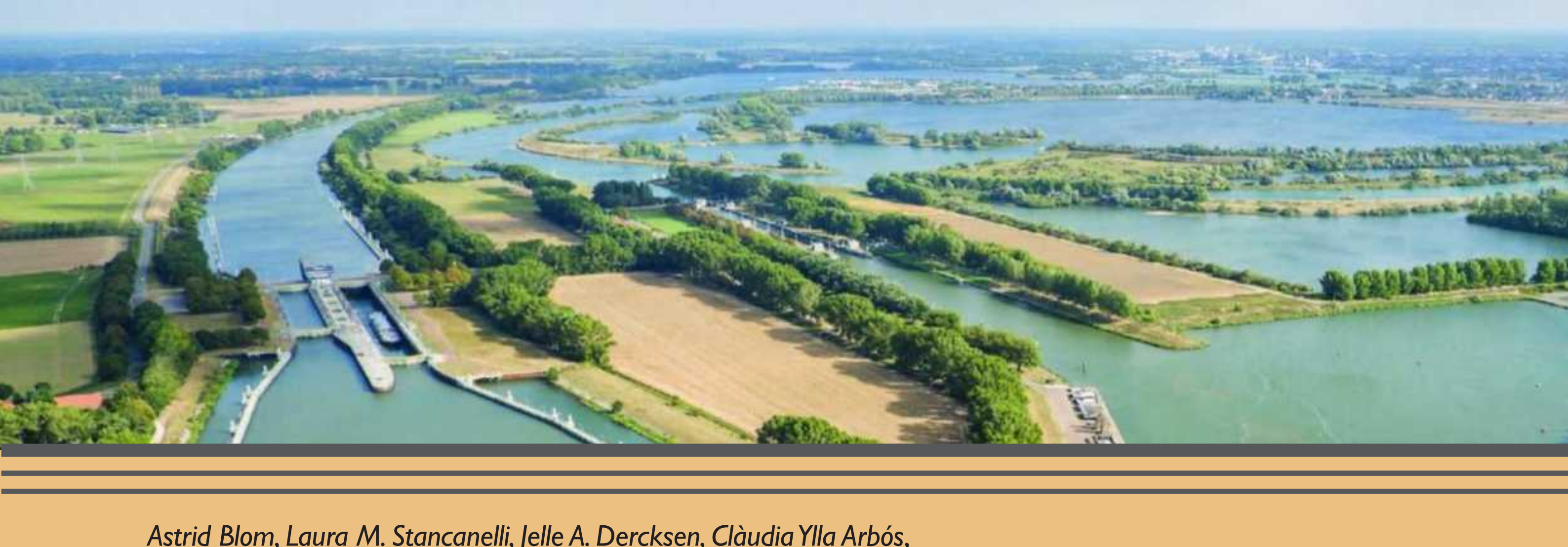
Anthropogenic Rivers

Book of Abstracts

NCR DAYS 2022

13-14 April | TU Delft



Astrid Blom, Laura M. Stancanelli, Jelle A. Dercksen, Clàudia Ylla Arbós, M. Kifayath Chowdhury, Shelby M. Ahrendt, Carolina Piccoli, Ralph M.J. Schielen, Kees Sloff & Jill H. Slinger (eds.)

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NCR

NCR DAYS 2022
Anthropogenic Rivers

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Shelby M. Ahrendt, Carolina Piccoli, Kees Sloff, Jill H. Slinger, & Ralph M.J. Schielen (eds.)

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Contents

Preface

Welcome to the 24rd edition of the NCR Days, the annual meeting of the Netherlands Centre for River studies (NCR), hosted by Delft University of Technology. Organized around the theme "Anthropogenic Rivers", this year's NCR Days will take place on 13-14 April 2022 in a hybrid format, in person in Delft as well as online.

This edition of the NCR Days presents a two-day program with oral and poster contributions in five thematic sessions: flood risk management, river functions under pressure, river morphodynamics and sediment management, challenges in river governance, and river restoration and ecology.

