local developments (ecology, economy and cultural heritage). This connection strengthens and increases the networks between involved parties on the different levels.
- An extensive database with information about 'flood-free' areas in the Province of Gelderland, made available for public purposes.
- Decision tools suitable for policy makers, directors, managers and education.
- Business cases for multiple 'flood-free' areas, serving as examples for area development and as case material for education.
- Improved quality of the curriculum of the involved educational institutes through development of teachers on the aspect of integral development and strategy for river related spatial development.

The adaptive strategy will be developed by all parties involved in this research project. Representative parties from the region, like Spiegelgroep WaalWeelde and the Association of River Communities in the Netherlands will regularly be consulted as well. Research activities will partly be performed by students from the different educational institutes, under supervision of researchers. The organisations involved in this research as well as the students themselves profit from the learning space created in this way.

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Session IIIb

Advances in river modelling large-scale systems

Finding common ground: uncertainty analysis made practical through Bayesian regression of correlated output

Koen D. Berends[a,b,*], Jord J. Warmink[a], Suzanne J.M.H. Hulscher[a]
[a] *University of Twente, Department of Water Engineering and Management, Faculty of Engineering Technology, P.O. Box 217, 7500 AE, Enschede, the Netherlands*
[b] *Department of River Dynamics and Inland Water Transport, Deltares*

Keywords — uncertainty analysis, multifidelity analysis, impact analysis

Introduction

With an ever increasing use of physics-based and data-driven computer models to support management decisions, there is also an increasing need to be realistic about uncertainties in model predictions (Uusitalo et al., 2015). Environmental models are used for a variety of tasks, including forecasting the near future and predicting effects of changes to the environment. Usually there exists a margin of error between model output and measurements of objective reality, which is termed model accuracy or model predictive uncertainty. Yet for many applications measurements are unavailable and the accuracy is unknown. For some of these applications, an assumption can be made that the accuracy remains the same under ungauged conditions, and this assumption can to some extend be tested using validation schemes. For many other applications validation is either not possible or requires strong assumptions. Instead, uncertainty analysis through Monte Carlo simulation allows for quantification of the propagation of uncertainty in model parameters, input, and context to model output (Warmink et al., 2013). However, computational models of water systems tend to be too resource intensive for Monte Carlo analysis to be practically feasible. In this paper, we summarize results from two case studies in which we used an alternative approach to significantly reduce the computational time of Monte Carlo simulation.

Methods

In recent years significant effort has been put into reducing the cost of uncertainty analysis, including importance sampling, efficient Markov-Chain Monte Carlo step methods and data-based emulation. While these methods have been succesfully applied to many problems, they still rely on a large sample sizes.

Here, we use an alternative approach that requires two physics-based models, with the first serving as the emulator ("predictor model") of the second model ("response model"). We then infer the statistical relationship between these two models through (nonparametric) Bayesian regression. With the statistical relationship established, we are able to do uncertainty analysis of the response model output, given a Monte Carlo sample from the predictor model. Significant reduction in computational effort can be achieved if one predictor model can serve many response models (case 1), or if the predictor model is much faster than the response model (case 2).

The key condition for a model to serve as predictor to a second (response) model, is that they have "common ground": they must be able to (a) take the same input as the response model and (b) have correlated model output. One of the most straightforward ways to achieve this is for the predictor to be a lower-resolution version of the response model. This approach is known as multifidelity analysis in literature. However, the "common ground methodology" is not limited to this application. For example, we have found this approach to be highly effective when applied to predicting the effects of man-made interventions in the natural system (case 1).

This method has several advantages. First, it is non-invasive, so it can be applied to currently existing models. Second, we use physics-based models so there is no need for black-box data-based emulation. Finally, we can assess the accuracy of the estimation method through the probabilistic nature of the statistical relationship.

Case studies

Case study: Impact analysis

In a study of a one-dimensional river model Berends et al. (2017) demonstrated that a pre-intervention model can be used as the predictor for post-intervention models, even after significant changes to the floodplains. Depending on the number of interventions, this method reduced the computational time by 65% to over 90% compared to traditional Monte Carlo. Traditionally, the effect of interventions is visu-

*Corresponding author
Email address: k.d.berends@utwente.nl (Koen D. Berends)
URL: www.utwente.nl (Koen D. Berends)

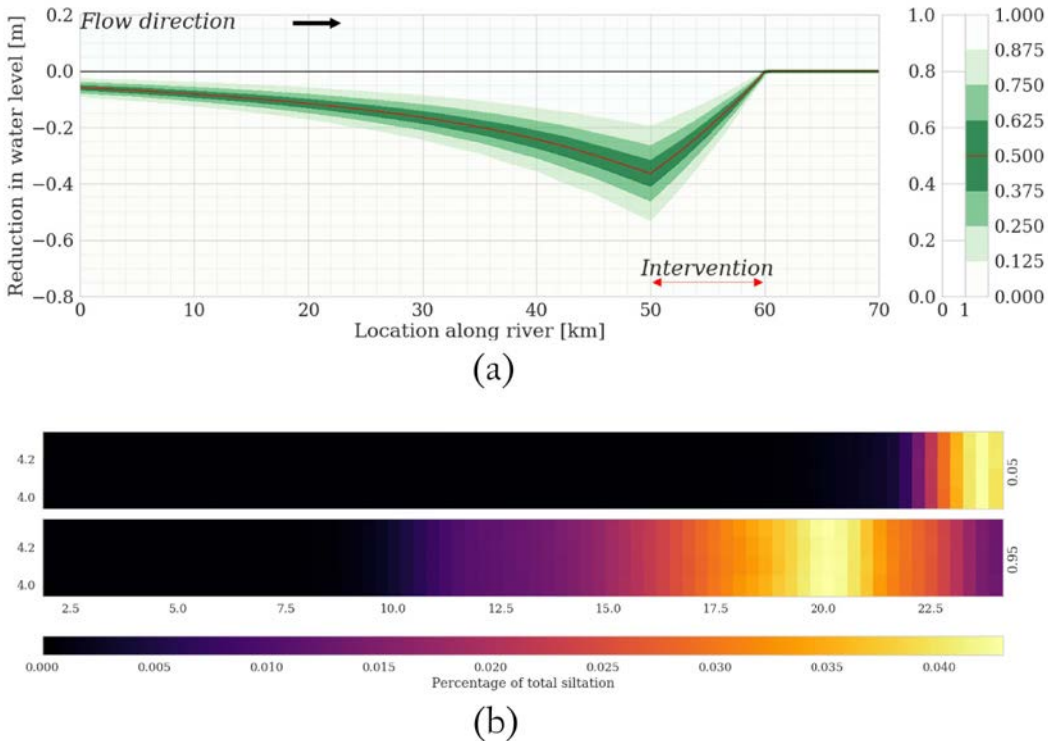

Figure 1: The upper panel (a) shows the probability of vegetation removal in the floodplains, with darker colors showing regions of higher probability. The lower panel (b) shows a 22 km long, 400 meter wide approach channel cut-out the bigger model. The upper fi ure shows siltation patterns at the 5th percentile, the lower figure at the 95th. Brighter colors denote more siltation.

alised as a backwater curve. By quantifying the uncertainty of system change, this backwater curve can be represented as a probability distribution instead (Fig. 1a).

Case study: Channel siltation

In a study of siltation of an approach channel to an estuary port, Berends et al. (2018) used models of varying resolution to assess the expected daily siltation (Fig. 1b). Here, a low-resolution model serves as a predictor to a high-resolution model for a reduction in computational time of almost 90%. We found the siltation probability distribution to be highly skewed, with the mean siltation up to ten times higher than the median siltation. Analysis of the spatial distribution of siltation show varying siltation patterns at different probability levels. These patterns were linked to different processes affecting siltation.

Outlook

The approach outlined in this paper has the potential to reduce the required computational time of an uncertainty analysis. Its practical application was demonstrated through two case studies. Currently we are applying this method in a large-scale study to intervention effect uncertainty on the Dutch River Waal, taking into account up to fourty sources of uncertainty in detailed two-dimensional river models.

Acknowledgements

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From time series to probability density functions at the boundaries in morphodynamic modelling

Liselot Arkesteijn[a,*], Robert Jan Labeur[a], Astrid Blom[a]
[a] *Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands.*

Keywords — numerical modelling, hydrograph schematization, boundary conditions

Introduction

Potential consequences of climate change are the amplification of extreme discharge events and an overall increase in flow rates. Their effects on river future morphodynamic behaviour (e.g., 100 years) has been assessed through numerical simulation of different climate scenarios (e.g., *Yossef et al.*, 2012; *Guerrero et al.*, 2013). Performing one simulation for a large river system is computationally expensive and hence studying multiple climate scenarios requires significant computational resources. Moreover, if one properly wants to account for the statistical variability of the flow a Monte Carlo procedure should be performed that requires even more simulations and computation time (e.g., *van Vuren et al.*, 2015).

To reduce computation times of long simulations the current practice of modelling river morphodynamic behaviour includes the use of a morphodynamic factor, combined with the compression of the time-series boundary conditions to have a realistic duration of flood events. Moreover, the discharge sequence is usually transformed into a stepwise hydrograph that is restarted at every change in discharge level to avoid over-excessive wave dampening (e.g., *Yossef et al.*, 2008). However, this means that we are manipulating the boundary conditions whereas the simulations are performed with the goal to study the effect of future trends in the boundary conditions.

In addition, other types of hydrograph schematization are frequently performed that may lead to too smooth results: by taking either a constant discharge (e.g., *Guerrero et al.*, 2013) or a yearly repeated hydrograph (e.g., *Viparelli et al.*, 2011; *Yossef et al.*, 2012), the natural variability in the flow rates is underpredicted, leading to an underestimation of bed level fluctuations related to flow variability (*Arkesteijn et al.*, 2018). A smoothening of the results generally increases the stability of the numerical simulation, yet the drawback is that only insight into the trend of morphodynamic adjustment is obtained.

Here we exploit the numerical benefits of commonly applied hydrograph schematization techniques by defining a new modelling strategy that considers the joint probability distribution of flow rates and downstream water surface elevation as hydrodynamic boundary conditions, rather than their time series. In comparison to existing methods this means that we assume an infinitely fast alternation of the flow rates (i.e., infinite compression), and an infinitely short cycle length, such that the entire hydrograph is effective at each time step. The proposed implementation in terms of probability distributions yields an increase in numerical efficiency.

Method

We use a backwater-Exner numerical model that is solved in a decoupled manner. Rather than having one set of boundary conditions at a specific time, we impose a discretized range of possible boundary conditions over time simultaneously. The hydrodynamic state for all these boundary conditions can be computed simultaneously (in parallel). In this way we compute an ensemble of hydrodynamic states along the entire profile. After that, applying a sediment transport relation yields an ensemble of sediment transport rates.

Next, given the joint probability of each set of boundary conditions, the expected average sediment transport rates can be computed. Given the average upstream sediment supply and applying a morphodynamic numerical model based on sediment mass conservation, the bed level at the next time level is computed. This scheme is repeated in time until the end of the simulation has been reached.

The total computational costs per time step are larger than for the normal modelling strategy since multiple hydrodynamic states are considered at each time step. Yet, the updates of the ensemble of flow states can be computed in parallel as they do not depend on each other. Eventually, this therefore leads to only a small increase of required cpu time per time step.

*Corresponding author
Email address: e.c.m.m.arkesteijn@tudelft.nl (Liselot Arkesteijn)

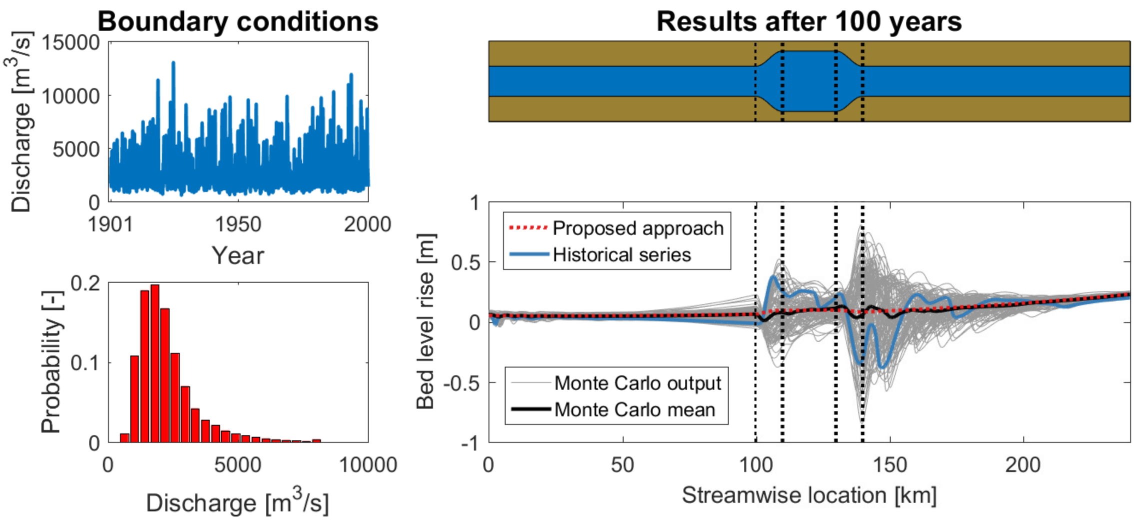

Figure 1: Validation results for a schematic test case. The left panels illustrate the historical time series at Lobith and its discrete probabilities. The right side shows the results after 100 years. The grey area shows 100 different Monte Carlo realizations, whose mean is represented in black. The historical series, imposed for the future prediction is indicated in blue, and the result of the proposed approach in red.

Results and discussion

We test the model on a 1D river section with a local widening. We consider the historical record of the Rhine at Lobith between 1901-2000 (Fig. 1) and discretize it into 20 probabilities as boundary condition for the proposed approach. We simulate 100 years of a sea-level rise of 3mm/year, starting from an equilibrium state under variable flow (*Arkesteijn et al.*, 2018). At the downstream of the reach the water surface elevation at a particular moment is the sum of the initial bed level, normal flow depth given the current flow rate, and the net change in sea-level rise since the start of the simulation.

The results are compared to the Monte Carlo output space of a numerical model that considers time-series at the upstream end. A resampling technique to reorder the different calender years was used to construct 100 realizations. The historical time series is one of these realisations. Fig. 1 shows the predicted state after 100 years for all models. The trend found by the proposed modelling strategy (red line) shows good agreement with the mean of the Monte Carlo output space (black line), yet the variability of the Monte Carlo members cannot be reproduced by the proposed approach.

The maximum time step is restricted by a CFL condition on the bed level update. In the proposed strategy the CFL number is an average of the CFL number during all flow rates, which is generally equal or larger than the CFL number of a normal simulation using time-series. For this specific test case the proposed strategy allows for a factor 3 increase in time step. Additional research to assess the numerical performance in other cases is ongoing.

Acknowledgements

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The influence of the vegetation structure on the water flow through the Noordwaard (Brabant, The Netherlands)

Derk Jan Stobbelaar[a], Jack C.M. Schoenmakers[a]

[a] *University of applied sciences Van Hall Larenstein, P.O. box 9001, 6880 GB Velp, The Netherlands*

Keywords – Remote sensing, drones, vegetation classification, surface modelling (SOBEK), flood prevention

Multiple objectives in the Noordwaard

De Noordwaard is a recently established high-water flow area located near the Brabantse Biesbosch (Rijkswaterstaat, w.d., figure 1). In this area, dykes have been adapted and creeks have been dug, some of which are connected to the Hollands Diep and are subject to tidal influence. A large part of the agricultural land has been transformed into a flow area with nature as a secondary function and is partly grazed by water buffaloes, koniks, Scottish highlanders and sheep. In order to guarantee the flow of the area at high water on the Merwede, additional mowing management is carried out in addition to grazing in autumn. To this end, all vegetation is reset to the maximum height that has been set as a standard for safety reasons. This mowing is expensive and sometimes contrary to the nature objective in the area, where a great diversity in structures is sought.

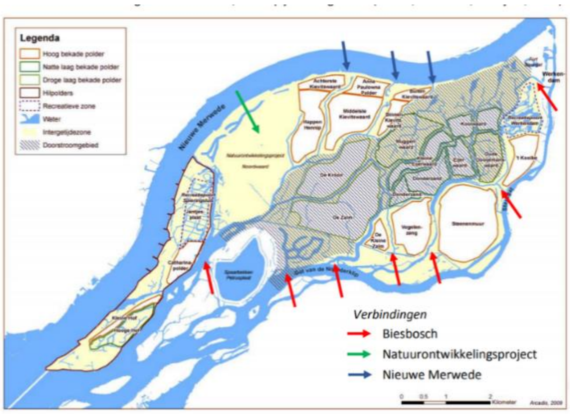

Figure 1: High water overflow area Noordwaard

The question now is to what extent that mowing management is necessary to ensure the flow. To answer this question, two studies were carried out: one to the flow of the area using the SOBEK model and one to the best remote sensing technique to be able to measure the vegetation structure by means of drone images.

Modelling water levels with SOBEK

Rijkswaterstaat has defined a zero situation for the Noorwaard in which the vegetation is divided into vegetation structure types. To this end, the WAQUA model was used (Project Office Noordwaard, Rijkswaterstaat Room for the River, 2010). Scenarios with a lower water level than the baseline situation, deliver more reduction than required and thus meet the safety requirement. From the zero situation, with the discharge-storm combination that is representative of the normative water level, a maximum water level of 5.16 meters + NAP follows at Gorinchem; that water level is leading. Without Noordwaard a water level of 5.59 meters + NAP is reached.

The expected water level at Gorinchem in the current situation was determined on the basis of the altitude and the vegetation present in 2016. The data were processed with the model SOBEK1D2D (Deltares, w.d.), that was first calibrated with the WAQAU model. However, the SOBEK model is a much easier to use model. The current situation, with the discharge-storm combination that is representative of the normative water level, gives 0.05 meter water level reduction compared to the zero situation. A maximum water level of 5.11 meters + NAP at Gorinchem has been achieved. The influence of different vegetation structure types in the Noordwaard was determined on the basis of the sensitivity analysis. This sensitivity analysis was performed by applying different

[1] Corresponding author
Email address DerkJan.Stobbelaar@hvhl.nl (Derk Jan Stobbelaar)

scenarios for the development of the roughness. From the calculations it follows that the situation from 2016 amply meets the flow requirement and that there is therefore less need to mow than is currently the case.

Tracking vegetation development via Remote sensing techniques

Before the start of this study, the vegetation structure in the Noordwaard was mapped using manual interpretation of RGB aerial photographs. This remote sensing technique does not deliver the desired result as classification of vegetation with these type of images has its limitations: it lacks the vegetation reflection in the near infrared part of the light spectrum. The aim of this research was therefore to find a better remote sensing technique to monitor the vegetation structure development in the Noordwaard. To this end, images were collected with a DJI Phantom 4 drone, equipped with a Sequoia multispectral camera. Based on literature (e.g. Dandois and Ellis, 2010) and interviews, 24 techniques were selected to analyze the resulting images. These 24 techniques have been tested in the Noordwaard and validated on the basis of a validation set. The results of the two best techniques have been compared with validation results of vegetation structure maps created by Bureau Waardenburg in 2016. Finally, an interview with Skeye BV has determined whether the best technique can be scaled up to application in the entire study area.

The results show that the remote sensing recording technique, consisting of the band combination Green, Red, Near InfraRed, Red Edge and a calculated digital terrain model with a resolution of 25cm, classified according to the Maximum Likelihood Classification, is the best technique. Vegetation structure classes that have a lot of resistance, such as reed and cattail, can still not be clearly distinguished. If aerial photographs are taken with good weather conditions and later in the growing season, a more reliable result could be achieved. But all in all, this technique gives such insight into the vegetation that it can be reliably monitored how the vegetation structure develops, what can be translated into new values for the vegetation rift. The drone technology still has limitations in terms of flight range, which can be accommodated by mounting the camera on another type of UAV.

Towards an integrated development of the Noordwaard

The SOBEK project has shown that in the current situation the vegetation in the Noordwaard is no obstacle to reaching the desired water level at Gorinchem. The remote sensing project has provided the technology to quickly and accurately measure the vegetation structure as it develops in the area. The results of this measurement are input for the SOBEK model. These two techniques together provide the opportunity to optimize the nature value within the conditions of flood risk management; more vegetation development is possible than Rijkswaterstaat initially thought possible. This is a building block for integral management where multiple goals can be served (Stobbelaar et al., in press).

A next step will be to find out how the vegetation development can be controlled with the help of the large grazers in the area so that the vegetation structure meets the requirements of water safety and nature quality.