We have four keynote speakers. The first is Nathalie Asselman of Deltares. She will reflect on her experiences with flood risk management in Limburg and address the July 2021 peak flow event in (the tributaries of) the Meuse River. Our second keynote speaker is prof Gary Parker from the University of Illinois at Urbana-Champaign. He will make us reflect on the ubiquitous appearance of rivers in his presentation on "Morphodynamics of lowland river networks modeled as simple binary trees". The third keynote speaker is Suzanne Linnane from Dundalk Institute of Technology in Ireland. She will underline the relevance of and teach us on river governance during her speech "Water governance for future proofing – an Irish perspective". The fourth keynote speaker is Bas Roels from WWF Netherlands. He will be illustrating the Room for Living Rivers project – WWF, commenting on the need to accelerate the implementation of nature-based solutions in Dutch river management practices.

It was a pleasant experience for the LOC members to organize the 2022 edition of the NCR Days. We thank the NCR Programme Secretary Koen Berends for his support and advice in this effort. Finally, we gratefully acknowledge NWO Science for offering financial support for the event.

We very much hope you will all be enjoying this 2022 edition of the NCR Days!

With riverine thoughts,

the LOC
Shelby Ahrendt, Astrid Blom, Kifayath Chowdhury, Jelle Dercksen, Otti Kievits, Nina Piccoli, Ralph Schielen, Jill Slinger, Kees Sloff, Laura Stancanelli, Clàudia Ylla Arbós

Delft, April 2022

Conference details

Organising partner

Organizing partner of the 2022 edition of the NCR Days is Delft University of Technology.

The venue

The conference venue is the Faculty of Civil Engineering & Geosciences at Delft University of Technology in Delft, Netherlands. Delft University of Technology was founded on 8 January 1842 by King William II of the Netherlands as Royal Academy for the education of civilian engineers, for serving both nation and industry, and of apprentices for trade. On 20 June 1864, Royal Academy in Delft was disbanded by a Royal Decree, giving a way to a Polytechnic School of Delft. Yet another Act, passed on 22 May 1905, changed the name of the school to *Technische Hogeschool van Delft* (Delft Institute of Technology), emphasizing the academic quality of the education. Polytechnic was granted university rights and was allowed to award academic degrees. After the end of the Second World War, TU Delft increased its rapid academic expansion. On 1 September 1986, Delft Institute of Technology officially changed its name to Delft University of Technology, underlining the quality of the education and research provided by the institution.

Local organising committee (LOC)

The LOC consists of the following members: Shelby Ahrendt, Astrid Blom, Kifayath Chowdhury, Jelle Dercksen, Otti Kievits, Nina Piccoli, Ralph Schielen, Jill Slinger, Kees Sloff, Laura Stancanelli, and Clàudia Ylla Arbós.

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Program

2022 NCR DAY 1 - WEDNESDAY 13 APRIL 2022

	9:00-9:30	Registration
	9:30-9:40	Opening and Announcements
Session 1	**Flood Risk Management**	
	9:40-10:30	Nathalie Asselman - Deltares Flood Risk Management in Limburg
	10:30-10:50	Poster pitches
	10:50-11:30	Coffee Break and Posters Sessions 1 and 3
	11:30-11:45	Hieu Ngo - University of Twente The discharge magnitude of the 1374 millennium flood event in the Rhine river
	11:45-12:00	Anne Thewissen - Delft University of Technology Flood of July 13-15 2021: a new type of floods in Western Europe?
	12:00-12:15	Madoche Jean Louis - IHE Delft Institute for Water Education Effects of urbanization, deforestation and climate change on flooding in Cap-Haitien, Haiti
	12:15-13:15	Lunch Break
Session 2	**River Functions under Pressure**	
	13:15-13:30	Jana Cox - Utrecht University Historic narrowing and deepening of the Rhine-Meuse estuary causes long term sediment deprivation
	13:30-13:45	Gonzalo Duro - Witteveen+Bos Nature-friendly banks in the IJssel River - Measurements, analyses and recommendations
Session 3	**River Morphodynamics and Sediment Management**	
	13:45-14:00	Lieke Lokin - University of Twente Modelling strategies for low flow dune behaviour
	14:00-14:15	Hermjan Barneveld - Wageningen University & Research & HKV Massive morphological changes during the 2021 summer flood in the River Meuse
	14:15-14:30	NCR & Knowledge Valorisation
	14:30-15:10	Coffee Break and Posters Sessions 1 and 3
	15:10-15:25	Matt Czapiga - University of South Carolina (online) Best Practices for Longitudinal Training Walls to mitigate channel bed erosion
	15:25-16:15	Gary Parker - University of Illinois@UC (online) Morphodynamics of Lowland River Networks Modeled as Simple Binary Trees
	17:00-18:00	Drinks and Bites*
	18:00-21:00	Conference Dinner