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Numerical River Laboratory: platform for long term development of river systems

Aukje Spruyt[a], Ralph Schielen[b], Bert Jagers[a], Willem Ottevanger[a], Jan Noort[a], Amgad Omer[a], Kees Sloff[a], Andries Paarlberg[c], Carolien Wegman[c], Filip Schuurman[d], Stef Boersen[d], Marcela Busnelli[d]
[a]Deltares, P.O. Box 177, 2600 MH, Delft, the Netherlands
[b]Rijkswaterstaat, Postbus 2232, 3500GE, Utrecht, the Netherlands
[c]HKV Consultants, Postbus 2120, 8203 AC, Lelystad, the Netherlands
[d]Royal HaskoningDHV, Postbus 1132, 3800 BC, Amersfoort, the Netherlands

Keywords — Long term river morphology, platform, community, D-Flow FM

Introduction

The Dutch rivers have a clear distinction between navigation channel and the floodplains and are almost completely confined within levees and groynes. However, this does not mean that the river bed does not change anymore. During high discharge the bed of the navigation channel rapidly changes and part of the sediment is deposited in the floodplains. Adaptation to river training works and Room for the River projects takes place on the scale of years to decades. Other changes have an even longer time scale, such as changes in sediment input from upstream, adaptation to sea level rise, and changes in discharge regime due to climate change.

The challenge is to guarantee that the Dutch river system remains stable for the next 50-150 years. Not only for safety against flooding, but also navigation and nature have to profit in an optimal way. Therefore, Rijkswaterstaat has initiated a research program on lowland rivers within the program National Knowledge and Innovation Program on Water and Climate (NKWK) which focusses on the long term development of rivers. The goal of this program is to gain knowledge about the behaviour of rivers that will lead to sustainable measures for the future, which will be applied to the Dutch rivers and abroad. The new concept 'Building with Nature' might help in achieving this.

The NKWK program requires both numerical models that are able to accurately predict long term morphological changes as well as the ability to apply new research results for policy making. Therefore the Numerical River Laboratory ('RiverLab') is set up as a platform where these numerical models and the accompanying software can be shared and further developed within the river community.

* Corresponding author
Email address: aukje.spruyt@deltares.nl (Aukje Spruyt)

Software functionality

The RiverLab focusses on large spatial scales and long term morphology. With these requirements a 1D modelling approach, with 2D and 3D parts where needed, appears to be the best choice. For this purpose, the RiverLab utilizes the Delft3D FM Software Suite that integrates these multi-dimensional approaches in one package. The key component of Delft3D FM is the D-Flow Flexible Mesh (D-Flow FM) engine for hydrodynamical and morphological simulations on unstructured grids in 1D-2D-3D. Until recently, only the 2D (morphological) functionality was fully validated and supported. Within NKWK, also basic 1D (morphological) functionality is added and validated. It is now possible to import existing 1D SOBEK3-models within D-Flow FM.

The Delft3D FM Software Suite is open source, which means that it is freely available under AGPL-licence. Separate branches for dedicated research can be generated and proven methods can be merged to the main version, such that they become available to all users.

The advantage of using one integrated software suite is that functionalities developed by other parties, such as universities or engineering companies, can be easily used and combined (e.g. new numerical schemes, friction formulations due to dune evolution, other processes such as water quality, bank erosion and waves). It is also possible to add functionalities via Python-scripting, without having to change the code itself. This allows researchers in the NKWK program (as well as other researchers) to adjust and extend the tools to suit their needs.

Numerical (pilot) models

The RiverLab not only provides the software for evaluating long-term morphological developments, but also aims to provide the model(schematisation) for the River Rhine branches such that they can be used for studies in the Dutch rivers. Other rivers may be added in the future.

Within the RiverLab, also several 1D standard test cases are available that are used to test all the software functionalities (hydrodynamic and morphological). These test cases are preferably based on analytical solutions or a comparison with available 2D results and can be used by the research community to test new functionalities that are implemented. An example of the results for a moving shoal is shown in Fig. 1, where the results for D-Flow FM 1D are compared with SOBEK3.

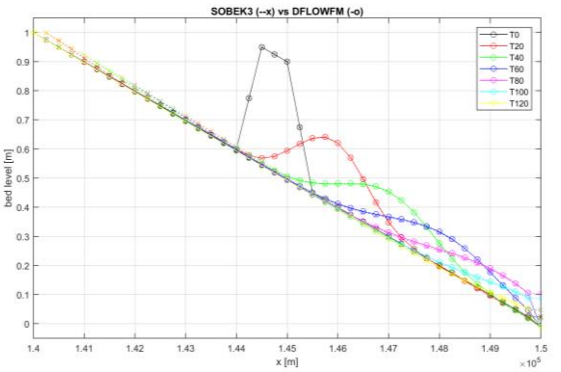

Figure 1. Bed level at different time steps for a moving shoal with Engelund-Hanssen transport formulation (o = D-Flow FM, x = SOBEK3).

In the first phase of the RiverLab project a pilot community model of the Waal is set up. This model is based on a recent hydrodynamic 1D (SOBEK3)-model (sobek-rijn-j11_5-v1) of Rijkswaterstaat (see Fig. 2). The SOBEK3-model is converted to D-Flow FM 1D and morphological information and boundary conditions are added based on the SOBEK-RE model that was used in an earlier pilot within NKWK (Sloff, 2006; Giri and Spruyt, 2017).

Platform and community

The ambition is to create a community of users, contributors and river managers (extending beyond the research community) that is stimulated to utilise the RiverLab as a communication and discussion platform.
To facilitate this, a web-based infrastructure is set up from which you can download the numerical models and software and which can be used as discussion platform. Third parties are allowed to download and adapt the RiverLab models for own use. Preferably, new versions of the models are uploaded again to this website for use by other parties. Third parties may develop a version of the model for own purposes. It should then be made publicly available according to conditions of the Creative Commons Attribution-ShareAlike 4.0 International License.

Figure 2. Structure of the 1D-model of the Rhine branches.

Future work

The Delft3D FM Software Suite is constantly improved and new features become available regularly. The 1D-functionality within D-Flow FM will be further developed and coupling with 2D (and even 3D) models will be made possible.
Universities, knowledge institutes and engineering companies are encouraged to test their new ideas within the RiverLab, both by improving and extending the models as well as adding new functionalities to the software.

Acknowledgments

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Large-scale uncertainties in river water levels

Matthijs R.A. Gensen [a], Jord J. Warmink [a], Suzanne J.M.H. Hulscher [a]
[a]Department of Water Engineering and Management, University of Twente, P.O. Box 217, 7500 AE, Enschede, the Netherlands

Keywords — River water levels, uncertainty propagation

Introduction

1430 kilometers of dikes protect the Netherlands from potential flooding from the Dutch rivers. The main dynamic load on these dikes are river water levels. The nearly completed Room for the River project consisted of 34 river interventions to reduce the river water levels at critical locations. Their effects were studied deterministically despite inherent uncertainties.

In 2014 the Dutch Flood Protection program adopted a new probabilistic risk approach in the design and assessment of the primary flood protections. This approach, which was implemented in 2017, marks the shift from designing and assessing according to exceedance probabilities towards probabilities of flooding. In this light not only the extreme water levels play a role, also lower water levels with larger probabilities of occurrence become important. These water levels may for instance still cause geotechnical failure mechanisms.

The new risk approach intends to explicitly quantify uncertainties. This can reduce the need for too conservative design and assessment calculations. Several studies have identified, quantified and reduced sources of uncertainty for river water levels (e.g. Warmink et al., 2013, Hegnauer et al., 2014). However, research on the propagation of multiple uncertainty sources through the Dutch river Rhine has not been conducted.

These factors combined call for research on uncertainties on ranges of river water levels for the Dutch river system. The intended results of the research are visualized in Figure 1.

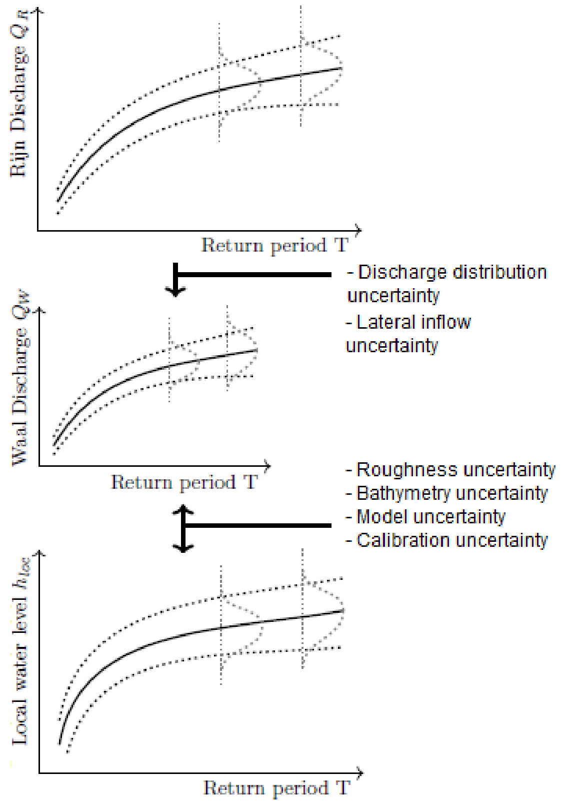

Figure 1: Visualization of the goal; from flood frequency curve on the upper Rhine to return periods of water levels locally including the various uncertainty sources

Uncertainty sources

Many sources of uncertainties have been identified in the scope of river water level modelling (e.g. Warmink et al., 2011). Two dominant sources are roughness uncertainty and discharge uncertainty. The roughness uncertainty comprises of uncertainties from both the main channel (Van Vuren et al., 2015) as the floodplain (Warmink et al., 2013).

The discharge uncertainty consists of statistical uncertainty at the boundary of the system as well as uncertainties related to the discharge distribution at bifurcation points. The discharge distribution at the Dutch bifurcations of the river Rhine has been fixed by policy. However, it is uncertain whether the natural system follows this distribution for a range of discharges. Furthermore, control structures were constructed as part of the Room for the River project. The influence of these structures on the discharge distribution is not fully known.

Methods

This PhD project intends to quantify the uncertainty sources for the river Rhine branches and to assess the effect of the uncertainties on river water levels. A key challenge will be to estimate the prior distributions of the input factors. Literature review and expert elicitation are conducted as a basis for these estimates. In this step a

* Corresponding author
Email address: m.r.a.gensen@utwente.nl
(Matthijs Gensen)

strong link exists with earlier STW-projects (e.g. VICI-RoughWater and RiverCare).

Subsequently, the preliminary plan is to apply a 1D numerical river model to get a rough quantification of the effects of uncertainty sources on the water levels via a Global Sensitivity Analysis (Hall et al., 2009). Subsequently, a 2D model is employed to evaluate the uncertainties in more detail with a strong focus on the bifurcation points. State-of-the-art Monte Carlo techniques and uncertainty quantification methods (Di Baldassare et al., 2010) will be applied during the research.

Acknowledgements

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Discharge and location dependency of calibrated main channel roughness: case study on the River Waal

B.C.A. Domhof[a,*], K.D. Berends[a,b], A. Spruyt[b], J.J. Warmink[a], S.J.M.H. Hulscher[a]
[a] *University of Twente, Department of Water Engineering and Management, Faculty of Engineering Technology, P.O. Box 217, 7500 AE, Enschede, the Netherlands*
[b] *Deltares, P.O. Box 177, 2600 MH Delft, The Netherlands*

Introduction

Hydrodynamic river models are used to predict water levels along the river and support decision making in river management. Therefore, the model predictions need to be sufficiently accurate. To increase the accuracy of the predictions, hydrodynamic river models are calibrated and validated. Often the hydraulic roughness coefficient is calibrated because it is the most uncertain parameter in hydrodynamic river models (Pappenberger et al., 2005).

The physical bed roughness can vary along the longitudinal direction of the river due to differences in bed sediment. Moreover, as discharge increases, river dunes grow leading to an increasing bed roughness (Julien et al., 2002). Therefore, it is hypothesized that the calibrated main channel hydraulic roughness is mostly sensitive to the discharge and location in longitudinal direction of the river. The calibration study of Warmink et al. (2007) confirms this hypothesis but does not explain why the calibrated roughness varies.

Our objective is to explain why variations in the calibrated roughness parameter occur and whether its value depends on the location or discharge used for calibration. We use a case study on the River Waal in The Netherlands.

Method

In this study we calibrated the Manning coefficient of the main channel roughness of the 1D Waal SOBEK 3 model for the winter of 1995. The location dependency is investigated using a varying number of roughness trajectories of roughly equal length for a bankfull discharge peak and a flood stage discharge peak. A roughness trajectory is defined as a river section between two water level observation stations with a uniform roughness. The discharge dependency is investigated using a varying number of discharge levels and five roughness trajectories. A discharge level is defined as the discharge for which the roughness is calibrated. A window around the discharge level of the peaks for the location dependency was applied to limit the calibration time period. Calibration is performed automatically using OpenDA (OpenDA, 2015) with a weighted non-linear least squares objective function and the DuD optimization algorithm (Ralston and Jennricht, 1978). Validation using the calibrated roughness values is performed with the 1D Waal models of the winters of 1993 and 2011 using a slightly adapted RMSE criterion (Domhof et al., 2017). This criterion accounts for the more frequent low and less frequent high water levels such that each water level range is equally important.

Results: calibrated roughness

The calibrated roughness values for the location dependency case show little variation along the river length. The calibrated roughness values for the discharge dependency show an overall roughness increases with increasing discharge (Fig. 1). As more discharge levels are added, a roughness decrease around 4000 m^3/s and a roughness peak around 6000 m^3/s appear. The decrease is a result of the transition from bankfull to flood stage and the peak is a result of floodplain compartmentation.

Results: validation

Comparison of the RMSE for the location dependency (Fig. 2) and discharge dependency (Fig. 3) show that the discharge dependent cases overall has a lower RMSE than the location dependent cases. Therefore, the calibrated roughness is more sensitive to discharge than location. For the location dependent cases no clear mininimum RMSE is found. For the discharge dependent cases a minimum RMSE is found at six discharge levels, though the differences in RMSE between other number of discharge levels is 9

Discussion

In this study we also calibrated the 1995 IJssel and the 2011 Waal model. The resulting calibrated roughness functions are similar to the ones presented in this abstract. However, the inaccurate description of flow in sharp bends in the IJssel leads to decreasing cali-

*Corresponding author
Email address: boyan.domhof@gmail.com (B.C.A. Domhof)

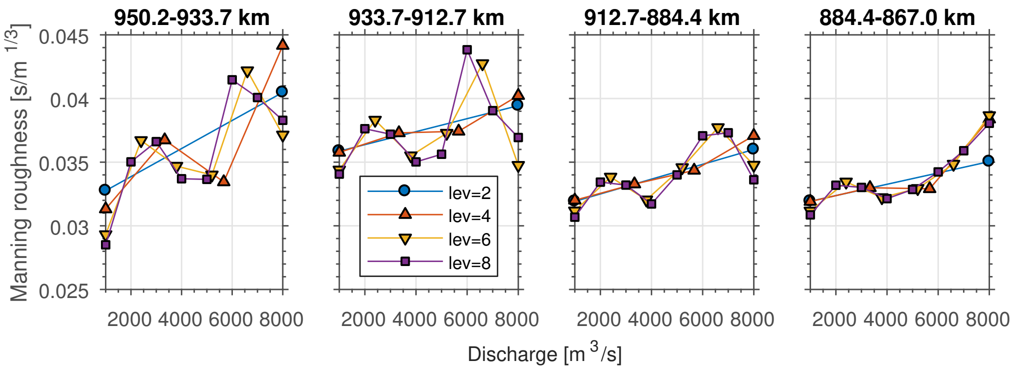

Figure 1: Calibrated roughness-discharge functions for varying number of discharge levels. From right to left plots show the functions from upstream to downstream sections between measurement stations. The most downstream section is not shown, because results are largely affected by the downstream boundary condition

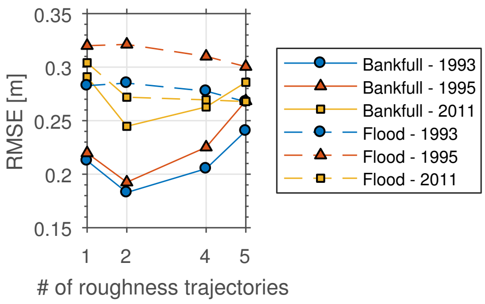

Figure 2: Validation of location dependent calibrations

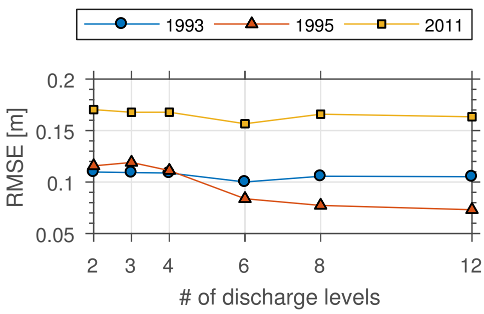

Figure 3: Validation of discharge dependent calibrations

brated roughness for increasing discharge. Additionally, a calibration of the 2D 1995 Waal model is performed. The resulting calibrated roughness-discharge functions lack the effect of the transition from bankfull to flood stage and the floodplain compartmentation. Therefore, these functions more closely resemble the expected increasing roughness due to river dune growth.

Conclusion

We conclude that in the calibration of 1D hydrodynamic river models the transition from bankfull to flood stage and floodplain compartmentation have a large effect on the calibrated main channel roughness. Furthermore, the calibrated roughness values and the validation show that calibrated main channel roughness is mostly sensitive to discharge compared to location. The calibrated roughness increases overall with increasing discharge as expected from river dune growth.

Acknowledgements

This research is part of the RiverCare research programme, supported by the Dutch Technology Foundation TTW (project-number 13520), which is part of the Netherlands Organisation for Scientic Research (NWO), and which is partly funded by the Ministry of Economic Affairs under grant number P12-14 (Perspective Programme). We would also like to thank Rijkswaterstaat for providing the models and observation data.

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Flood patterns in the Old IJssel Valley

Anouk Bomers[a*], Ralph M. J. Schielen[a,b], Suzanne J. M. H. Hulscher[a]
[a] *University of Twente, Department of Water Engineering and Management, Faculty of Engineering Technology, P.O. Box 217, 7500 AE, Enschede, the Netherlands*
[b] *Ministry of Infrastructure and Water Management-Rijkswaterstaat, Arnhem, the Netherlands*

Keywords — dike breaches, inundations, discharge partioning

Introduction

To protect the Dutch hinterland from flooding, safety levels for flood defences have been established. These safety levels are based on a statistical analysis of the return period of discharges. Throughout Europe, flood frequency analyses are generally used to estimate discharges associated with different return periods (Benito et al., 2004).

In the Netherlands, it is assumed that approximately 1/3 of the design discharge at Lobith flows towards the river Waal, 2/9 towards the river Nederrijn and 1/9 towards the river IJssel. This discharge partitioning is used to determine the design discharges and hence flood protection measures along the Dutch river Rhine branches. Until 2015, a design discharge of 16.000 m^3/s at Lobith, corresponding with a return time of 1:1250 years, was the standard. After the introduction of a system of new safety standards (Dutch Ministry of Infrastructure and the Environment & Ministry of Economic Affairs, 2014) the concept of a single design discharge has changed and multiple design discharges should be taken into account, corresponding to the multiple downstream safety levels. During the determination of the design discharges, the consequences of flow patterns caused by dike breaches or overtopping are not included. This is an important prerequisite which seems obvious from protection point of view (dike breaches are unwanted and need to be provided) However as a result of the low lying area of the Old IJssel Valley, flow patterns in the embanked areas may evolve in case of a dike breach which can consequently change the discharge portioning along the Dutch river branches significantly (Figure 1). This may lead to substantially more discharge to one of the branches (and obviously to less discharge to another branch) and hence to increase (decrease) of the potential risks.

Preliminary runs with a numerical model of the found that water can potentially flow around the higher grounds of the Montferland towards the Rijnstrangen area (Figure 1). For this particular test run, the discharge wave near the city of Emmerich decreased from 11,984 to 9,531 m^3/s. The flow pattern through the Old IJssel Valley was predominant such that almost all water that left the river Rhine flowed towards the river IJssel, resulting in great inundations along this river branch.

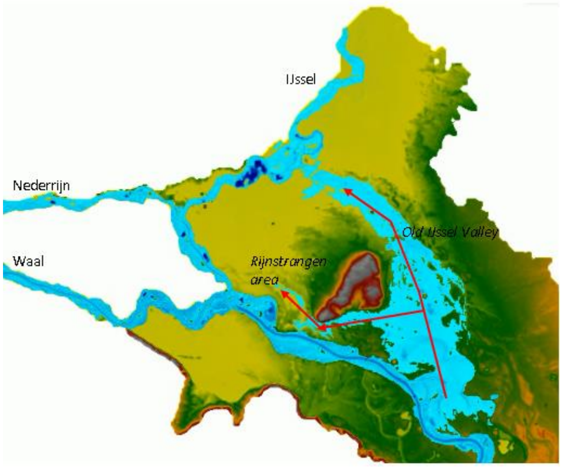

Figure 1. Flow patterns through the Old IJssel Valley as a result of a dike breach near the city of Emmerich (DE)

Method

In this study, the effect of multiple dike breaches along the river Rhine upstream of Lobith on discharge partitioning is investigated. Particularly, the maximum discharge at the river IJssel in case of dike breaches will be compared with the design discharges for which the dimensions of the flood protection measures were determined.