	16:15-17:45	*NCR Board Meeting

POSTERS on NCR DAY 1 - WEDNESDAY 13 APRIL 2022

S0-1 Young-NCR (YNCR)
The new board of NCR: Young NCR

Session 1 Flood Risk Management

S1-1 Arjen Haag - Deltares
River ice and flood monitoring from space: bridging research and operational practices

S1-2 Bram Peters - Wageningen University & Research
Role of Albert Canal system in July 2021 flood: what can we learn from this?

S1-3 Leon Besseling - University of Twente
Assessing the performance of an LSTM neural network and a HAND model for long-term real-time flood forecasting

S1-4 Zeina Abi Aad - IHE Delft Institute for Water Education
Geul River flooding reproduced with a Delft3D depth-averaged model

S1-5 Earvin van Alderwegen - Delft University of Technology
Modelling open channel flow for the features of a flexible groyne

S1-6 Shelby Ahrendt - University of Washington & Delft University of Technology
The influence of floodplain geometry on riverbed elevation change within and between flood events

S1-7 Paul Hudson - Leiden University
Sedimentation from the extreme summer 2021 flood along the Maas River, Netherlands

Session 3 River Morphodynamics and Sediment Management

S3-1 Bart Kemp - Wageningen University & Research
Linking hydraulic roughness to dune slipface angle: a RANS numerical model study

S3-2 Claudia Ylla Arbos - Delft University of Technology
Mid-Century Channel Response to Climate Change in the Lower Rhine River

S3-3 Iris Niesten - Wageningen University & Research
Residual sediment transport in a stratified estuarine channel

S3-4 Judith Zomer - Wageningen University & Research
Competition and interaction between two bedform scales in the Dutch river Waal

S3-5 Kifayath Chowdhury - Delft University of Technology
Channel Bed Erosion Characteristics in the Upper Dutch Rhine Bifurcation Region

S3-6 Mathijs van Oostrum - University of Twente
The effect of longitudinal training dams and groyne lowering on river dunes

S3-7 Mohammed Gamal Mezied - IHE Delft Institute for Water Education
Effects of Suspended Sediment Transport on Bar Characteristics

S3-8 Patricia Buffon - Delft University of Technology
Sediment-driven flows induced by an impinging water jet

S3-9 Pepijn van Denderen - HKV Consultants
An interactive atlas of river morphodynamics

S3-10 Ralph Schielen - Rijkswaterstaat & Delft University of Technology
Sediment transport measurements in the Lower Rhine: preliminary findings

S3-11 Willem Ottevanger - Deltares
Quantification of accuracy in morphodynamic modelling

S3-12 Thorvald Rorink - University of Twente
How effective are multiple side channels in the River Waal in mitigating bed degradation?