A coupled1D-2D model constructed in HEC-RAS will be used to perform the hydraulic simulation runs. In this model, the summer bed and its floodplains are schematized with one dimensional profiles whereas the embanked areas are discretized by a two dimensional grid (Figure 2). Both the 1D as 2D profiles are based on a high-resolution geographical database. A coupling between the 1D profiles and 2D grid cells is made with the use of a lateral structure, corresponding with the dimensions of the dikes in this study. A coupled 1D-2D model is preferred above a fully 2D model because of the relatively short

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* Corresponding author
Email address: a.bomers@utwente.nl (Anouk Bomers)
URL: https://www.utwente.nl/en/et/wem/staff/bomers/ (Anouk Bomers)

computation time while model accuracy is still sufficient. Since computation time is relatively low, it is possible to simulate many scenarios of potential dike breaches.

A Monte Carlo analysis framework is set up in which the location and dimensions of the dike breach are randomly modelled. Typical properties of a dike breach that are included in the analysis are dike breach duration, total dike breach width and time of dike breach. Up till now, it is commonly assumed that a dike breach occurs at maximum water depth or when a water depth threshold is exceeded for a certain period of time. We will randomly sample the starting time of the dike breach such that a broad spectrum of potential scenarios is included in the analysis.

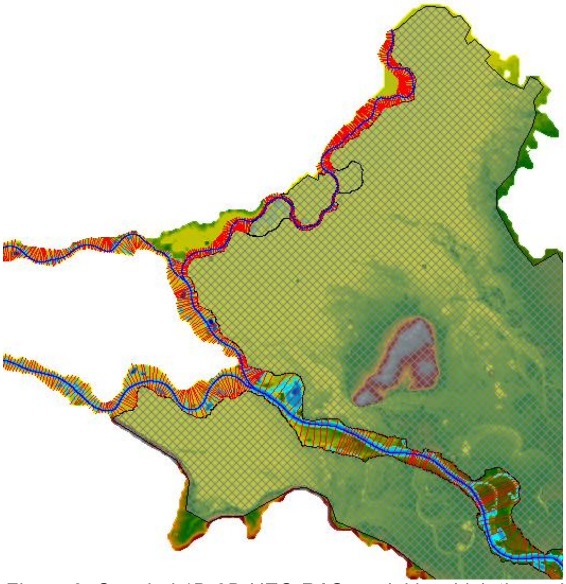

Figure 2. Coupled 1D-2D HEC-RAS model in which the red lines represent the 1D cross sections and the embanked areas are discretized by a 2D grid

Results

The Monte Carlo analysis gives insight in the sensitivity of dike breach location and dimensions on the maximum discharge at the river IJssel as a result of overland flow through the Old IJssel Valley. With this information it is possible to determine which location and under which conditions a dike breach in Germany will result in major changes of the discharge portioning along the Dutch river Rhine branches. In particular, the runs give insight in the most critical dike breach locations for which large areas will be inundated and great problems along the river IJssel evolve. Also the sensitivity of dike breach timing (e.g. at maximum water level, when certain water level threshold is exceeded) on inundation extend can be evaluated.

Besides, the model runs will show which embanked areas are flood prone in case of dike breaches. This information can be highly valuable for future design of flood measures and evacuation plans.

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Flood modelling along the Dutch and German Rhine with extreme discharge waves by SOBEK1D2D

Asako Fujisaki[a], Anke Becker[a]
[a]*Deltares River Dynamics and Inland Shipping, P.O. Box 177 2600 MH Delft, The Netherlands*

Keywords — German Rhine, SOBEK3, 1D2D, Flexible Mesh, Dike breaching, GRADE

Introduction

GRADE Rhine (Generator for Rainfall and Discharge Extremes) is an integrated hydrologic and hydrodynamic model which covers the Rhine river basin in Germany. It derives the discharge into the Dutch Rhine at Lobith (the border between the Dutch and German Rhine), and is applied to the risk assessment in the Dutch rivers. Up to now, a purely 1D hydrodynamic model (in Sobek-RE) was used, in which dike overtopping and breaching was modelled by means of a complex set of lateral retention options, calibrated on results of a 2D model. Now, a new approach for risk assessment for primary dikes is introduced which requires the simulation of very extreme discharges (up to 26,000m^3/s at Lobith), and the purely 1D model is not considered appropriate anymore. Therefore, it was decided to create a new SOBEK3 model which replaces the hydrodynamic part of GRADE and fulfils the requirements for the new assessment. The new model includes dike breaching at 9 specified locations.

Model setup

The new model consists of 1D SOBEK branches representing the river and its flood plains, and a 2D D-FLOW FM (Flexible Mesh) part representing the hinterland, and the coupling is known as SOBEK 1D2D. The interface between 1D and 2D is the primary dike (river embankment) along the Rhine. Each 2D grid cell at the embankment boundary is automatically linked to the nearest 1D computational point; however, several 1D2D links are manually modified such as at river ports where the nearest algorithm is physically not appropriate. When the water level at the 1D computational point exceeds the embankment height imposed at the link, the water overtops to the 2D grid, and vice versa.

SOBEK network

The extent of the 1D model is up to Andernach (rkm 614) including tributaries Sieg, Ruhr and Lippe, and the downstream boundaries are at Werkendam, Krimpen aan de Lek, Keteldiep and Kattendiep. The German part of the 1D river network is imported from a SOBEK2 model built by the German Federal Institute of Hydrology (BfG). The computational length is 200m, and cross-sections are allocated at each computational point. It is merged to the standard 2015 Dutch Rhine river model with 500m grid length. There are 13 weirs/gates operated by RTC (real time control) based on the water level and/or discharge.

D-FLOW FM

The 2D part is located behind the primary dike (embankment) and is constructed by a triangular mesh. The majority of the mesh size is 200m, matching the 1D computational grid, but the size along the Dutch Rhine is 500m due to the 1D Dutch computational lengths. There is no infiltration or evapotranspiration in the model.

Embankments

Embankment heights are derived from high resolution DEMs and complemented with information about (mobile) flood protection walls from local authorities.

Boundary conditions

The boundary conditions and the lateral discharges on the 1D part of the model are provided by the hydrology model of GRADE. The most extreme discharge wave from GRADE consists of two remarkable peaks at approximately 17,000m^3/s and 25,000m^3/s (fig. 1). Qh relationships are given at all downstream boundaries.

The 2D model boundaries are at primary dikes. At the outer edge, the model extends to high grounds that are never flooded.

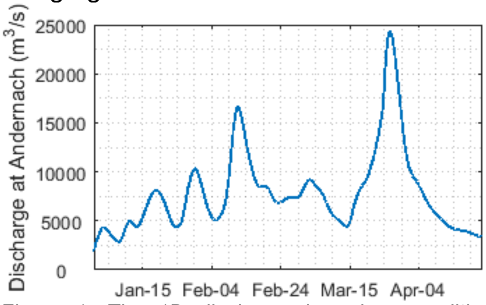

Figure 1: The 1D discharge boundary condition at Andernach. There are 3 other inflow discharge boundaries at German side branches; the total discharge almost adds up to 26,000m^3/s at the peak.

* Corresponding author
Email address: Asako.Fujisaki@deltares.nl (Fujisaki)

Dike Breaching

The dike failure mechanism incorporated in the model is only by overtopping. It is triggered when the water level reaches the top of the embankment, and the overtopping flow causes erosion on the dike (Zhang, et al., 2015). In the model the dike breaching potentially occurs at 9 locations (tab. 1). These locations are based on earlier analyses with a 2D Delft-FLS model (Van der Veen, et al., 2004). Since the embankment height cannot be changed during the simulation, the behaviour is modelled by steering the crest height and width of a weir by RTC according to the Van der Veen, et al. (2004) formula. Once the breaching starts when the water level reaches the crest height of the dike breaching weir (*CH*), it is linearly lowered in 2 hours from the original height (EH_0) to the breached embankment height (EH_B) which is the mean bed level at the corresponding 2D grid cell (eq. 1.1 and 1.2):

$$CH = EH_0 - \frac{(EH_0 - EH_B)t}{2} \qquad 0 \le t \le 2 \quad (1.1)$$

$$CH = EH_B \qquad t > 2 \quad (1.2)$$

where *t* is time (hr) from the dike breaching moment. The crest width (*CW*) also changes from 35m to 200m which is equal to the size of 2D grid in 28 hours after the crest height lowering is completed (eq. 2.1, 2.2 and 2.3).

$$CW = 35.0 \qquad t < 2 \quad (2.1)$$

$$CW = 44.65(t-2)^{0.45} \qquad 2 \le t < 30 \quad (2.2)$$

$$CW = 200.0 \qquad t \ge 30 \quad (2.3)$$

In the future, we intend to replace this approach by a more physics based breach grow formula, e.g. Verheij & Van der Knaap (Verheij, 2002).

Table 1: List of dike breaching locations and conditions.

Name	RKM (side) / RKM 1D	Embankment height (+NAP m) Original height (EH_0)	Embankment height (+NAP m) Fully breached height (EH_B)
D_019	703R / 703.1	46.77	39.2
D_023	724R / 723.9	41.33	36.55
D_026	737L / 736.9	38.21	35.16
D_027	741.5L / 741.5	37.445	32.99
D_027b	764.5L / 764.5	32.56	24.19
D_031	748R / 748.1	34.508	28.17
D_033	762R / 761.9	33.57	28.72
D_034	777R / 777.3	31.64	25.4
D_039	843.5L / 843.5	20.58	16.79

Results

The result of the 1D2D integrated model is considerably different from that of a 1D standalone version that does not include dike overtopping or breaching. The flooding over the embankment takes place in the German area even before the river discharge reaches 16,000m^3/s. The maximum river discharge at Lobith is significantly reduced due to overtopping.
The new 1D2D model is capable of capturing the exchange of flow between the river and the hinterland in a better, physically based way than the previous Sobek-RE model. The effect of dike breaching is rather local; the decreased river discharge due to dike breaching is balanced approximately within 40km as the water flows back into the river (fig. 2 and 3).

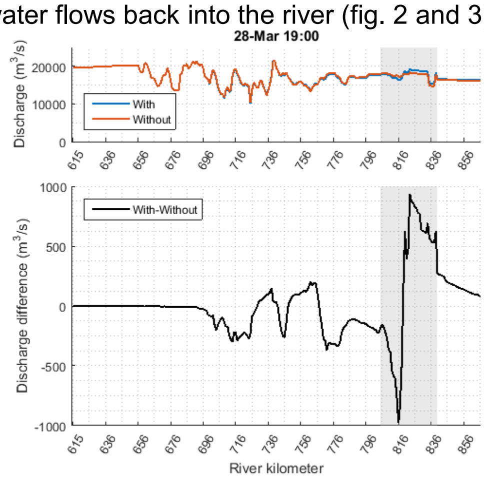

Figure 2: Discharge along the rivers (1D) when the discharge difference is the maximum. With & Without mean with/without dike breaching. The shaded range corresponds to the results shown in fig. 3.

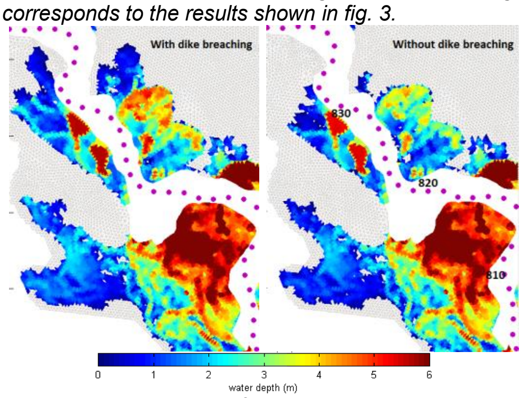

Figure 3: Water depth of the 2D part on 29 March at 00:00 (left: with dike breaching and right: without). Purple dots are river kilometres (805-840).

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Estimation of daily discharge for the river basins under different natural conditions in Latvia

Anda Bakute[a*], Inga Grinfelde[a]
[a] Latvia University of Agriculture, Scientific Laboratory of Forest and Water Resources, Faculty of Environment and Civil Engineering, 19 Akademijas Street, Jelgava, LV-3001, Latvia

Keywords — simulation of daily discharge, conceptual model

Introduction

The river basins of Latvia are characterized by different natural conditions – uneven relief, humid climate and geological development. These natural conditions are essential aspects in the hydrological regime of rivers. However, not always all parameters of the hydrological regime or river basins have been observed. One of the explanations is that hydrological monitoring is rather expensive and there have been financial problems during the last fifteen years in Latvia.

One possible method to get results nevertheless is the use of conceptual rainfall-runoff models which are widely used tools in hydrology (Seibert, 1999; Uhlenbrook et al., 1999; Jayawardena, 2006; Beven, 2012).

The aim of this study was to test the conceptual model METQ2007 for the ungauged river basins under different natural conditions.

Materials and Methods

Like previous versions of the model METQ, the METQ2007 is applied for the simulation of the daily runoff for the rivers with the different catchment areas. The METQ model is a conceptual rainfall-runoff model of catchment hydrology which simulates daily discharge and evapotranspiration as input using the following variables: daily air temperature, precipitation and vapour pressure deficit observations (Zīverts and Jauja,1999). The model consists of different routines representing snow accumulation and ablation, water balance in the root zone, water balance in groundwater and capillary water zone and runoff routing (Fig. 1).

The METQ2007 has 23 parameters where most of them are physically based, and the rest of parameters could be estimated by calibration.

In the present study, the model is tested for the simulation of daily discharge for The River Iecava, The River Malta, the River Pērse, the River Mālmute, the River Neriņa, and the River Imula. These pilot river basins are characterised by different natural conditions – sandy lowlands, lakes, forested areas, swamps, agricultural lowlands and hilly agricultural lands. The calibration and validation of the model were done for the various periods from 1956 to 2015. To perform the analyses of the results of model calibration, a statistical criterion *NSE* (Nash and Sutcliffe, 1970), a correlation coefficient *r* and average values were used.

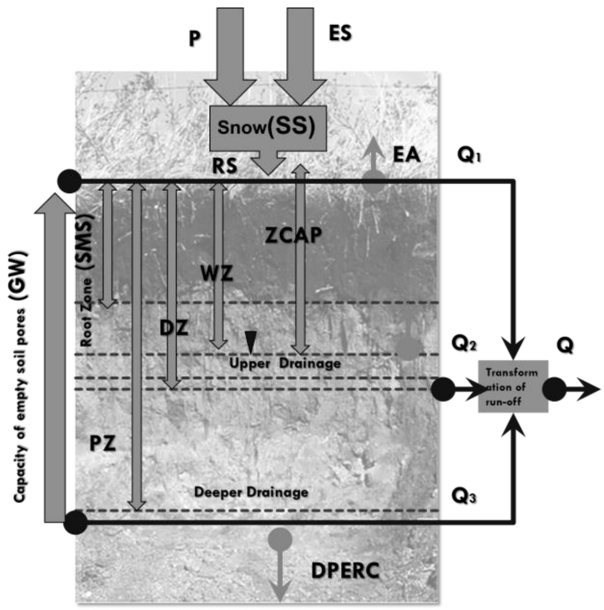

Figure 1. Structure of the conceptual model METQ2007

Results

In this research, the data series of at least thirteen year periods of six hydrological and nine meteorological stations have been used for the calibration of a conceptual rainfall-runoff METQ2007 model for six different size river basins. There is a conclusion that for such drainage areas, the number of observation points and the calibration periods are sufficient.

The results of the METQ2007 model calibration for the study river basins did show sufficient or good coincidence between the observed and

* Corresponding author
Email address: abakute@gmail.com (Anda Bakute)

simulated daily discharges from 1956 to 2015: *NSE* varies from 0.78 to 0.52 and correlation coefficient *r* from 0.88 to 0.77 (Table 1).

Table 1. The results of calibration of the model METQ2007

Runoff gauge station	**Results of calibration**	
	NSE	**r**
Iecava - Dupši	0.66	0.82
Imula - Pilskalni	0.66	0.77
Malmuta - Kažava	0.52	0.65
Malta - Viļāni	0.78	0.88
Neriņa - Bulduri	0.55	0.78
Pērse - Ūsiņi	0.65	0.85

The best performance of the modelling results was obtained for the River Malta basin: *NSE* – 0.78 and *r* – 0.88 (Fig. 2). This is due to precipitation observations in the river basin. There is a meteorological station Viļāni, and its data could be used for the model calibration. The weaker results are obtained for the River Neriņa at Bulduri.

Discussion

The main source of difference between the simulated and observed runoff values is the quality of precipitation input data and the location of the available meteorological stations to characterise the spatial and temporal distribution of precipitation in the drainage basins. The weaker coincidence was identified for the River Neriņa basin, and one of the reasons could be insufficient meteorological observations to do the better model calibration. Since large areas of bogs in a river basin play an important role in the generation of the river runoff, meteorological observations of evaporation from bogs are important for such basins. Another explanation is connected with not well-marked riverbed.

The numerical values of the model parameters for each basin reflect the geomorphologic conditions of studied drainage areas. The obtained results of model calibration show that the model METQ2007 for these pilot basins is widely applicable.

Future work

This research is a part of a doctoral thesis by Anda Bakute. In the near future, a methodology will be developed for the regionalisation of the parameters of the conceptual rainfall-runoff model METQ2007.

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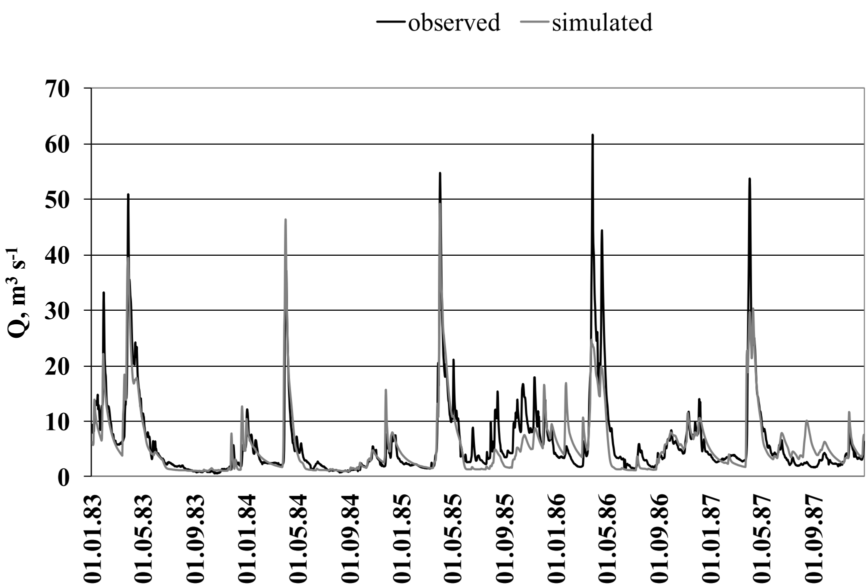

Figure 2. Simulated and observed discharge at Viļāni on the River Malta

NCR

The Future River

Session IVa

Estuaries and Deltas

Sedimentation in the mouth of the Magdalena river

L. Ambagts[a,*], W.J. Jansen[a], A. Kosters[a], C. Oerlemans[a], H. Avila[b], E. Mosselman[a,c]
[a]*Delft University of Technology, Section of Hydraulic Engineering, Faculty of Civil Engineering and Geosciences, Delft, the Netherlands*
[b]*Universidad del Norte, Department of Civil and Environmental Engineering, Barranquilla, Colombia*
[c]*Deltares, P.O. Box 177, 2600 MH Delft, the Netherlands*

Introduction

Historically, the Magdalena river has been important for inland transportation in Colombia. However, the Magdalena river has ceded its importance as a mode of transportation to the road over the last decades. This is largely due to the difficulty to navigate the river (*De Pietro*, 2013). Especially at the river mouth, heavy sedimentation hinders large sea-going vessels to enter the port areas of Barranquilla, that are located along the first 22 km of the river. To guarantee sufficient navigation depth in the access channel, costly dredging operations are required throughout the year (*Otero et al*, 2016). The dynamic behaviour of the river mouth is poorly monitored and understood, which makes it difficult to develop a long-term maintenance strategy.

The objective of our research is therefore to obtain a better understanding of the morphodynamic behaviour of the river. Firstly, we determine which processes influence the sedimentation in the mouth of the Magdalena river. Secondly, we propose river training measures that could improve navigability in the access channel of the port area.

Method

We carried out a system analysis on the basis of available literature and expert consultation to determine the processes that play an important role in the morphodynamics of the Magdalena river at Barranquilla. Subsequently, we set up a Delft3D model of the first 38 km of the river to evaluate the behaviour of the river mouth for different discharge scenarios.

System analysis

Multiple processes play a role in the dynamic system of the mouth of the Magdalena river. Precipitation patterns vary strongly with the seasons and the El Niño-Southern Oscillation (ENSO), causing high discharge variability. Furthermore, waves, wind and interaction between fresh and salt water influence the sediment transport, and so does human interference in the form of groyne construction and maintenance dredging.

Model calibration

The Delft3D model includes the above-mentioned processes. We calibrated it in three steps. The hydrodynamics were calibrated by varying the Manning roughness coefficient of the bed. This resulted in a Manning coefficient of n = 0.030 s/m$^{1/3}$.

The interaction between salt and fresh water can lead to stratified flow, which is strongest for low river discharges. We calibrated salinity on measurements during an extremely low discharge period at the beginning of 2010 (*Cormagdalena and Universidad del Norte*, 2010). In this event, the salinity intruded up to 21 km upstream of the mouth. We applied the k-ϵ turbulence model, with a horizontal eddy viscosity of 1 m^2/s and a horizontal eddy diffusivity of 10 m^2/s to close the system of equations. The vertical viscosity and diffusivity was 10^{-6} m^2/s. In this way the model reproduced the strongly stratified salinity intrusion as observed in the measurements.

Finally, we calibrated the morphodynamics. We used bathymetric surveys from January and April 2012 to construct two bed topographies. The bed topography of January 2012 was the starting point for a morphodynamic simulation of 3 months. A daily discharge time series at the upstream boundary was constructed from measured discharges at the Calamar gauging station (115 km upstream of the river mouth) from January to April 2012. In this calibration step we compared the bed topography resulting from the model simulation with the surveyed bathymetry of April 2012. To model sediment transport, we used the relation by *Engelund and Hansen* (1967):

$$S = S_b + S_{s,eq} = \frac{0.05\alpha q^5}{\sqrt{g}C^3\Delta^2 D_{50}} \quad (1)$$

With:

α	calibration coefficient (O(1))
q	magnitude of flow velocity [m/s]
C	Chézy friction coefficient [m$^{1/2}$/s]
Δ	relative density $(\rho_s - \rho_w)/\rho_w$
D_{50}	median grain diameter [m]

A calibration coefficient of α = 0.5 gave the best agreement between modelled and sur-

*Corresponding author
Email address: `l.r.ambagts@student.tudelft.nl` (L. Ambagts)

veyed bottom topography, although the model overestimates the rates of bed level change (Figure 1).

Multi-criteria analysis
We investigated several measures to improve the navigation conditions of the Magdalena river. We divided the access channel into two sections, ranging from 0 to 12 km and 13 to 22 km respectively. Subsequently, we identified in each section the most promising idea for further research by means of a multi-criteria analysis (MCA) based on hydraulic, environmental, socio-economic and financial criteria.

Preliminary results

Preliminary results show that sedimentation and erosion rates increase in the access channel above a discharge of around 5000 m^3/s. For discharges below this value, the salt intrusion length increases faster than for higher discharges. This salt intrusion leads to a low flow velocity at the bottom that is directed upstream, making the reach over which salt intrudes susceptible to sedimentation. Waves mainly influence bar formation in the river mouth and are not important further upstream.

Most promising measures
For each section we identified the most promising measures for further research, based on the outcome of the MCA:

- Section I (0-12 km): This section is characterized by the sedimentation in the mouth. Based on the local characteristics, the most promising measure for this stretch is Water Injection Dredging (WID). In this dredging method sediment is fluidised by water injection and subsequently transported by the river flow (*PIANC*, 2013).
- Section II (13-22 km): In the river bend 15 km upstream of the mouth, the depth is sufficient but the width of the navigation channel is limited. This is a result of transverse sediment transport by the secondary flow that is induced by the river bend. To minimise the sediment transport towards the inner bend and increase the width of the channel, a fixed bottom layer is the most promising measure for further research.

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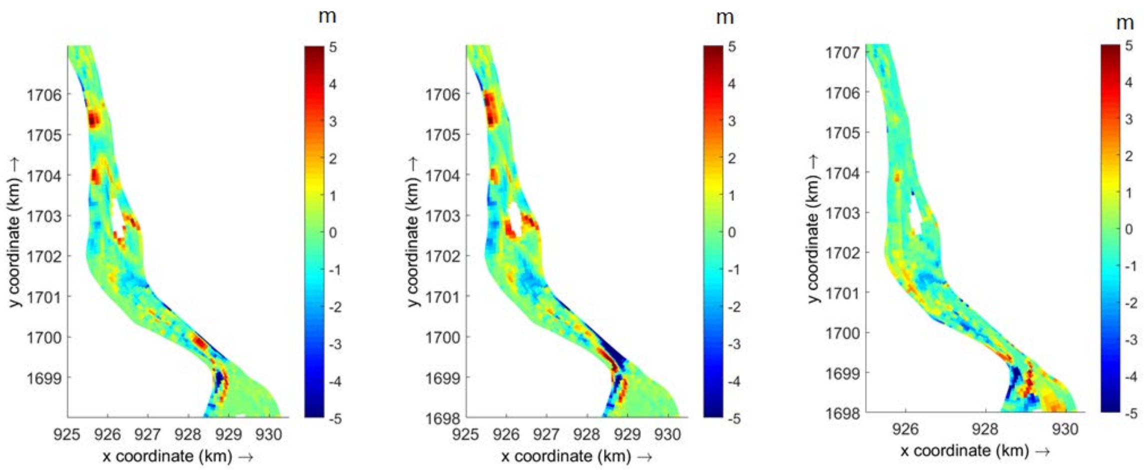

(a) Modelled bed level change with a 2D model.
(b) Modelled bed level change with a 3D model using σ-layers.
(c) Measured bed level change.

Figure 1: Modelled and measured bed level change in the period January - April 2012 at section 18-29 km. Positive bed level change is sedimentation, negative bed level change is erosion.

Morphology, water discharge and suspended load distribution along the Mara River Wetland, Tanzania

Francesco Bregoli[a*], Alessandra Crosato[a,b], Paolo Paron[a], Michael McClain[a,c]
[a] *Department of Water Science and Engineering, IHE Delft Institute for Water Education, Westvest 7, 2611 AX Delft, The Netherlands*
[b] *Faculty of Civil Engineering and Geosciences, Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands*
[c] *Department of Water Management, Delft University of Technology, Building 23, Stevinweg 1, 2628 CN Delft Delft, The Netherlands*

Keywords — Wetland, Morphology, UAV, Suspended Load, Mara River

Introduction

The transboundary Mara River, Kenya and Tanzania, is the only perennial source of inflowing surface water of a vast area including the Mara-Serengeti region. The river sustains millions of wild animals as well as a human population of nearly one million (McClain et al., 2014; Gereta et al., 2009). The basin receives two rainy seasons: a lighter in October-December and a heavier in March-May. The river is rich in suspended sediments, which has further increased by recent deforestation, change of land uses and mining (Defersha & Melesse, 2012). Before flowing into the Lake Victoria in Tanzania, the river forms a wide wetland that acts as a natural filter, sinking the large amount of suspended load and releasing clean water to the lake (Fig. 1). The wetland is fed by sediments and nutrients transported by the river and represents an essential but, at the same time, fragile ecosystem.

The vegetation, here dominated by papyrus, plays an important role in the stability of the wetland system. However forest fire and farming are intense along the wetland and have deeply modified the vegetation spatial distribution.

The construction of a new dam is planned immediately upstream of the wetland, primarily for irrigation porpoise and secondarily for hydropower generation. The dam solid and liquid discharge regulation, together with land use and land cover changes, will likely influence the river and wetland morphodynamics and will potentially jeopardize the related ecosystem.

Therefore this work is undertaken to set up a hydro-morphodynamics model in order to predict the short and long term effects that the mentioned drivers are generating on the Mara Wetland habitat.

* Corresponding author
Email address: f.bregoli@un-ihe.org (F.Bregoli)
URL: *https://www.un-ihe.org/francesco-bregoli*

Field works

During October - November 2018 a multidisciplinary field work has been conducted visiting 10 different locations along a stretch of 130 km of the Lower Mara River between Mara Mine and Kirumi Bridge (Fig. 1). The field work has been built on two past missions realized in 2016 and 2017 by a team of IHE Delft.

An Unmanned Aerial Vehicle (UAV) has been deployed obtaining 16 high resolution ortophoto mosaics (resolution of 5 cm) and digital elevation models (resolution of 20 cm) having enhanced accuracy thanks to ground control points surveyed with GPS RTK. The ortophoto mosaics have been extremely useful for the observation of vegetation and other features in unattainable areas. The low flow condition permitted the mapping of the floodplains, otherwise inundated in wet season (Fig. 2).

A sonar operated from an inflatable boat has been used to map the bathymetry of some stretches of the wetland. An ADCP and a current meter have been employed to measure the river discharge on 3 locations. Water samples have been gathered from 5 locations and analysed to get the total suspended sediment concentration.

The water level has been measured in Mara Mine and Kirumi Bridge, where monitoring station are installed. Additionally the water level has been measured in several intermediate locations with the objective of inferring the water balance of the wetland.

Preliminary observations

The meandering river approaches the wetland and forms a delta where the suspended sediments are quickly settled. The delta has around 30 km of main stream length. Between the delta and the Lake Victoria the river flows through a wide papyrus swamp. The lower part of the swamp is highly dominated by the Lake Victoria level. According to the measurements, the wetland remove nearly the 90% of the total river suspended sediments.

During the mission we witness intense human pressures on the water resources. Particularly, cultivation and grazing are quickly expanding in the floodplains and are inducing losses in riparian and wetland vegetation. These practices likely modify also the river morphology and should be taken into account to preserve the habitat.
A further mission is planned at the end of the heavier rainy season, in order to gather suspended sediment data and water storage at high flow condition.

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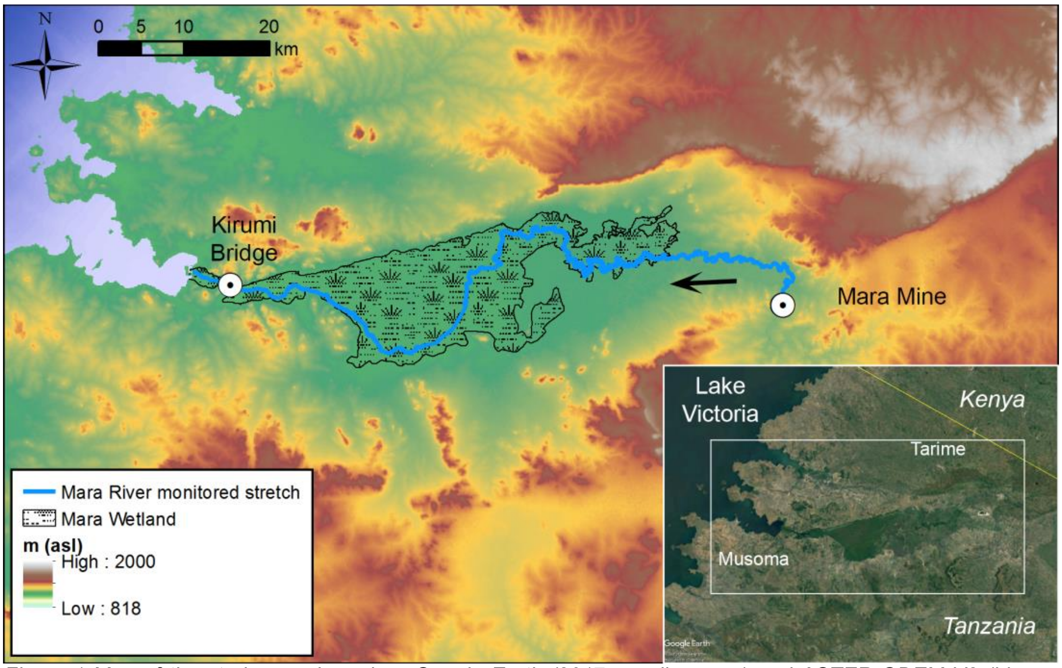

Figure 1 Map of the study area based on Google Earth (2017, small square) and ASTER GDEM V2 (big square). The arrow show the flow direction.

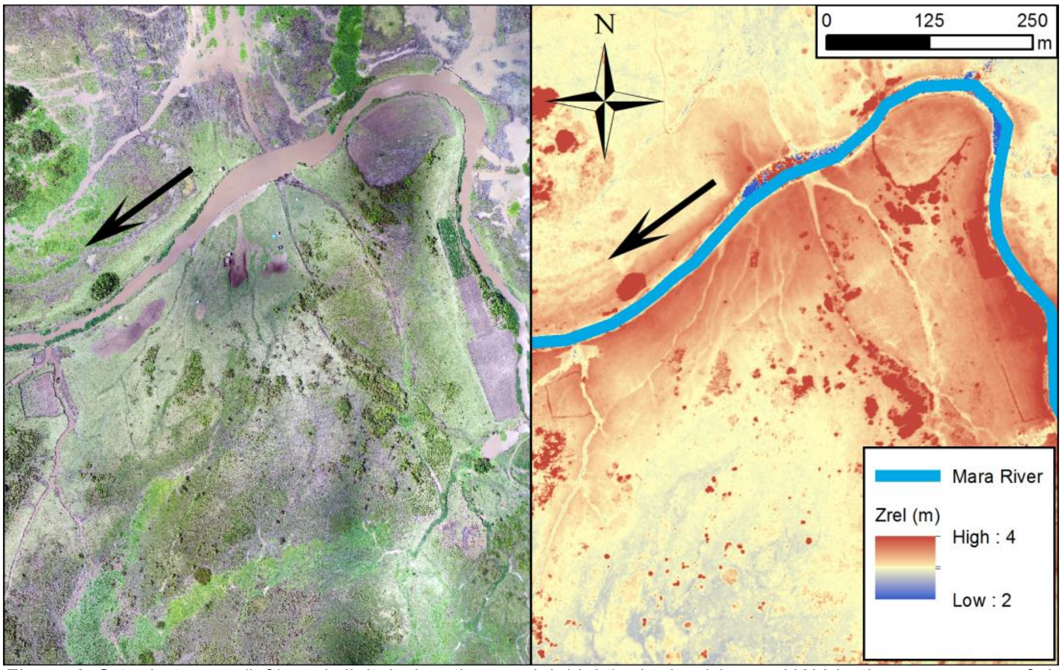

Figure 2 Ortophotomap (left) and digital elevation model (right) obtained by an UAV in the upper area of the Mara Wetland showing intense farming and floodplain negative relief. Arrows show the flow direction.

Water and sediment transport in the Biesbosch Freshwater Tidal Wetland

Eveline C. van der Deijl*[1] Marcel van der Perk[1], Hans Middelkoop[1]
[1] *Utrecht University, Department of Physical Geography, Faculty of Geosciences, PO Box 80115, 3508 TC Utrecht, The Netherlands*

Keywords — Sediment fluxes, field measurements

Introduction
The creation of new wetlands and the re-activation of sedimentation in wetlands are potentially effective measures of delta restoration. Through diversion of water and sediment into adjacent drowning delta wetlands, renewed sediment accumulation is established to provide a platform for regeneration of the ecosystem and to compensate sea-level rise and soil subsidence. The success of such measures, however, relies on a sound understanding of the flow pathways and deposition patterns within the wetlands and their feeding channels.
This study aimed to identify the pathways for water and sediment in the Biesbosch, a small inland delta within the lower Rhine and Meuse delta in the southwest of the Netherlands (Fig. 1). The area forms a network of channels that now connect recently partially de-poldered freshwater tidal wetlands. This channel-wetland system currently serves to divert excess water during peak discharges of the Rivers Rhine and Meuse, but at the same time functions as dynamic ecosystem and trap of fluvial sediment.
Specific objectives were: (a) to determine the major flow paths within the system; (b) to quantify the sediment fluxes to, within, and out of the system, and (c) to determine the relative contribution of the Rivers Rhine and Meuse to the water and sediment budget of the channels and wetlands.

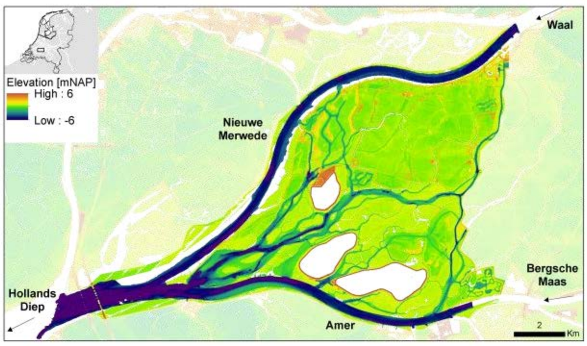

Fig.1. The Brabantse Biesbosch study area

* Corresponding author

Email address: E.C.vanderDeijl@uu.nl (E.C. van der Deijl)
URL: https://www.uu.nl/staff/ECvanderDeijl/0
(E.C. van der Deijl)

Methods
Moving boat surveys were carried out to measure suspended sediment concentrations, electrical conductivities, and channel discharge throughout the study area (Fig. 2).
Electrical conductivity measurements were used to distinguish the distribution and mixing of Rhine and Meuse water, based on the higher electrical conductivity of Rhine water.
Flow velocities and suspended sediment concentrations were combined to calculate the change in flow-weighted mean concentrations (FWMC) and suspended sediment load (SSL) over channel sections in the study area.
Existing bathymetric data, collected by Rijkswaterstaat was used to determine the rates and patterns of sedimentation in the channels of the Biesbosch study area.

Flow pathways
Most channels have a Southwest orientation with flow to the southwest during ebb tide, and to the northeast during flood tide. The flow direction in North-South oriented channels is southwards during ebb tide and northwards during flood tide, except for the channels in the east, which form a major side channel of the River Meuse and therefore always flow towards the North (Fig. 3).

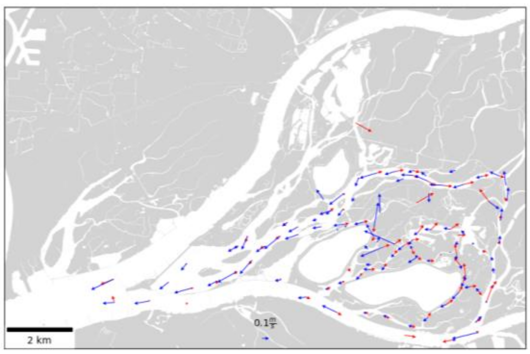

Fig.3. Depth mean flow velocities for ebb (blue) and flood tide (red)

Rhine water penetrates into the northern part of the study area, while the River Meuse feeds the channels in the south. Within the central part of the area almost no mixing of Rhine and Meuse water occurs, in spite of the tide-driven changing flow direction in most channels.

Sediment fluxes

The decrease in SSL over the channel sections indicates that the major part of the study area functions as a local sink for sediment both during flood and during ebb tide. Increases in SSL along the channel are mainly observed in smaller channels, which thus function as a local source of sediment

Channel section budget

Channel bed sedimentation was on average 12.8 mm yr^{-1} over the period 2007 – 2013, with highest values up to 0.97 m yr^{-1} in the newly de-poldered wetlands. Sedimentation primarily occurred in the deeper channels, while smaller and shallower channels experienced erosion.

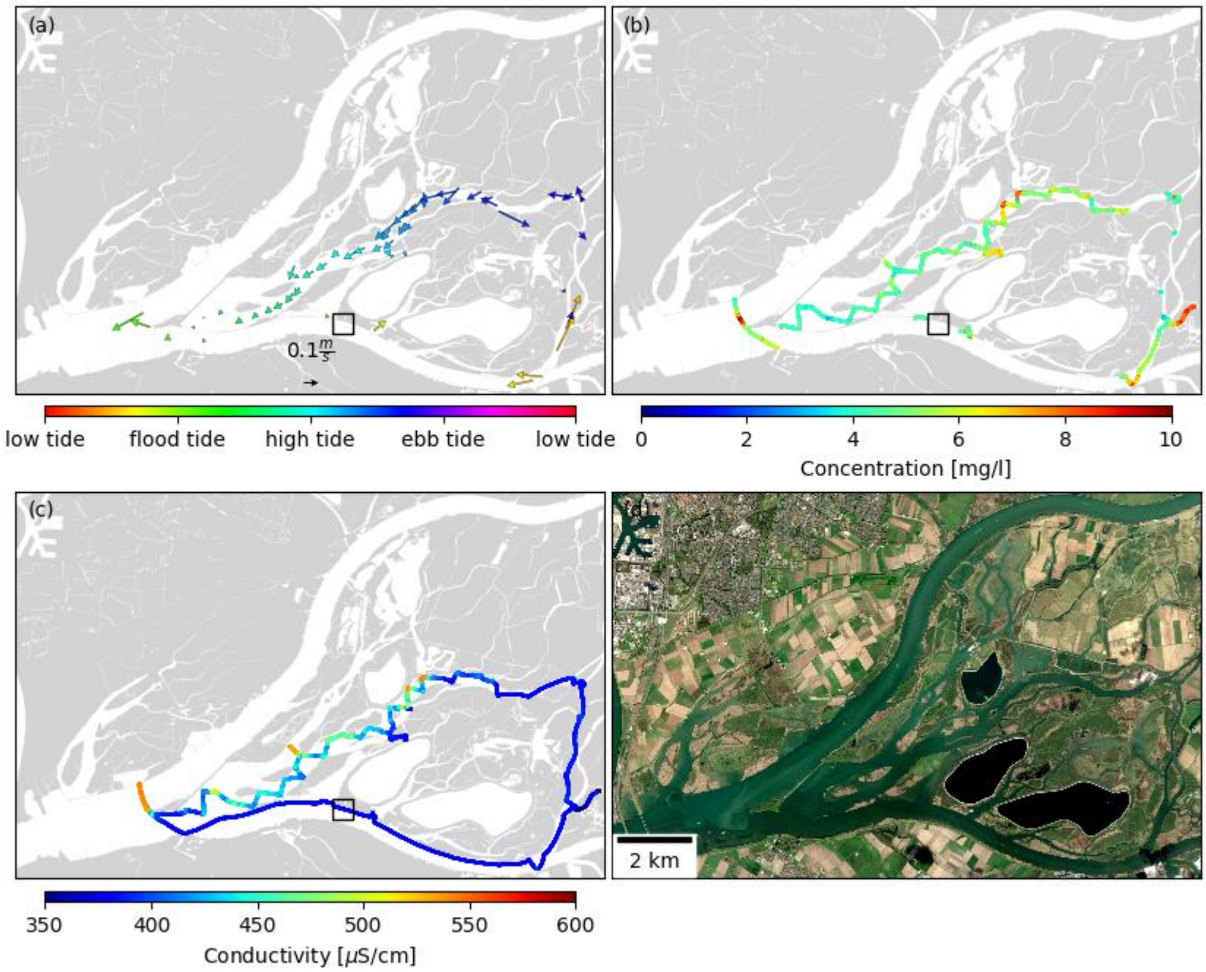

Fig. 2. The flow velocity (a), suspended sediment concentration (b) and electrical conductivity(c) as measured during the field campaign of 01-04-2016. The satellite image (d), taken at 10: 50 is indicated by the square in panels a,b and c.