S3-13 Libby Casavant - University of Iowa, USA
Evaluating Sediment Diversion Channels on Sediment-Heavy Rivers

2022 NCR DAY 2 - THURSDAY 14 APRIL 2022

Session 4	**Challenges in River Governance**	
	9:30-10:20	Suzanne Linnane - Dundalk Institute of Technology, Ireland Water governance for future proofing – an Irish perspective
	10:20-10:35	Gertjan Geerling - Deltares Urban floods and human health impacts
	10:35-10:55	Poster pitches
	10:55-11:35	Coffee Break and Posters Sessions 2, 4 and 5
	11:35-11:50	Astha Bhatta - Delft University of Technology Living labs for improved collaboration in river management
Session 5	**River Restoration and Ecology**	
	11:50-12:05	Frank Collas - Radboud University Migration of migratory fish species through shore channels along longitudinal training dams in the River Waal
	12:05-13:05	Lunch Break
	13:05-13:55	Bas Roels - WWF Netherlands Room for Living Rivers; the need to accelerate the implementation of nature based solutions in Dutch river management practice. An overview of urgencies and concepts
	13:55-14:10	Michael Tritthart - BOKU Austria Optimization of side channel reconnection measures at the Austrian Danube
	14:10-14:25	Natasha Flores - Radboud University Detection of macroplastics in riverine ecosystems using imaging sonars
	14:25-14:40	Twan Stoffers - Wageningen University & Research The role of habitat heterogeneity as driver for diversity and abundances of young-of-the-year riverine fishes
	14:40-15:20	Coffee Break and Posters Sessions 2, 4 and 5
Session 2 cont'd	**River Functions under Pressure**	
	15:20-15:35	Eveline van der Deijl - Deltares Basisrivierbodemligging - A reference river bed level - Application to the Meuse flood of 2021
	15:35-15:50	Bart Strijker - Delft University of Technology Vulnerability of villages in the Dutch Geul valley
	16:00-16:15	Awards, wrap up and closing
	16:30-....	YNCR Activities

POSTERS on NCR DAY 2 - THURSDAY 14 APRIL 2022

S0-1	Young-NCR (YNCR) The new board of NCR: Young NCR
Session 2	**River Functions under Pressure**
S2-1	Maria Barciela Rial - HAN University of Applied Sciences Beneficial (re)use of local sediment as a means for sustainable river management
S2-2	Chit Yan Toe - Delft University of Technology Predicting the flow and transport of plastic debris in open waters
S2-3	Erik Mosselman - Deltares & Delft University of Technology Final evaluation of longitudinal-training-walls pilot in the river Waal
S2-4	Tim van Emmerik - Wageningen University & Research Plastic transport through the Dutch rivers
S2-5	Andries Paarlberg - HKV Consultants Real-time monitoring of the rivers Boven-Rijn and Waal to support dredging operations
S2-6	Gamal Alahmady - IHE Delft Institute for Water Education River Bar Downscaling with Bed Sills and Bottom Groynes: A Numerical Study
S2-7	Leon de Jongste - Witteveen+Bos Towards scaling up sediment nourishments in the Dutch Rivers
S2-8	Parisa Khorsandi Kuhanestani - University of Twente Inventing a hydraulic river modelling approach to simulate high flow and low flow conditions
S2-9	Tatjana Edler - Utrecht University Trends in suspended sediment fluxes across the Rhine river basin (1997-2014)
Session 4	**Challenges in River Governance**
S4-1	Evelien van Eijsbergen - Rijkswaterstaat-WVL Long-term development of lowland rivers Rivers2Morrow - a research program
S4-2	Raoul Rademaker - Delft University of Technology Modelling both local and national effects of construction and operation of the Pwalugu Multipurpose Dam
S4-3	Hammond Antwi Sarpong - Dundalk Institute of Technology, Ireland Communicating water availability to improve awareness and implementation of water conservation: A study of the 2018 and 2020 drought events in the Republic of Ireland
Session 5	**River Restoration and Ecology**
S5-1	Frank Collas - Radboud University The use of UV traps to monitor mayflies, stoneflies and caddisflies along the river Waal
S5-2	Giulio Calvani - University of Florence, Italy Exploring natural vegetation flow resistance for large-scale simulation of Dutch rivers
S5-3	Jakob Grosfeld - Delft University of Technology Variability and dynamics of riverbank litter in groyne fields
S5-4	Jelle Dercksen - Delft University of Technology Exploring the relationship between eDNA and eRNA to advance biomonitoring techniques in rivers
S5-5	Martine van der Ploeg - Wageningen University & Research Anthropogenic drivers of river levee heterogeneity: present and past interventions
S5-6	Rose Pinto - Wageningen University & Research Plastics on the move: Discharges to plastic transport in the Odaw river, Ghana
S5-7	Wilco Verberk - Radboud University Adding up effects of warming and hypoxia and translating these to heat stress experienced by riverine animals