Scour holes in heterogeneous subsoil: A numerical study on hydrodynamic processes in the development of the scour holes

S. Bom[a,b,*], Y. Huismans[b], N.G. Jacobsen[b], W.S.J. Uijttewaal[a]
[a]*University of Technology Delft, Department of Hydraulic Engineering, Faculty of Civil Engineering and Geosciences, P.O. Box 5048, 2600 GA, Delft, the Netherlands*
[b]*Deltares, P.O. Box 177, 2600 MH, Delft, the Netherlands*

Keywords — Scour holes, Hydrodynamics, Numerical modelling

Introduction

In the densely populated Rhine-Meuse Delta in the Netherlands, deep scour holes develop very suddenly. The holes may form a potential risk for the stability of surrounding riverbanks, dikes, bridges, tunnels and buildings, risking flooding of the hinterland. Approximately 40% of the scour holes in the delta are found to be (partially) caused by the composition of the subsoil Koopmans (2017). The Rhine-Meuse Delta has large variations in the subsoil, reaching from poorly erodible clay and peat layers to highly erodible sand. The geological evolution in this area created layers of different soil types in the lithology of the subsoil. Local incision of sand between two poorly erodible clay layers causes scour holes to be formed abruptly. This may lead to deep scour holes with steep slopes (Huismans et al., 2016; Sloff et al., 2013).

In the past three years, analyses of field data and experimental research has been performed on scour holes in heterogeneous subsoil (Van Zuylen, 2015; Koopmans, 2017; Stenfert, 2017). However, a distinct method to predict the development of scour holes in heterogeneous subsoil has not been found yet. In this paper a numerical model that simulates the hydrodynamics in a scour hole is used to gain more insight in the hydrodynamic processes that are present in such a hole.

Method

The numerical model that is used in this research is simulating a scour hole from the experimental study by Stenfert (2017). The model is set up in the open-source CFD toolbox OpenFOAM and is based on the model that is used by Jacobsen et al. (2014). It uses the Generalized k-ω turbulence model by Wilcox (2006), logarithmic wall functions and a rigid lid at the surface boundary. At the upstream boundary a fully developed velocity profile is induced. The model is validated using velocity measurements in backward facing step cases (Nakagawa and Nezu, 1987; Ampadu-Mintah and Tachie, 2015) and both two and three-dimensional scour holes (Van Zuylen, 2015; Stenfert, 2017).

The model is used in a parameter study, where the influence of some parameters on the hydrodynamic processes in and around the scour hole is examined. Besides, the bed shear stress from the model is investigated. From this, a rough estimate of the erosion and sedimentation patterns in the hole is made.

Results

The hydrodynamic processes that are found in this scouring situation are a recirculation zone, a flow contraction, a horseshoe vortex and vortices downstream of the hole. The latter two are visualized in Fig. 1.

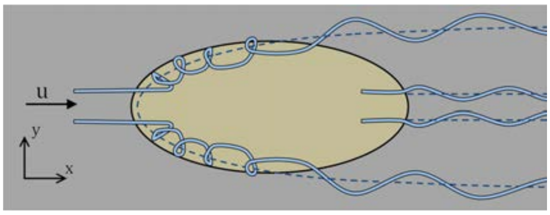

Figure 1: Visualization of the horseshoe vortex and the downstream vortices. In reality, the horseshoe vortex makes one rotation inside the scour hole.

In order to check the influence of the depth of the scour hole, the bed topography is multiplied with a certain factor. The recirculation zone is present for holes with an upstream slope of $20°$ ($\tan\beta = 0.36$) in the three-dimensional simulations (see Fig. 3). Two-dimensional simulations show a flow separation for scour holes with milder upstream slopes ($\beta > 16.7°$). This indicates that three-dimensional effects suppress the formation of a recirculation zone. However, once a recirculation zone is present, the three-dimensional effects strengthen the recirculation, as the relation for the circles in Fig. 3 has a steeper slope.

*Corresponding author
Email address: sambom@live.nl (S. Bom)
URL: www.tudelft.nl (S. Bom)

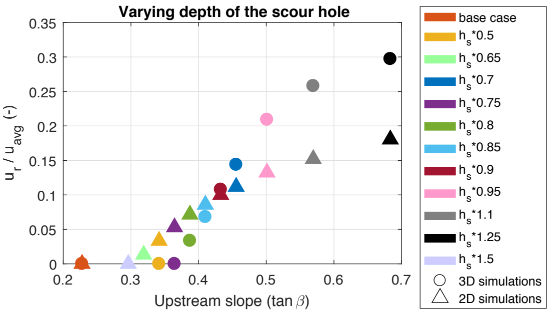

Figure 3: Relation between the relative recirculation velocity and the angle of the upstream slope. Both two-dimensional and three-dimensional simulations are included in the graph.

The magnitude of the flow contraction does not always increase for a larger depth of the scour hole. A peak in this relation is present around a scour hole with a depth of 0.85 times the base case depth. For deeper scour holes, the flow contraction becomes weaker. This is found to be the result of the presence and size of the recirculation zone. This zone does not attract flow and therefore is not responsible for the flow contraction.

From the bed shear stress in the model simulation, a first rough estimation of the erosion and sedimentation in the hole can be made. A top view of the bed shear stress is shown in Fig. 2. Two yellow ovals are included, which indicate low magnitude bed shear stress strips. These strips are present at the exact same location where sediment ridges are present in the experiments by Stenfert (2017). The experimental part of the research by Koopmans (2017) showed expansion of the hole with a poorly erodible top layer in downstream direction. This expansion has the same slope as the strips in Fig. 2, which is 1:8.

Conclusion

The numerical model is able to reproduce the most important flow processes in a scour hole. Calculations of erosion using bed shear stress confirm findings in experimental studies. However, locations where fluctuations are important for sediment transport are not modelled correctly. When taking this into account in the analysis, the model can be a first rough estimation of the erosion in a scour hole in heterogeneous subsoil.

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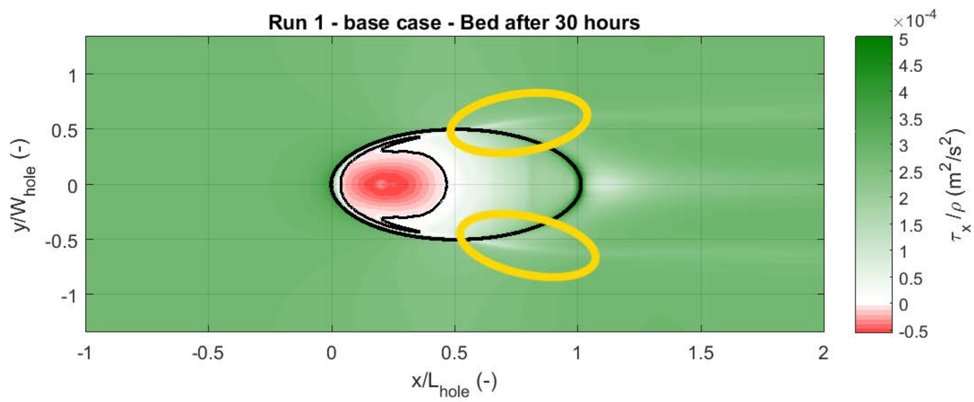

Figure 2: Bed shear stress in streamwise direction in the model domain. The yellow ovals indicate low magnitude bed shear stress strips with a 1:8 slope, which is also found in sediment ridges and erosion patterns in experimental studies by Stenfert (2017) and Koopmans (2017) respectively.

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The Future River

Session IVb

Understanding river engineering

On the uptake of natural water retention measures in German flood risk management – How far have we got?

Mario Brillinger*
[a] Leibniz Universität Hannover, Institute of Environmental Planning, Faculty of Architecture and Landscape
Herrenhäuser Straße 2, 30419 Hannover, Germany

Keywords — Flood Risk Management, Natural Water Retention Measures, Assessment approaches

Introduction

Climate change poses dramatic challenges to the management of river landscapes, including altered river flow regimes and increasing risks of floods and associated economic losses. Along the line of efforts to support a paradigm shift towards more integrated approaches for dealing with these impacts (cf. Samuels, Klijn & Dijkman, 2006), the EU Floods Directive, adopted in 2007, promotes the concept of flood risk management to analyse, evaluate and reduce risks of flooding in a more holistic and adaptive way. The directive requests Member States to assess the adverse effects from flooding, to map the flood extent and assets and humans at risk, as well as to set up flood risk management plans for river catchment areas. The flood risk management plans require considering and ranking not only structural, hydraulic engineering measures, but also non-structural measures (e.g. land-use planning, warning systems) and natural water retention measures (e.g. floodplain restoration) to achieve appropriate objectives for flood risk reduction.

In light of the increasing European policy interest to apply nature-based solutions (NBS) for water management (European Commission, 2015), natural water retention measures (NWRM) can be recognised as one type of NBS that is multifunctional and can deliver multiple ecosystem services. By enhancing or restore natural hydrological processes, NWRM can help to reduce risk of flooding as well as contribute to improving water quality and promoting increased biodiversity. In consequence, NWRM are important for achieving goals of the EU Floods Directive, Water Framework Directive and nature conservation policies.

However, there are a number of barriers to a more holistic and sustainable approach to flood risk management, reflected by the persisting emphasis on applying more technical measures in practice. Assessment approaches focusing on structural measures base their evaluation usually on direct effects at a local level, whereas indirect costs and benefits as well as regional effects are neglected (Dehnhardt et al. 2008). Reasons for the preference of structural measures include aspects related to the contextual conditions of decision making, for example, organisation structures, the presence of formal and informal institutions or the knowledge base of an individual decision maker (Schanze et al., 2008). Additionally, approaches used to evaluate, compare and prioritise different kinds of measures are missing (Meyer, Priest, & Kuhlicke, 2012). Therefore, the scope of evaluation and choice of evaluation criteria can have a major impact on assessment results and therefore for the integration of natural water retention measures in management plans.

The aim of this contribution is to analyse the uptake of natural water retention measures in flood risk management plans in three federal states in Germany. Due to different administrative structures of the federal system in Germany, a variety of flood risk management plans with different flood risk assessment approaches and conclusions of appropriate risk reduction measures exists. This study focuses on the approaches used in the states of Hesse, Saxony and Lower Saxony which are representative for the diversity of approaches applied across the country. The research questions are (i) what types of measures are proposed in the flood risks management plans of the selected federal states to fulfil risk reduction targets; (ii) to what extent can the proposed types of measures be considered technical or nature-based solutions; (iii) which assessment and evaluation procedures are applied to choose between alternative measures.

* Corresponding author
Email address: brillinger@umwelt.uni-hannover.de
(Mario Brillinger)

Data basis

The study compares and analyses flood risk management plans from the states of Hesse, Saxony and Lower Saxony. Additionally, background documents such as past flood management concepts and appropriate guidelines are used to support the content-related analysis of the plans.

Research design

The analysis is conducted using a qualitative content analysis (Mayring 2003). I developed a coding scheme comprising descriptive and normative components. The descriptive components allow me to collect information about frequencies (e.g. amount of natural water retention measures) as well as descriptions of the assessment approaches and justifications. The normative components are related to the conformity with requirements of the EU Floods directive and consideration of corresponding guidelines from policy and science.

First results indicate a relatively similar list of measures considered in the analyses of flood risks management plans, but clear differences in the kinds of evaluation approaches used. The outcomes from my research will shed light on some of the challenges for enhancing the uptake of natural retention measures in practice, and provide the foundation for a development of guidelines of how a more comprehensive consideration of options to apply such natural measures could be achieved.

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Influence of water level duration on dike breach triggering in system behaviour

Alex Curran[a,b], Karin M. De Bruijn[b], Matthijs Kok[a]
[a] *Faculty of Civil Engineering and Geosciences, Delft University of Technology, Stevinweg 1, 2628 CN, Delft, The Netherlands*
[b] *Department of Flood Risk Management, Deltares, Rotterdamseweg 185, 26 MH Delft*

Keywords — System behaviour, fragility curve, floodwave duration

Introduction

Reliable hazard analysis is a crucial step in flood risk management, and for large river systems, the effects of breaches on downstream regions should be taken into account. Accounting for these breaches in hazard analyses is often termed 'hydrodynamic system behaviour' analyses, and has become increasingly popular in flood risk assessment.
Methods to perform such analyses usually focus on high water levels as a trigger for dike breaching. However, the duration of high water levels is known to be an important criterion in the mechanisms that cause dike breaching, for example piping. This study aims to demonstrate the effect of the duration on hydraulic system behaviour analyses, using a computational framework in which two dike breach triggering methods are compared in a large river system. The Dutch Rhine is used as a case-study. The first method triggers dike breaches based on water levels, and the second method is dependent on both water-level and duration, with the relationship of the two variables inferred via expert opinion. This comparison is made for dike failure probabilities based on the proposed future standards of protection.

Method

For the river system, dike strengths, R, and hydraulic loads, S, are sampled according to their probability distributions, and used as inputs to a hydrodynamic simulation. Output distributions are generated from the simulations and analysed.

This process is repeated for 3 system behaviour scenarios:

- Scenario 0: No system behaviour
- Scenario 1: System behaviour with water level as dike failure trigger
- Scenario 2: System behaviour with water level and duration as dike failure trigger

* Corresponding author
Email address: alex.curran@deltares.nl (Alex Curran)

In all tested scenarios, the input load distributions are the same; peak discharge and waveshape. The dike strengths are distributions of failure probability that relate to either water level or both water level and duration of exceedence of that water level. These two strength distributions have been termed 'fragility curves' for scenario 1, 'fragility surfaces' for scenario 2, and 'fragility functions' collectively. In scenario 0 system behaviour is not implemented, i.e. no out of bank flow occurs, and is therefore used to gauge the effect of the other scenarios.

Rhine Case-study

The presented case study area is the lower Rhine region along its three branches in the Netherlands; the IJssel, the Waal and the Lek/Nederrijn. The study is delimited upstream at Lobith on the German border.

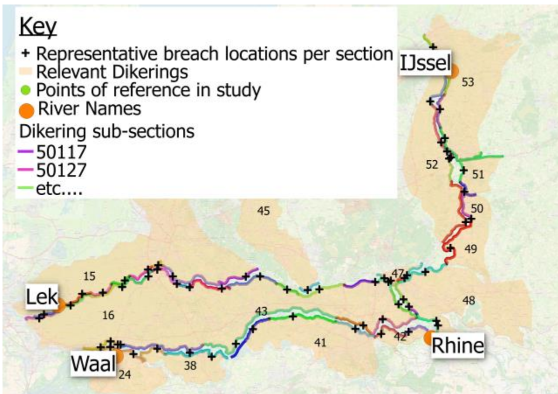

Figure 1. Case study area

The river system is modelled in Sobek 3, with each breach location schematised as a weir that flows to a reservoir that represents the capacity of the adjacent dikering. In the system behaviour scenarios, the weir is triggered by the fragility function for that location, with breach heights and widths controlled by the breach growth formula described by Verheij & der Knaap, (2002), using default parameters

Loads and Strengths

The downstream boundary conditions on all 3 branches were modelled using discharge-water levels relationships. The upstream boundary condition at Lobith used a variable input based on the GRADE distributions of discharge peak and wave-shape.

The fragility curves were built using data from the BOA project, (Levelt, 2017) and adjusted to achieve the desired failure probabilities described in the WBI project, (Slomp, 2016). In scenario 1, breaches occur when a threshold water level is reached, which is the minimum of the values sampled for the three breaching mechanisms of overtopping, piping and macrostability.

In scenario 2, breaching occurs due to a combination of water-level and the duration of time that level is exceeded in a simulation. For probabilistic estimates of these thresholds, the fragility curves were expanded to include the duration as a second variable, as seen in Fig. 2 below. Uniformly sampled probabilities applied to this curve gave an incremental range of water levels and associated exceedence durations for which failure would occur according to that probability. At each location, the ranges resulting from each mechanism were combined using the smallest duration for the increment, resulting in a single failure criteria. The conversion from fragility curve to surface was made using expert opinion on the applicability of the curves to different durations.

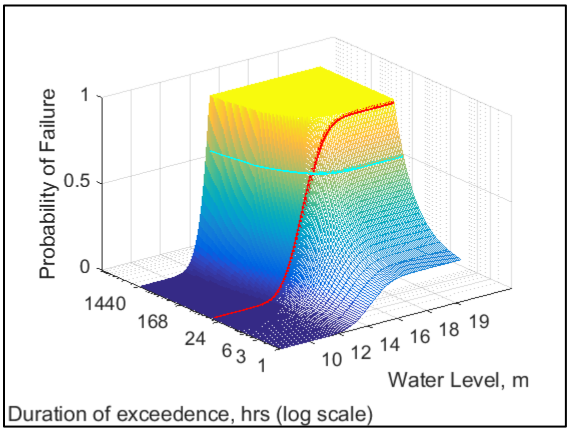

Figure 2. Example fragility surface derived from local fragility curve and expert opinion on durations. Failure probability is related to water level and duration of exceedence of that water level. Original fragility curve shown in red, and example sampled failure threshold shown in cyan

Results

The return period water levels and discharges for a certain location are given in Fig. 4, below. It is immediately apparent that system behaviour has a reduction in the water levels, which is to be expected at all downstream locations. Although it is small, a reduction of this impact is seen in scenario 3, due to the lower abstraction from the river when failure occurs after the peak of the flood wave. For very extreme flows, the difference between Scenarios 1 and 2 seems to reduce, as failure occurs early in the floodwave in both cases. Further analysis of different locations and hydraulic variables shows interesting aspects of system behaviour, such as reductions in breaching volume, and even increases of discharge when system behaviour is applied.

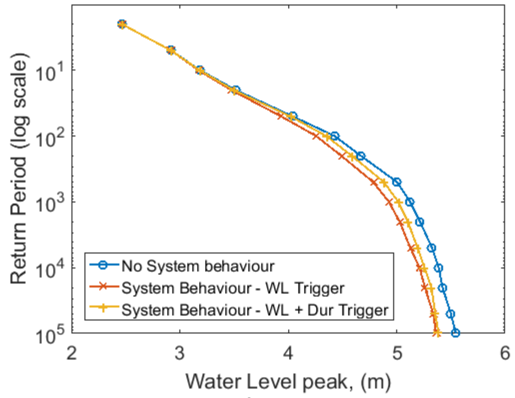

Figure 3. Return period of water level at a breach location on the Lek, for all scenarios

Conclusion

Although results are still preliminary, the work suggests that the assumption of water level triggering for dike breaches in system behaviour analysis is insufficient.

The results show that including the duration as a breach triggering variable in system behaviour analyses has a significant effect on the hydraulic loads and breaching patterns in the system. There are a number of reasons for these differences, and the results are highly dependent on the way that the fragility surfaces are generated. Although further work is required to fully understand the impact of system behaviour on the case-study, the study suggests that the duration of water levels should be included in future system behaviour analyses.

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Response of flow and bed morphology to the introduction of large wood for sediment management

Judith Y. Poelman[a,*], Timo V. de Ruijsscher[a], A.J.F. (Ton) Hoitink[a]
[a] *Wageningen University & Research, Hydrology and Quantitative Water Management Group, Department of Environmental Sciences, PO Box 47, 6700 AA, Wageningen, the Netherlands*

Keywords — Large wood, Submerged vanes, Physical model

Introduction

Implementation of large wood (LW; defined as dead trees and tree trunks) in river systems, placed in set-ups comparable to those of submerged vanes, is a promising method both for sediment management and the improvement of bio-diversity. Submerged vanes alter sediment transport by inducing a secondary circulation, with little to no impact on the conveyance capacity of the river (Fig. 1) (Odgaard et al., 2009). LW serves to increase bio-diversity and, in some cases, is applied to control flow and sediment. This is usually by placing LW as an obstruction to the flow, creating a wake region (Bennett et al., 2015). In Dutch rivers, where river management should ensure flood protection and enable navigation, this is not always a feasible option. A proposed method therefore, is to use LW in a set-up that is comparable to the technique of submerged vanes.

A laboratory study is conducted to investigate whether LW can be used to manage sediment transport and what its effects are on flow conditions and bed morphology.

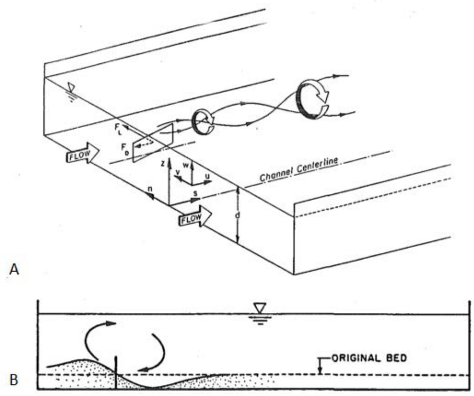

Figure 1: Vane-induced circulation (A); resulting bed-morphology (B) (Odgaard and Wang, 1991)

Methodology

Experiments are performed both with a fixed bed and a movable bed. The experiments are conducted in a tilting flume (14.4 m × 1.2 m) in the Kraijenhoff van de Leur Laboratory for Water and Sediment Dynamics at Wageningen University and Research. In the fixed-bed experiment, detailed three-dimensional velocity measurements (acoustic Doppler velocimeter, manufactured by Nortek) are taken for seven experimental set-ups. Three different types of objects are constructed, representing vanes, a screen of tree trunks and an individual tree trunk. The objects are placed in a set-up that is similar to that of Wang and Odgaard (1993), in eight arrays of each four objects, and for two angles of approach ($\alpha = 15°$ and $\alpha = 25°$). Velocity measurements are taken over the entire experimental range to gain understanding of the general flow conditions. In one cross-section, measurements are taken for a dense grid.

In three movable-bed experiments, the three types of objects are installed with $\alpha = 15°$. After running an experiment, the bed elevation is measured (line laser combined with a 3D camera; De Ruijsscher et al., 2017).

To get results that are indicative of what the effects of a similar set-up would be in a lowland river, scaling of important parameters is done according to the approach of Vermeulen et al. (2014). Polystyrene is used as surrogate for sediment in the movable-bed experiments.

Processing of the velocity data includes filtering based on correlation values (<70%); removal of spikes and cubic interpolation to replace removed values. Subsequently, mean streamwise and transverse velocities are calculated, as well as the vertical Reynolds stress:

$$\tau_{uw} = \rho\overline{u'w'}, \qquad (1)$$

where $u' = u - \overline{u}$.

Results and conclusions

Results from the fixed-bed experiments show that a reduction of streamwise velocity occurs in the vane or LW field, which is largest for the trunks (Fig. 2). The trunks are also least effective in inducing a secondary circulation and

*Corresponding author
Email address: judith.poelman@wur.nl (Judith Y. Poelman)
URL: www.wur.nl (Judith Y. Poelman)

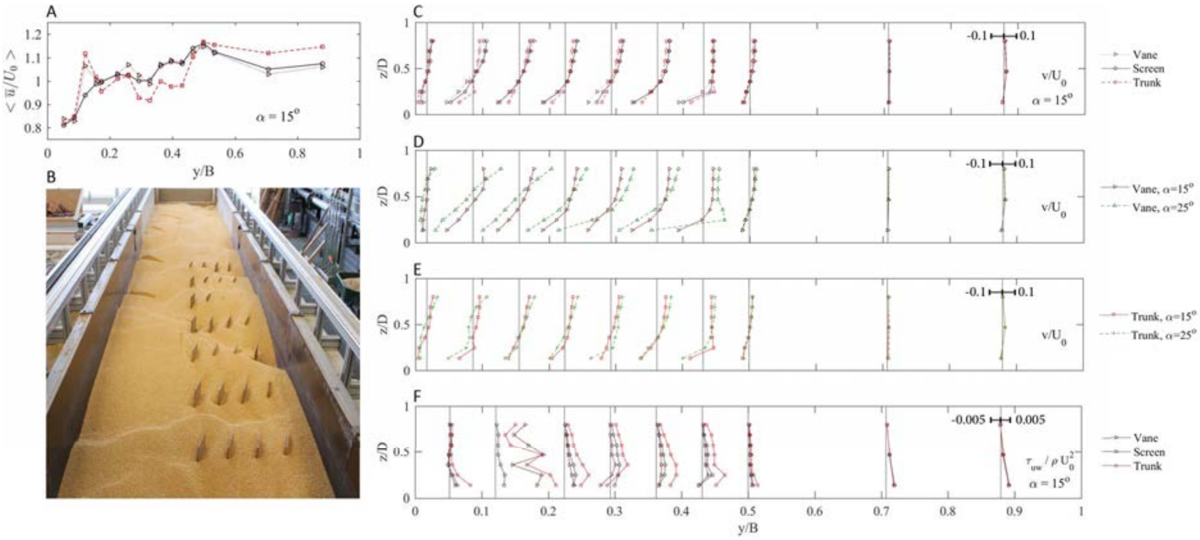

Figure 2: Depth-averaged streamwise velocity (A); Photo of experiment (B); Profiles of the mean transverse velocities, $\overline{v}/U_0$ (C - E); vertical Reynolds stress (F). The mean velocities are all measured in one, densely-measured cross-section

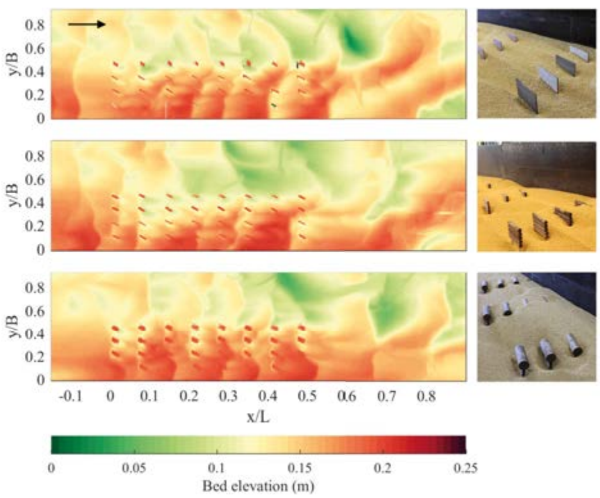

Figure 3: Bed morphology determined at the end of the experiment with vanes (upper panel), with screens (lower panel) and with trunks (lower panel)

lead to higher Reynolds stress (Fig. 2). The vanes are most effective in inducing a secondary circulation, especially for $\alpha = 25°$.

In experiments with a movable sediment bed, all experiments show increased bed elevation in the vane or LW field. For the vanes and screens, we can see clear dunes extending over the width of the flume. Mainly between y/B = 0.2 and y/B = 0.4, the orientation of the dunes indicate a bottom current that is in line with the expected secondary circulation. This is different from the experiment with trunks.

Based on the velocity measurements and scanned bed morphology, we propose that two mechanisms affect the bed morphology. These two mechanisms are the secondary circulation induced by the vanes and LW, and the reduction of streamwise velocity. The effects of trunks on flow and bed morphology are distinct from the effects of both vanes and screens. Trunks do induce a weak vortex and are effective in redistributing sediment. However, considering depth-averaged streamwise velocity, turbulent parameters and bed morphology, the deceleration of streamwise velocity in the field of trunks is expected to be the dominant mechanism affecting bed morphology.

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Flow Bifurcation at a Longitudinal Training Dam: a Physical Scale Model

Timo V. de Ruijsscher[a,*], Suleyman Naqshband[a], A.J.F. (Ton) Hoitink[a]
[a] Wageningen University, Department of Environmental Sciences, Hydrology and Quantitative Water Management Group, P.O. Box 47, 6700 AA, Wageningen, the Netherlands

Keywords — Flow bifurcation, Longitudinal training dam, Physical scale model

Introduction

Longitudinal training dams (LTDs) have been built over a length of 10 km in the inner bend of the Dutch Waal River near the city of Tiel. They serve as an alternative to traditional groynes, splitting the river in a main channel and a bank-connected side channel in the inner bend, as shown in Fig. 1. The LTDs in the Waal River have a design height to be submerged about 100 days per year. LTDs serve to restrict the river width at low discharges, to increase discharge capacity at high discharges and to minimize bed degradation. Moreover, ecologically favourable conditions are created in the side channel compared to the former groyne fields.

The entrance of an LTD side channel may be seen as a specific case of a flow divide, with a sill located at the divide. The situation also bears some similarity to the classical situation of flow and bed load transport over an oblique weir. Here, we study the physical mechanisms governing the three-dimensional flow and its effect on local morphology at this specific type of flow divide, to be able to predict hydro- and morphodynamic effects after future construction of LTDs more accurately.

Figure 1: Aerial photograph of an LTD in the Dutch Waal River, which is used as prototype for the scale model. The arrow denotes the flow direction. (Courtesy: Rijkswaterstaat)

*Corresponding author
Email address: timo.deruijsscher@wur.nl (Timo V. de Ruijsscher)
URL: www.wur.eu/hwm (Timo V. de Ruijsscher)

Method

In the current study, the flow divide at the entrance of an LTD side channel is studied using a scale model with a movable bed. Both the bed level and flow velocities are measured.

Figure 2: Scale model of the LTD with flowing water. The arrow denotes the flow direction in the main channel.

Physical scale model

In the Kraijenhof van de Leur Laboratory for Water and Sediment Dynamics at Wageningen University & Research, a flume with a physical scale model of an LTD is used. The flume has an internal width of 2.6 m and a length of the measurement reach of 12.0 m, whereas the scale model is scaled from the prototype with a factor 60 in all spatial dimensions. A view from downstream on the model with flowing water is offered in Fig. 2. To assure dynamic similarity, lightweight particles (polystyrene granules) are used as surrogate sediment. For details on this method, see Vermeulen et al. (2014).

Bed level measurements

Bed level is measured continuously during certain phases of the experiment, being the initial dry-bed condition, the initial submerged condition and after development of dunes. For this

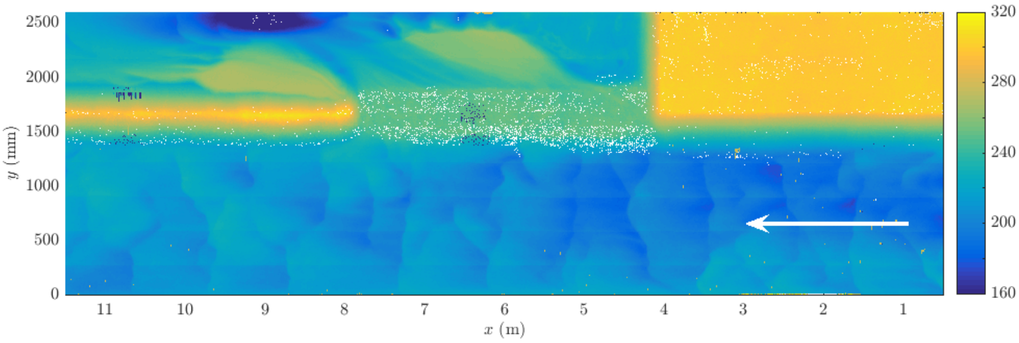

Figure 3: Top view of the LTD scale model making use of a line laser scanner at the end of a movable bed experiment. The white arrow denotes the flow direction.

purpose, a line laser scanner is used, as described by de Ruijsscher et al. (2017). The bed is scanned with an along-flow resolution of 2 mm and an average cross-flow resolution of approximately 3 mm, in eight parallel partly-overlapping swipes. Fig. 3 shows a dry-bed scan of the scale model, where the upstream riprap bank, the sill and the LTD itself are clearly visible.

Flow velocity measurements

Flow velocity is measured using a Vectrino Profiler, which is a profiling acoustic velocimeter, measuring flow magnitude and direction in vertical bins of 1 mm over a total height of 3 cm. Besides, a point measurement of the bed level directly underneath the instrument is taken. The data gathered are used to quantify the flow patterns around the intake of the LTD side channel, and to estimate the discharge and the sediment transport distribution over the two channels.

Expectation

Erosion is expected at the fairway side of the LTD, just downstream of the LTD head. this hypothesis is based on scour around bridge piers, where a horseshoe vortex creates local scour upstream and along the sides of a pier. Yet, at the studied bifurcation the flow is bending into the side channel (ergo, not parallel to the LTD), probably causing an asymmetry effect with most erosion occurring in the main channel. Previous experiments with a slightly different set-up agree with the expectation of erosion at the slope of the LTD that faces the main channel. When comparing the present situation with traditional bifurcations erosion may be expected at the LTD head, with (again) erosion at the slope of the LTD that faces the main channel.

Ongoing work

Experiments with different set-ups of the sill at the side channel entrance are being performed. Four different situations are studied: a uniform low, uniform heigh, downstream increasing and downstream decreasing sill height. All situations are studied with emerged and submerged LTD crest.
Results from the physical scale model experiments will be compared to field measurements from the prototype in the Waal River. The combined dataset will be used to get a better understanding on flow and bed load sediment transport over oblique weirs.

Acknowledgements

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Flood level peaks at downstream terminations of Room-for-the-River projects

Jerry Gerges Tadrous[a*] and Erik Mosselman[a.b]
[a]*Delft University of Technology, Department of Hydraulic Engineering, Stevinweg 1, 2628 CN Delft*
[b]*Deltares, Department of River Dynamics and Inland Shipping, Boussinesqweg 1, 2629 HV Delft*

Keywords — Room for the River, flood levels, hydrodynamics

Introduction

The Room-for-the-River programme reduces design flood levels by giving more space to rivers, thus decreasing the need of further dike reinforcements (Fig. 1). The effectiveness in lowering flood levels is computed using 1D and 2D depth-averaged hydrodynamic models. Remarkably, however, the results of these models always show a local rise of the water level at the downstream terminations of Room-for-the-River interventions (Fig. 2).

Figure 1. Excavation of flood channel along river Waal at Nijmegen under the Room-for-the-River programme.

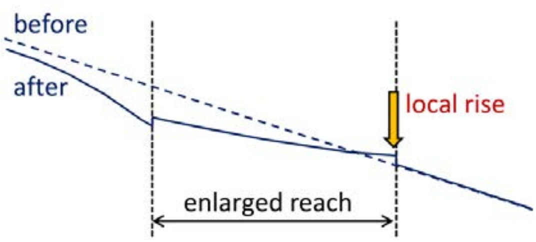

Figure 2. Longitudinal water level profiles before and after implementation of a Room-for-the-River project, showing general lowering of water levels but a local rise at the downstream termination.

This mysterious water level peak has puzzled hydrodynamic modellers in the Netherlands for a long time, since text-book solutions of longitudinal water level profiles based on the Bélanger (1828) equation do not show it. Some have called the peak a numerical artefact, because changing the space step in 1D models or the grid cell size in 2D models affects its height. However, the peak does not vanish at very fine grids and hence must have some physical basis that might be understood from the hydrodynamic equations.

Others therefore ascribed the peak to the Bernouilli effect by which lower flow velocities in enlarged river reaches induce higher water levels to conserve the total energy head. However, the observed water level peaks are sometimes higher than what could be expected from the Bernouilli effect.

Method

We analytically reviewed the effect of enlarged river reaches in the fundamental hydrodynamic equations to see whether a derivation with less limiting simplifications could produce a more complete solution than the Bélanger equation. We verified whether the additional terms of this more complete solution could explain the height of the water level peak. The classical derivation of the Bélanger equation is expressed per unit width. The central idea behind our more complete derivation is that the effects of a wider reach can be represented by a lower specific discharge, *i.e.* a lower discharge per unit width. Gradients in specific discharge then generate extra terms as a proxy for the effect of giving more space to the river.

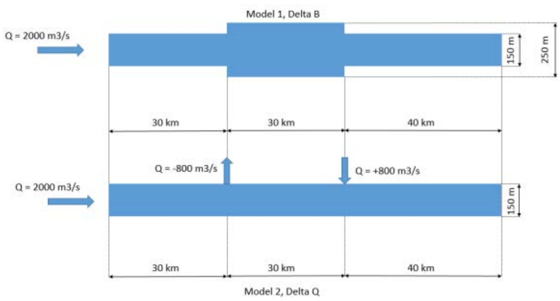

Figure 3. Schematization of Room-for-the-River interventions in numerical simulations: widening (top) and diversion (bottom).

Subsequently we carried out 1D numerical simulations using Sobek-RE. We considered a straight river with rectangular cross-sections, a gradient of 0.1 m/km, a reference width of

* Corresponding author
Email address: J.GergesTadrous@student.tudelft.nl

150 m, a constant reference discharge of 2000 m^3/s, and a Chézy coefficient of 50 $m^{1/2}/s$. The corresponding flow depth and flow velocity are 8.95 m and 1.49 m/s, respectively. We considered two ways of giving more space to a 30 km long reach: one by widening the river to 250 m and the other one by diverting 800 m^3/s through a flood channel (Fig. 3). Both ways reduced the specific discharge from 13.3 to 8 m^2/s. We used space steps of 50, 100 and 200 m. Gerges Tadrous (2017) documents the simulations more completely. We compared the computational results with the analytical solutions and evaluated the validity of our new explanation.

Analytical results

The fundamental 1D steady hydrodynamic equations read

$$\frac{\partial q}{\partial x} = h\frac{\partial u}{\partial x} + u\frac{\partial h}{\partial x} \qquad (1)$$

$$u\frac{\partial u}{\partial x} + g\frac{\partial z_w}{\partial x} + \frac{gu^2}{C^2 h} = 0 \qquad (2)$$

where C is the Chézy coefficient for hydraulic roughness, g the acceleration due to gravity, h the flow depth, q the specific discharge, u the depth-averaged flow velocity, x the co-ordinate along the river, and z_w the water level. The classical derivation of the Bélanger equation assumes $\partial q / \partial x = 0$. Without this assumption, the equations can be written as

$$\left(1-\frac{h_c^3}{h^3}\right)\frac{\partial z_w}{\partial x} = i_b\left(\frac{h_c^3}{h^3}-\frac{h_n^3}{h^3}\right) - \frac{q}{gh^2}\frac{\partial q}{\partial x} \qquad (3)$$

where h_c denotes critical depth, h_n normal depth and i_b bed level gradient. The first term on the right-hand side corresponds to the classical Bélanger equation (written here for $\partial z_w / \partial x$ instead of $\partial h / \partial x$). The second term on the right-hand side is "new" and represents the effect of gradients in specific discharge on longitudinal water level profiles. As $\partial q / \partial x > 0$ at downstream terminations of enlarged river reaches, the term makes water level gradients more negative. These steeper slopes raise the water levels immediately upstream, thus contributing to water level peaks.

Numerical results

Table 1 lists the results of the Sobek-RE simulations. The Bernouilli effect can be calculated from the continuity consideration that the ratio of upstream and downstream flow velocities is inversely proportional to the ratio of upstream and downstream river widths, *i.e.* inversely proportional to 250/150. The flow velocity immediately upstream of the downstream termination is hence equal to 0.89 m/s. Thus the Bernouilli effect is 73 mm.

However, the results in Table 1 show a strange difference between the proxy based on river widening and the proxy based on flood diversion. The proxy based on widening suggests that the flood level peaks can be explained fully by the Bernouilli effect, without having to resort to contributions from gradients in specific discharge. Peaks computed with flood diversion, however, are twice as high. We suspect that one of the two interventions has been implemented incorrectly in the software, but we have not been able to verify this and to figure out which one.

Table 1. Water level peak heights as a function of space step: heights computed using Sobek-RE for two types of schematization and contribution of $\partial q / \partial x$ term.

Space step (m)	Water level peak height from Sobek-RE (mm) widening	diversion	Term of *q* gradient (mm)
50	67	134	57
100	65	131	59
200	61	124	62

Conclusions

Results for our original objective have remained inconclusive. We have found indications, nonetheless, that either river widening or flood diversion has been implemented incorrectly in Sobek-RE. If the implementation of widening is wrong, flood level peaks at downstream terminations can be explained by a combination of the Bernouilli effect and the local gradient in specific discharge. If the implementation of flood diversion is wrong, flood level peaks can be explained entirely by the Bernouilli effect and something is wrong with the proposed extended theory.

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Towards a quantitative assessment of the influence of heterogeneity on piping

W.J. Dirkx*[a], T.G. Winkels[a], L.P.H. van Beek[a], M.F.P. Bierkens[a,b]
a University of Utrecht, Department of Physical Geography, Faculty of Geosciences, P.O. 80.115, 3508 TC, Utrecht, the Netherlands
b Department Stochastic hydrology and geohydrology, Deltares, P.O. 85467, 3508 AL, Utrecht, the Netherlands.

Keywords — Piping, Heterogenity, Backwards erosion, Modelling

Background

The Netherlands is protected from river floods by thousands of kilometers of dikes. Maintaining these in an adequate state to resist several multiple failure mechanisms is of paramount importance to our nation. Piping is one of these potential failure mechanisms. Due to its subsurface nature piping is poorly understood. Piping can be initiated when the water level rises on the outside of the dike, if the resulting increase in hydraulic gradient is sufficient to initiate erosion a pipe may form under the dike, leading eventually to its collapse (Richards and Reddy, 2007; Vrijling, 2010).

The evolution of a pipe is described by two distinct erosion processes. The primary erosion occurs at the very tip of the pipe where the initial grains are dislodged. Secondary erosion refers to the widening and deepening of the open space created by the primary erosion as water flows to this drop in hydraulic head. At present only secondary erosion is incorporated into piping models due to the fact that primary erosion is extremely difficult to quantify (van Beek, 2015; Froiio, 2017).

Secondary erosion, the widening and the deepening of the pipe, indirectly influences the primary erosion by influencing the gradient over the pipe tip, creating a positive feedback loop. This makes calculating secondary erosion of paramount importance to quantifying piping as it indirectly influences the primary erosion.

Different scales of heterogeneity

In the subsurface heterogeneity occurs at many different scales (Weerts, 1996; Stouthamer, 2011) (see abstract T.G. Winkels, this volume), which do seem to have an effect on the piping process (Negrinelli, 2016). These variations in heterogeneity occur on a process scale up to the architecture scale of channel belts. Currently, piping is determined using only the d70 value of the substrate (RWS, 2017) and does not account for differences between facies and differences in grain size distribution within the facies. This is evidenced by instances of experiments performed at Deltares where a pipe would progress perpendicular to the direction of flow along the front of a coarser vertical layer. Additionally it was found that micro scale vertical layering of the porous medium delayed the progression of the pipe, further indicating that interfaces and variations in porous media on the process scale have an impact on the pipe evolution (Negrinelli, 2016). So both on the process and the channel belt scales, interfaces between and differences in the substrates through which piping occur have a significant, but potentially different, impact on the piping process.

Project aims and approach

The overarching aim of this project is to connect these different scales, to create a probability model for piping at larger scale scenarios. Up to the level at which governance for the levees operates. To this end, the heterogeneity at the lower scales also needs to be understood and the impact of piping at the various scales needs to be quantified in relation to the subsurface heterogeneity.

This project is twinned with that of T.G. Winkels and combines experimental with modelling development with data from the field to create an overall assessment of the piping hazard around the rivers in the Netherlands

Few experiments have been performed for measuring erosion on non-uniform sands under laminar flow conditions (Van Beek, 2015). So, the experiments that are to be performed for piping will initially test for different grain size distributions that do occur close to the cover layer in the field, but have not been tested yet for piping in an experimental setting. This should give more insight in how piping occurs in various different substrates.

* Corresponding author
Email address: w.j.dirkx@uu.nl (W.J. Dirkx)
URL: https://www.uu.nl/staff/WJDirkx

In a parallel development a model of the piping evolution is to be created. This model will couple the flow velocity field per time step to the possibility of erosion, updating the permeability of the model per time step to derive the evolution of the pipe over time. Using the information gathered from the physical experiments the model is to be calibrated for the process scale, after which it should be able to be upscaled to situations on the architecture scale. A flowchart of the intended project process is illustrated in figure 1.

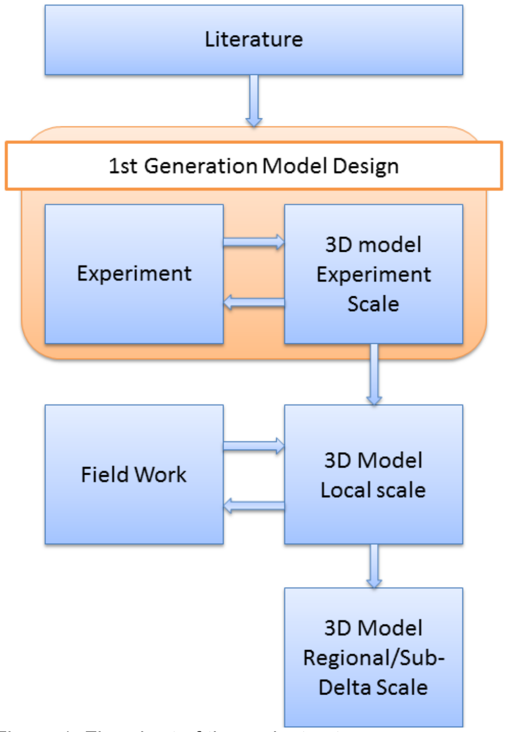

Figure 1: Flowchart of the project set-up

Describing piping at the process scale will allow for quantifying piping at larger scales, incorporating the new data from the experiments on different grain size distributions and median grain sizes. With this knowledge in hand it should be possible to construct a hazard map for the entire river area of the Netherlands.

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Role of bhawana bridge on Chenab river flooding, Punjab, Pakistan

Muzaffar Khan[a*], Alessandra Crosato[a]
[a]*IHE Delft, Dep. Water Science and Engineering, Westvest 7, Delft, the Netherlands*

Keywords — Floods, River Chenab

Introduction

The Chenab is the second largest river of Pakistan. It flows through the province of Punjab and is about 1240 km long with catchment area of 68000 km^2. The River has caused floods of various magnitudes in the past, for example in 1992, 1993, 1994, 1995, 1996, 1997, 2006, 2013, 2014 and 2016. Fig. 1 shows the discharges corresponding to past flood events (Drainage and Flood Zone, Irrigation Dep. Punjab, 2016). In each of these events, the overall damages to both the public and private properties were enormous as shown in Table 1 (FFC, 2014).

The construction of Bhawana Bridge in year 2014 is the most recent intervention made on River Chenab.

There are worries that the narrowing at the bridge location may enhance flooding upstream as it acts as a bottle neck for flood water flow.

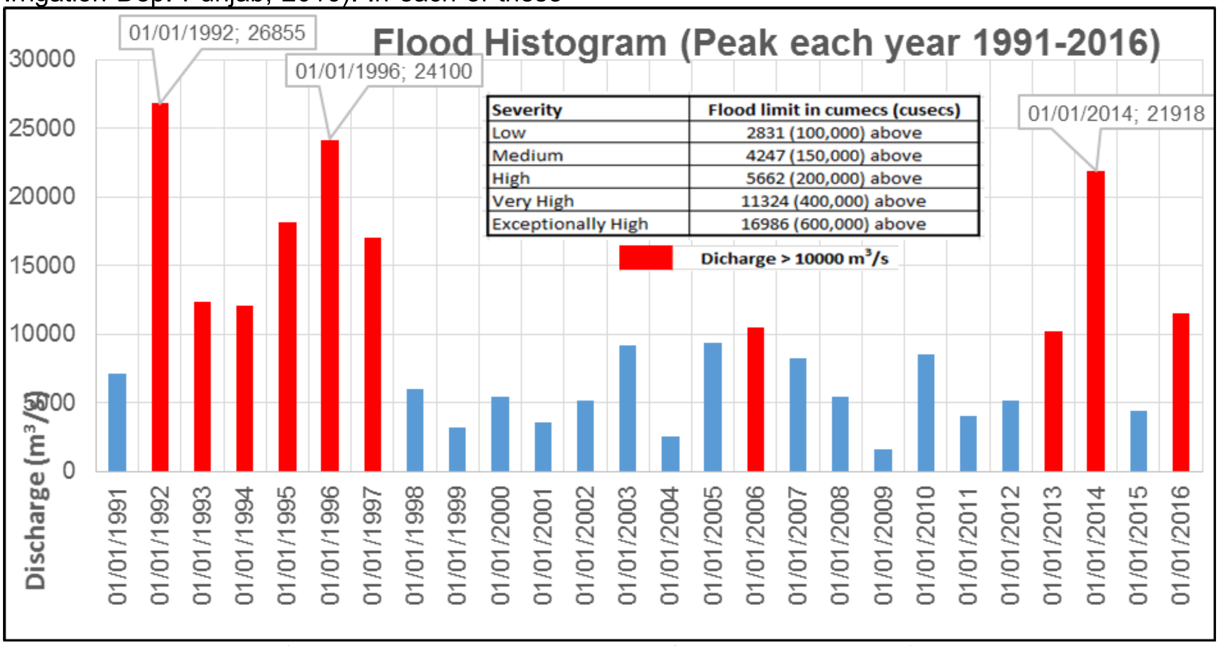

Figure 1 Flood Histogram from year 1991 to 2016 recorded at Qadirabad Barrage (D&F Zone, 2016).

Table 1 Historic flood damages in Pakistan 1992-2014

Sr. No	Year	Direct Losses (US$ Million)	Lost Lives (No.)	Affected Villages (No.)	Flooded Area (km^2)
1	1992	3010	1,008	13,208	38,758
2	1994	843	431	1,622	5,568
3	1995	376	591	6,852	16,686
4	2010	10000	1,985	17,553	160,000
5	2011	3730	516	38,700	27,581
6	2012	2640	571	14,159	4,746
7	2013	2000	333	8,297	4,483
8	2014	500	367	4,065	9,779
Total		**23099**	**5,802**	**104,456**	**267,601**

A devastating flood with peak of 21,917 m^3/s, recorded at Qadirabad Barrage, heavily hit Punjab province in September 2014 (Drainage

* Corresponding author
Email address: khan44@un-ihe.org

and Flood Zone, Irrigation Dep. Punjab, 2016) (Fig. 2). At least 25 deaths reported, 1769 houses damaged and 132 villages were affected in District Chiniot only (USAID, 2014).

It is believed locally that most of the flooding upstream of the Bhawana Bridge is because of the bottle neck effect of the bridge.

Figure 2 Bhawana Bridge experiences flood in 2014

Objective of this study

This study investigates the role of Bhawana Bridge and relative narrowing on upstream flooding.

Methodology

The work is carried out using a two-dimensional Delft3D hydraulic model as a tool for the investigation (Fig. 3). Two scenarios, with and without bridge are analysed and compared to determine the effects of the intervention through the simulation of several events. The morphological changes during a single flood event having magnitude greater than 10.000 m^3/s will also be analysed by allowing mobile bed to better establish the role of the bridge during floods considering the short term morphological changes that occur during the passage of a flood wave.

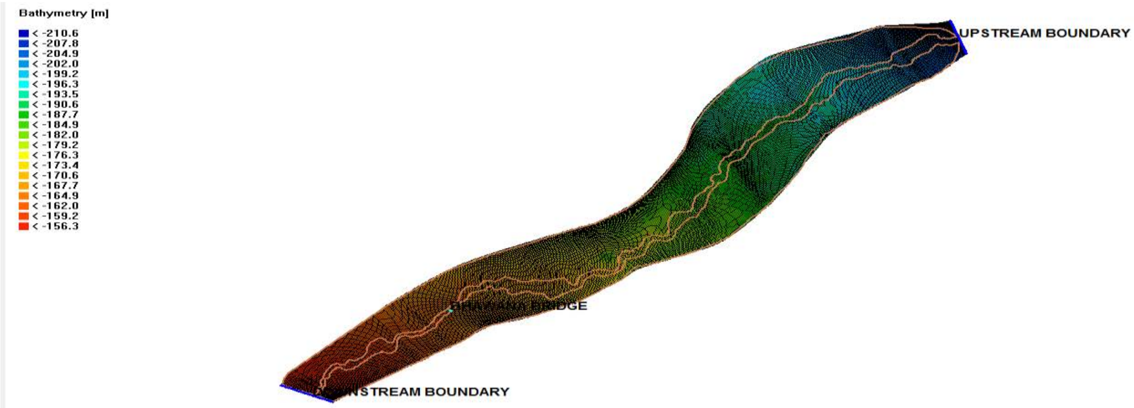

Figure 3 Model domain showing upstream and downstream boundaries.

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Effects of groynes on opposite bank erosion: a modelling approach

Tsegaye Tiga[a*], Alessandra Crosato[a,b], and Mohamed F. M. Yossef [c]
[a]IHE Delft, Dep. Water Science and Engineering, Westvest 7, Delft, the Netherlands
[b]Delft University of Technology, Dept. of Hydraulic Engineering, Stevingweg 1, Delft, the Netherlands
[c]Deltares, Boussinesqweg 1, 2629 HV, Delft, the Netherlands

Keywords — Groynes, opposite bank erosion

Introduction

Long series of groynes are constructed along river banks to reduce the channel width and to protect the banks from erosion (King, 2015). Single groynes are mainly constructed to deflect water to a desired course (Beckstead, 1975) and to protect local areas from erosion.

In the past decades, much work has been conducted to understand the effects of groynes on river flow and bed topography (Yossef, 2005, among others). Most studies consider long series of groynes that are constructed on both sides of a river or along one side. At present, it is hard to find studies that consider opposite bank erosion. Studies that focus on the effects of a single or a short series of groynes on the opposite bank are lacking.

Preliminary research in this direction has been conducted by Bonilla-Porras (2017) and Pinkse (2017) who described the effects of a single or a short set of groynes on opposite bank erosion in laboratory experiments. Bonilla-Porras (2017) tested four constant discharges and 2 groyne lengths to study the effects of a single groyne and three groynes on opposite bank erosion. Pinkse (2017) measured the flow field around those groynes. Their results show that bank erosion occurs not in front of the groyne(s), but more downstream, opposite to a forced bar, as shown in Figure 1. Figure 2 shows that a similar situation is observed along the Mara River, in Tanzania, where a small irregularity on the left bank (circled feature) that acts like a groyne has similar effects on opposite bank. This means that the effects observed in the laboratory might be representative also for real rivers. The assessment of bank erosion triggered by groyne(s) would allow identifying the right area that needs to be protected, which is an important information for river engineers and managers.

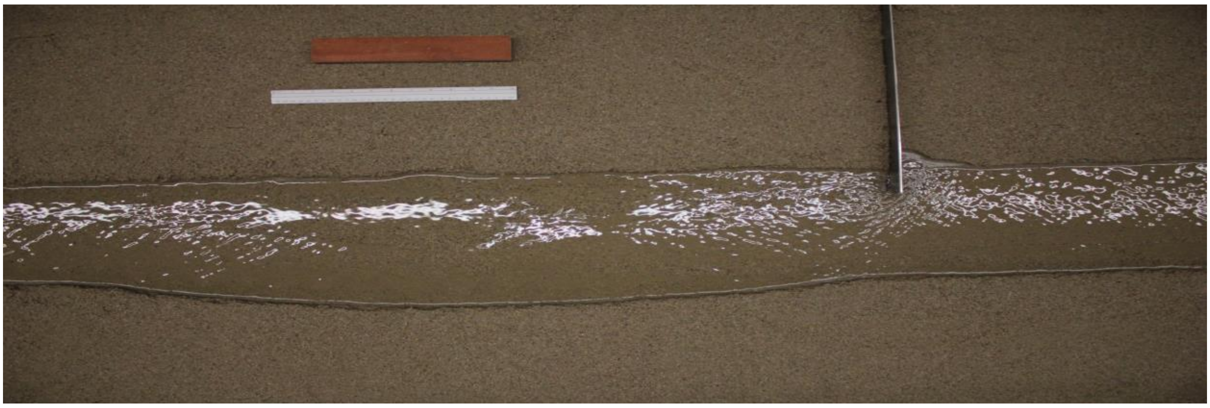

Figure 1. Opposite bank erosion with spatial lag (flow from right to left). Bonilla-Porras (2017)

* Corresponding author
Email address: ietiopica@gmail.com (Tsegaye Tiga)

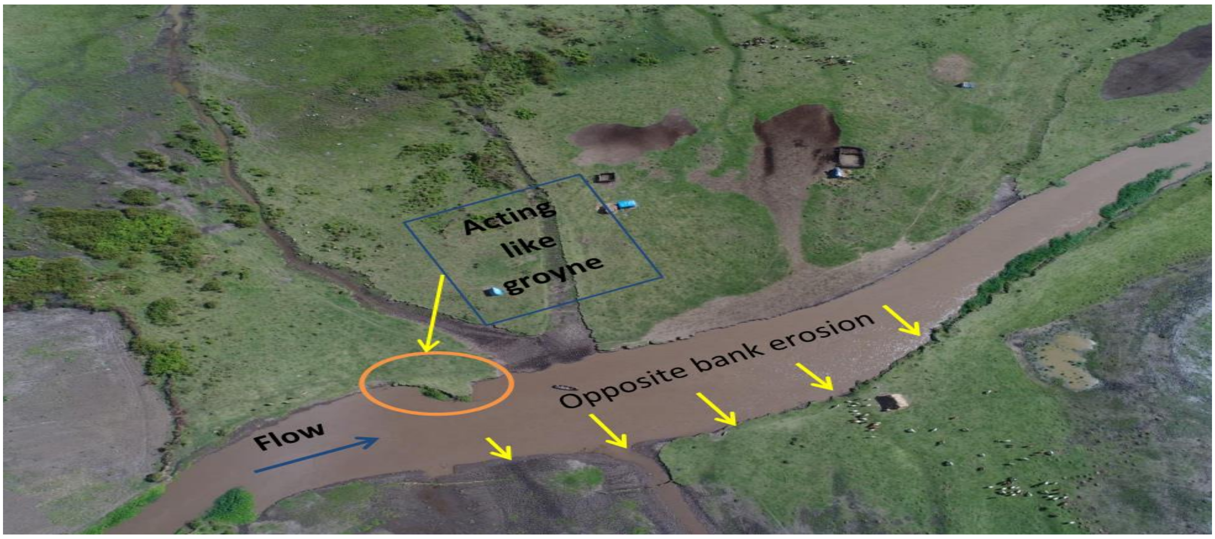

Figure 2. Real river example of groyne (small irregularity) induced opposite bank erosion: Mara River (Tanzania). Flow from left to right. Photo: courtesy Francesco Bregali.

In the experiments of Bonilla-Porras and Pinkse, the maximum bank erosion was observed for the combination longest groyne - highest discharge. However, high bank erosion was also observed with the shortest groyne and lowest discharge. These outcomes of laboratory experiments cannot be easily explained without numerical simulations describing the flow field in detail. In particular, it is important to estimate the forces acting on the opposite erodible bank.

Goal of this study

The goal of this study is to explain the laboratory observations made by Bonilla-Porras (2017) and Pinkse (2017) and generalize them.

Methodology

Considering the very small size of the experimental channel and the limitation of the Delft 3D software in representing such smaller dimensions, a numerical model is designed to reproduce an upscaled version of the experiments. After upscaling, 2D and 3D hydrodynamic simulations with LES (large eddy simulation) are carried out analyse the flow field around the groyne(s) and near the opposite bank. Formation of spiral flow and development of eddies is considered. Several scenarios are studied with different constant discharge values and 2 groyne lengths.

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Modelling assessment of the effectiveness of groyne lowering as a measure for bed stabilization

Simon van Laarhoven[a,b]*, Arjan P. Tuijnder[b], Johan Kabout[b], Maarten G. Kleinhans[a]
[a] *Utrecht University, Faculty of Geosciences, Department of Physical Geography, P.O. Box 80.115, 3508TC Utrecht, The Netherlands*
[b] *Arcadis Nederland B.V., Department of River Coast & Sea, P.O. Box 137, 8000 AC Zwolle, The Netherlands*

Keywords — Bed-stabilization, River expansion, Groyne lowering, Morphology, Delft3D, Waqua

Problem definition

The Dutch Rhine branches are exposed to structural erosion due to a disequilibrium between transport capacity and sediment supply. Historic normalization of the Rhine branches caused an increase in flow velocities, due to the increase in gradient and a decrease in cross-sectional area (Frings et al., 2009; RWS Oost-Nederland, 2016). As a consequence, the capacity to transport sediment increased. Additionally, the supply of sediment decreased, partly due to the construction of upstream weirs, which retain sediment (RWS Oost-Nederland, 2016). This combination, has resulted in structural erosion of the summer bed with an average of 1.5 cm/y (RWS Oost-Nederland, 2016).

All socio-economic and environmental functions accommodated by Rhine branches are affected by the subsiding bed (Arcadis, 2017b). Erosion up- and downstream of hard constructions generates obstacles for shipping (e.g. the hard bend protection at Nijmegen). Pipelines lose their cover, making them vulnerable. Water levels drop with the subsiding bed-level, resulting in among others drier floodplains which has a negative impact on the overall winter bed ecology. Especially wetlands are affected. The negative effects are progressive. To counteract these negative effects, the bed level should be stabilized.

Generally, large scale sedimentation is undesirable from the viewpoint of flood safety. Consequently, any sedimentation should be compensated by a river expanding measure to prevent raised water levels. Groyne lowering decreases the flow velocity and the associated transport capacity by expanding the cross-sectional area, causing both lower water levels and either less erosion or additional sedimentation (Arcadis, 2016; Busnelli et al., 2011). Downstream of the lowered groynes, the transport capacity is unchanged. This causes an erosion pit to form downstream of this section, as the river picks up sediment to satisfy its transport capacity (Arcadis, 2016).

The aim of this study is to assess the effectiveness of groyne lowering in combination with downstream nourishments as a combined measure for both bed stabilization and river expansion. A modelling approach was chosen to evaluate the effects of groyne lowering on both the hydrologic and the morphologic development of the summer bed.

* Corresponding author
Email address: simonvlaarhoven@gmail.com (S.van Laarhoven)

Methodology

In this study three scenarios were tested against a reference computation: 1) groyne lowering, 2) a nourishment downstream of Nijmegen and 3) combined groyne lowering and nourishment. In scenarios 1 & 3, 317 groynes were lowered with an average of 2.35 m. Groynes were only lowered along the Boven Rijn (BR) and Boven Waal (BW), as groynes have already been lowered downstream of Nijmegen (Arcadis, 2016). The nourishment applied in scenarios 2 & 3 consisted of 188000 m^3 of sand over a 10 km stretch downstream of the bend protection at Nijmegen, which coincides with the end of the groyne lowering section. This volume is approximately 4 times the yearly sediment deficit over this stretch (Arcadis, 2017a).

For Scenario 1 both the hydraulic and morphological effects were computed. For the other scenarios, only the morphological effects were computed, to assess the effect of nourishing on the erosion pit downstream of Nijmegen. The numerical hydraulic model Waqua was used to compute the initial change in water levels after groyne lowering (Scenario 1) for a BR discharge of 2000, 4000 and 18000 m^3/s. Additionally, Delft3D computed the morphological change over the period between 2015 and 2040.

Results

The Waqua results indicate a clear decrease in water levels caused by the groyne lowering upstream of river kilometre 880 (Fig. 1A). Downstream of Nijmegen water levels increase due to the river expansion along the BW, causing larger discharges over the Waal. This changes the discharge distribution at the Pannerdense Kop. The largest effects are observed for a BR discharge of 4000 m^3/s (approximately bank-full). At this discharge the effect of the groyne roughness is maximal. For smaller discharges the lowering is not yet fully effective, for larger discharges the discharge through the floodplains becomes important.

The Delft3D computations indicate erosion along the BRBW, despite groyne lowering (Fig. 1B). Compared to the reference situation in 2040, there is an overall decrease in erosion of about 20 cm along the BRBW (Fig. 1C). However, Fig. 1C shows several locations where erosion increases due to groyne lowering: 1) the expected erosion downstream of the lowered section (Fig. 1B illustrates its development through time), and 2) some locations along the BRBW where groynes are only situated along one side of the river (Fig. 2). At the second cluster of locations, groyne lowering is less efficient as the number of groynes is limited, causing a smaller reduction of the transport capacity than over the rest of the BRBW, resulting in local erosion.

Fig. 1C also indicates that implementing the nourishment reduces the total erosion downstream of the bend protection of Nijmegen with a couple of centimetres. In combination with the groyne lowering this nourishment is not sufficient to reduce erosion w.r.t. the reference situation in 2040. However, this could not have been expected, as the added sand volume was equal to the current sediment deficit over approximately four years.

Conclusions

The question on the effectiveness of groyne lowering as a bed stabilizing measure can be answered as follows: groyne lowering will not cause a raise in bed level elevation, however, the structural erosion is locally reduced with about 20 cm over 25 years. Erosion is increased downstream of the lowered groynes. Therefore, downstream measures are required as well. Either as nourishments or continued river expansion to match the decreased transport capacity. Additionally, groyne lowering should be optimized to reduce the local increase in erosion at locations with a limited number of groynes.

River expansion along the BW causes an undesired change in the discharge distribution at the Pannerdense Kop. Therefore, additional measures would be needed to maintain the discharge distribution.

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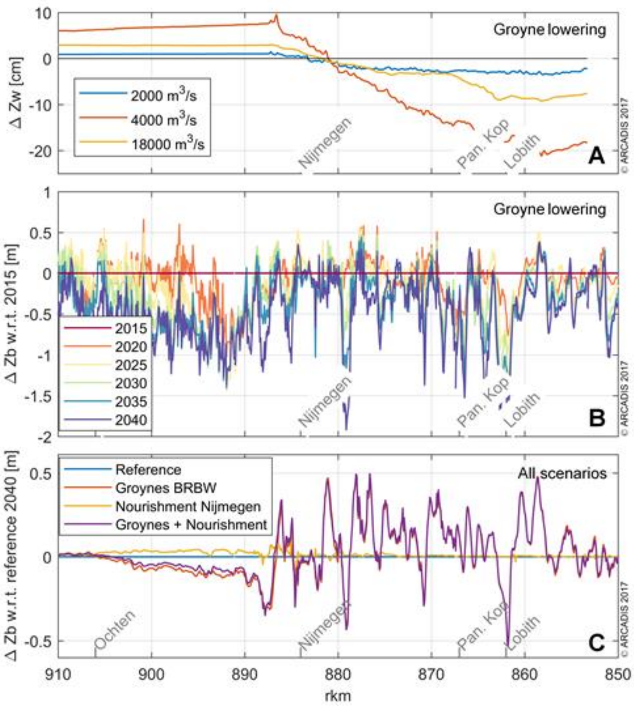

Figure 1. Hydro-morphologic effects of groyne lowering and two nourishment scenarios plotted along the river (rkm is kilometres along the river axis). A) illustrates the initial change in water level after lowering of all groynes along the Boven-Rijn and Boven-Waal (BRBW), as computed by Waqua. B) shows change in bed level elevation (w.r.t. the situation in 2015) caused by the groyne lowering along the BRBW (Delft3D). C) shows the difference between the bed level elevation for each scenario and the reference situation in 2040 (Delft3D).

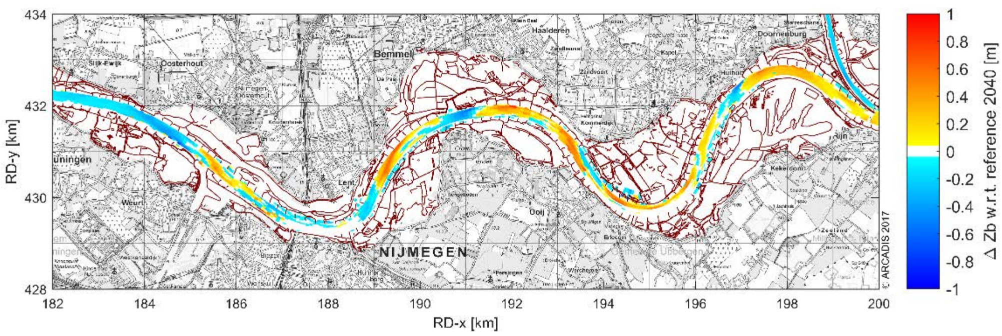

Figure 2. Map indicating the difference in bed level elevation for the situation in 2040 with (scenario 1) and without groyne lowering (reference), as computed in Delft3D. The brown lines indicate Baseline (river database) weirs, including groynes.

Response of engineered channels to changes in upstream controls: Simplified 1D numerical simulations

Meles Siele[1,*], Astrid Blom[1], Enrica Viparelli[2]
[1] Delft University of Technology, Faculty of Civil Engineering and Geosciences, Department of Hydraulic Engineering, P.O. Box 5048, 2600 GA, Delft, the Netherlands
[2] Department of Civil and Environmental Engineering, University of South Carolina, Columbia, USA

Keywords — transient response, equilibrium state

Introduction

Engineered alluvial channels are dynamic systems and continuously adjust their bed slope (by aggradation and degradation) and bed surface texture in response to changes in the upstream controls i.e., the water discharge, the rate and calibre of the sediment supply (Mackin 1948, Blom et al. 2016, 2017a). These adjustment processes (the transient phase) proceed until a new equilibrium state is reached. The equilibrium state can be disturbed, for instance, by natural changes or measures such as river training, repeated sediment extraction and nourishment measures. The resulting changes in sediment transport capacity, sediment supply rate or caliber of load induces adjustment of equilibrium.

From a practical point of view, knowledge of the two phases (transient response and long-term response) is essential, for instance, to avoid and minimize potential problems associated with gradient adjustment such as navigation, flood control and ecology (e.g. Blom 2016, Frings et al 2014). Examples are degradational rivers such as the Rhine, the Elbe and the Danube which are characterized by long-term trends of bed degradation (Blom 2016).

Few studies have addressed the transient state, for example, De Vries (1975) and Howard (1982), and these are restricted to unisize sediment cases. Here we extend these studies and assess the transient and long-term response (regarding bed level and bed surface texture) of mixed-size sediment channels to 1) an increase in the water discharge, 2) fining of sediment supply and 3) coarsening of the sediment supply.

Method

We apply a 1D numerical research code (Elv) (Blom et al 2017a,b) to simulate the temporal and spatial change of bed level and bed surface texture. The code solves for the flow (the backwater equation), changes in bed level and bed surface texture (using the Hirano equations). We apply the Meyer-Peter and Müller (1948) load relation and the hiding relation of Egiazaroff (1965). The code is applied to a one dimensional schematic river, 100 km long. We use two grain size fractions: gravel and sand.

The initial state (regarding bed slope and bed surface texture) is an equilibrium state associated with an initial upstream control. A perturbation is introduced to the initial upstream controls in three cases (1) 25% increase in water discharge; (2) 25% fining of the sediment supply (increase in the sand content of the supply by 25%); (3) 25% coarsening of the sediment supply (increase in the gravel content of the supply by 25%). The initial bed surface and substrate is assumed to have the same texture.

Results and discussion

The initial and final equilibrium states (regarding bed slope and bed surface texture) for the three cases agree with the results of the analytical models of Blom et al (2017a). The equilibrium slope and bed surface texture are set by the requirement of transporting the imposed sediment supply rate and caliber downstream without aggradation and degradation (e.g. Blom et al 2016, 2017a). Fig 1 shows the results of the numerical runs.

Case 1: increase in water discharge

When the water discharge is increased, the channel attains a new equilibrium state that is characterized by a smaller bed slope without a change in the bed surface texture (Fig 1, left). The slope adjusts such as the flow velocity suffices to transport the supplied sediment downstream. As the sediment supply does not change the required flow velocity to transport the load downstream does not change. As the flow velocity does not change, the mobility difference between gravel and sand does not change and the surface texture does not change. In the transient state, the increase in water discharge increases the sediment

* Corresponding author
Email address: m.s.tewolde@tudelft.nl (Meles Siele)

transport capacity compared to the supply and hence a degradational wave and a coarsening wave (and subsequent fining wave) form that migrate downstream (Fig 1, left).

Case 2: fining of sediment supply

When the sand content of the sediment supply to a mixed-size sediment channel increases, the equilibrium state is characterized by a smaller slope and a finer bed surface as a finer load requires a smaller slope and a finer surface (Fig 1, middle) to be transported downstream (Blom et al 2016, 2017a). The transient state is characterized by a degradational wave and a fining wave both migrating downstream (Fig 1, middle). This confirms flume experiments (e.g. Curran and Crowe 2005), which have demonstrated that an increase in sand supply to a gravel bed river increase the gravel mobility, indicating that smaller bed slope suffices to transport finer sediment supply.

Case 3: coarsening of sediment supply

When the volume fraction content of the coarse size fraction of the sediment supply to a mixed-size channel is increased, the equilibrium state is characterized by a larger slope and a coarser bed surface, in order to transport the coarser sediment downstream (Fig 1, right). In the transient state, the coarsening of sediment supply leads to an aggradational wave and a coarsening wave (Fig 1, right). The coarsening wave induces a downstream sediment deficit and consequently a preceding degradational wave.

Preliminary conclusions

We present and explain the results of simplified numerical runs that assess the transient and long term response of mixed-size sediment channel to changes in upstream controls.

Acknowledgements

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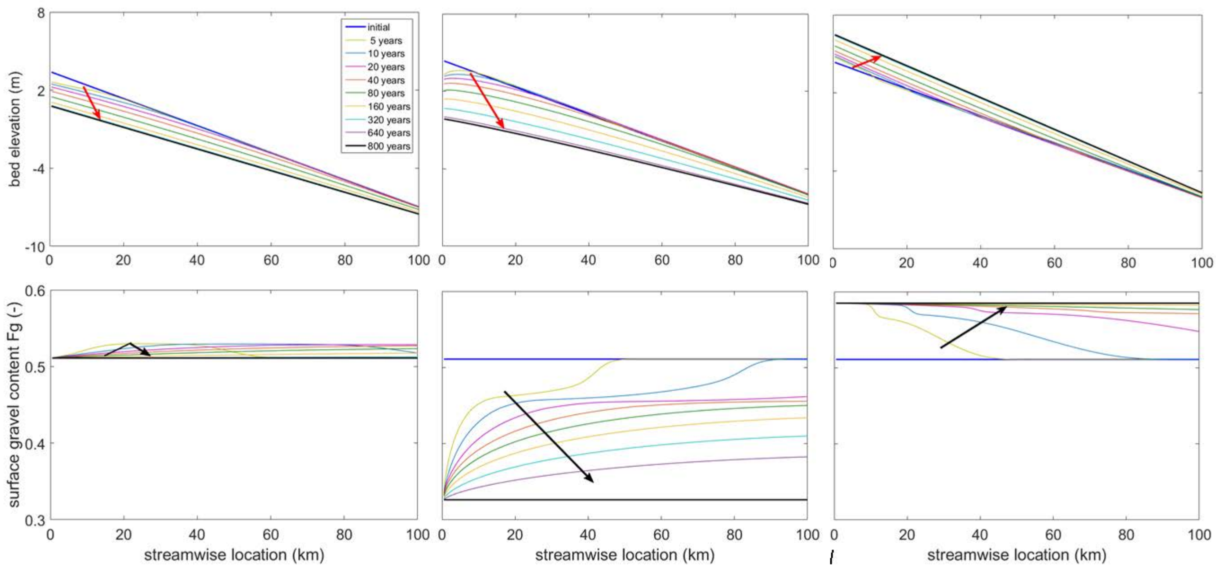

Figure 1. Transient and equilibrium response in case 1 (25% increase in water discharge, left); case 2 (25% fining of sediment supply, middle); and case 3 (25% coarsening of sediment supply, right). Top plot shows changes in bed elevation and bottom plot show change in surface gravel content. Arrows indicate the transient phase

Subsurface heterogeneity at different spatial scales: Impact on piping hazard zones in the Netherlands

T.G. Winkels[*a], W.J. Dirkx[a], E. Stouthamer[a], K.M. Cohen[a,b], H. Middelkoop[a]
[a] *Utrecht University, Department of Physical Geography, Faculty of Geosciences, P.O. 80.115, 3508 TC, Utrecht, the Netherlands*
[b] *Department of Applied Geology and Geophysics, Deltares, P.O. 85467, 3508 AL, Utrecht, the Netherlands.*

Keywords — Fluvial deposits, heterogeneity, piping

Introduction

River embankments form an essential part of the primary flood defence in the Netherlands. In addition to the construction of the embankments itself, the subsurface beneath embankments plays an important role in their stability. The Dutch subsurface is however extremely heterogenic, resulting in various subsurface build-ups underneath these embankments. At locations where a river dike overlies a permeable sand body, seepage-pathways can emerge during flood periods, creating so called pipes, which can ultimately trigger dike destabilization (Van Beek et al., 2013). At present, piping risks are calculated using the Sellmeijer formula which assumes the sandy body to be homogenous (Kanning, 2012; Sellmeijer, 2006; Sellmeijer et al., 2011; Van Beek et al., 2013). However, it is widely recognized that the internal build-up of channel belts is much more complex, (Bridge, 2002; Toonen et al., 2012; Miall, 1996; Weerts, 1996; Van de Lageweg et al., 2016). Despite this, incorporating the wide range of sedimentary characteristics within these fluvial sand bodies into the piping assessment tools remains challenging. This project focusses on the characterisation and schematisation of these heterogenic (fluvial) deposits to better identify potential hazard zones for piping. The challenge is however to incorporate the various nested scales of heterogeneity, within and between these deposits, into the piping modelling.

Reconstruction scales

Within this project we identify the following three scales: delta scale, within channel-belt scale and process scale. Each scale has its own potential and limitations for assessing the piping process.

* Corresponding author
Email address: T.G.winkels@uu.nl (Tim Winkels)

Scale-1: Delta scale.
The Dutch subsurface is extremely heterogenic, due to the presence of multiple generations of sandy channel belts in the subsurface (Stouthamer and Berendsen, 2000). Potential piping zones are already directly linked to the locations of these paleo-channels (Taal, 2015). However, at present connectivity to the sandy Pleistocene substrate, consisting of fluvial / aeolian deposits, is not taken into account. The hypothesis is that connectivity with these deeper aquifers changes the large scale groundwater flows thus effecting the smaller scale seepage flows during high waters. Incorporating these variations in hydrological models will help to better understand the processes involved and study the effects of these large scale non-uniformities.

Scale-2: Within channel-belt scale.
Differences in depositional processes within both active and abandoning river systems result in distinct sedimentary units each with their own distinct hydrological characteristics. Identifying these units, i.e. architectural elements, is crucial when trying to better understand the internal heterogeneity of channel belts. This project aims to make a full three-dimensional reconstruction of these internal architectural elements and surrounding overbank deposits, by subdividing them into 1) cross-bedded sandy deposits, 2) vertically aggraded sandy deposits (e.g. plug-bars, chute-bars), 3) overbank deposits and 4) fine-grained, locally organic, laminated deposits. The resulting subsurface models will contribute to a better understanding of the systematics behind the distribution of these architectural elements and to set-up prediction parameters for each element. This method of sedimentary reconstruction is an important step to more functional hydrological characterisation of channel belts than what is currently available.

Scale-3: Process scale.
Multiple studies show that architectural elements can be subdivided into multiple subunits (e.g. Bridge et al., 2002, Makaske and Weerts, 2005; Miall, 1996). Most of these

studies use sedimentary structures, acquired by the studying of exposed sections, as a tool for the subdivision of architectural elements. Exposed sections (within trenches) are however limited due to cost and often only reveal the upper section of channel belt deposits. Although the digging of trenches is outside the scope of this project, joining up with ongoing (archeological) projects which incorporate these trenches, makes it possible to study this small scale heterogeneity and give insight in the boundaries and sedimentary structures present within and between architectural elements.
At present this type of subsurface heterogeneity is not taken into account within the piping models. It however may have a strong influence on seepage flow patterns and subsurface stability, therefore impacting the formation and progradation of pipes in the subsurface. By integrating this type of subsurface heterogeneity into the hydrological models, the impact of these sedimentary structures on the piping process can be investigated (see abstract W.J. Dirkx, this volume).

Although these scales are presented separately it is important to realize they all intertwine and effect each other. The result is that all scales should always be kept in mind when working on subsurface heterogeneity and stability of water defences.

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NCR Organisation

The Netherlands Centre for River studies (NCR) is the leading cooperative alliance between all major Dutch institutes for river studies. We integrate knowledge, facilitate discussion and promote excellent science. By linking the strongest expertise of its partners, NCR forms a true centre of excellence in river studies. The disciplines within NCR are contributed by its partners and include Hydrodynamics and Morphodynamics, Geomorphology and sedimentology, River ecology and water quality and River governance, serious gaming and spatial planning.

The NCR has three bodies: the program secretary, program committee and supervisory board. Their tasks are agreed upon in the cooperation agreement (samenwerkingsovereenkomst) 2012, which is an update from the original 1998 agreement.

Program committee

The program committee consists of representatives from each of the NCR partners. The program committee chooses the chair, which currently is dr. Ralph Schielen of Rijkswaterstaat. The program committee is responsible for the (scientific) program of NCR. The committee initiates and stimulates research activities, proposals, and exchange of knowledge, ideas, experience, and results. The committee has regular meetings, with a frequency of about four times per year.

Supervisory board

The supervisory board consist of one senior member of each NCR partner. The member of the board choose their chair, which currently is prof. dr. Jaap Kwadijk of Deltares. The board supervises the implementation of the cooperation agreement, mediates in disputes and approves the annual program.

Program secretary

The program secretary is responsible for the continuity, day-to-day management, communication (e.g. website, mailing, social platforms) and reporting of the NCR. Additionally, the program secretary is part of the program committee and supervisory board in the role of secretary. The secretary is appointed by the Supervisory board. The current secretary is ir. Koen Berends of Deltares.

Netherlands Centre for River studies

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Notes

secretary@ncr-web.org | https://ncr-web.org

Netherlands Centre for River studies

NCR c/o University of Twente
Drienerlolaan 5
Building Horst, Room HR-W205
7522 NB Enschede
P.O. Box 217
7500 AE Enschede
The Netherlands

NCR c/o Deltares
Boussinesqweg 1
2629 HV Delft
P.O. Box 177
2600 MH Delft
The Netherlands

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