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Invited Abstracts

Keynote Presentation

Nathalie Asselman

Deltares

Bio

Nathalie Asselman has a PhD in Physical Geography. Since 1999 she has been working at Deltares to provide advise on Integrated Flood Risk Management. She started as flood inundation modeller and later also became project leader of large, integrated projects on flood risk management. Example projects comprise implementation of the EU Floods Directive, the development and implementation of integrated flood risk management strategies in the Netherlands (e.g. the Dutch Deltaprogramme, and the programme on Integrated River Management) and abroad (e.g. Bangladesh Deltaplan 2100). In July 2021, Nathalie participated in the Task Force Fact Finding and presented the hydraulic and morphological findings related to the Meuse river in the Netherlands. She now also is the project leader of the water system evaluation, for which Deltares functions as a coordinating partner for the water board and province Limburg.

Title

Flood Risk Management in Limburg

Abstract

In July 2021, large areas in the province of Limburg in the Netherlands were affected by extreme rainfall. Record high discharges were measured in the Meuse river, but also in the tributaries that enter the Meuse river in the Netherlands (e.g. the Roer and the Geul). The resulting floods caused severe damage to buildings and infrastructure. Immediately after the floods, the Task Force Fact Finding was commissioned by ENW (the Dutch Expertise Network on Flood Risk and Flood Defenses) to start with data collection and use these data for a first analysis. Shortly after the Task Force presented their finding, the water board and the province Limburg started a project to evaluate the functioning of the water system in the south of Limburg. This evaluation consists of a description of what happened in July 2021, additional analysis to understand the processes behind the extreme flood event, and a first assessment of potential measures. This presentation will provide a brief summary of some of the findings published by ENW (2021), followed by an overview of the first results of the water system evaluation.

Keynote Presentation

Gary Parker

University of Illinois at Urbana-Champaign, USA

Bio

Gary Parker has been a professor at the University of Illinois since 2005, holding the W.W. Grainger chair at Civil and Environmental Engineering and the W.H. Johnson chair at Geology. He received numerous honours, including the ASCE Huntour Rouse Hydraulic Engineering award and was elected to the US National Academy of Sciences. His research interest include river morphodynamics, landscape evolution and response of rivers to climate change. Some recent research involves the study of dendricity of drainage networks (10.1073/pnas.2015770118) and lateral migration of meanders (10.1029/2020JF005645). Approaching his status emeriti, Gary Parker happily agreed to give a keynote presentation at the annual NCR meeting.

Title

Morphodynamics of Lowland River Networks Modeled as Simple Binary Trees

Abstract

River networks are ubiquitous in nature. The example of the Amazon River, South America, is shown here. Typically, channel branches farther upstream tend to be steeper than branches farther downstream. Here we explain this tendency via a simple model of lowland sand-bed stream networks. Any given downstream branch bifurcates into two branches upstream, here each assumed to have discharges equal to half of the downstream branch. Each branch satisfies (at bankfull flow) a relation each for flow resistance, sand transport and sediment mobility Shields number. We show that if the transport rate of sand increases downstream in proportion to the water discharge, the river slope must be the same everywhere, so that the long profile following any path shows no upward concavity. When the sand load increases downstream at a lower rate than the water discharge, on the other hand, upward concavity is manifested. The bifurcations are allowed to continue upstream until a specified drainage density is reached. The inverse of drainage density scales the distance from any channel to the nearest ridge; at an appropriately low value, it is assumed that sediment can be delivered to the nearest stream solely through overland processes. We use the above conditions to determine the extent of the spatial network, and also the spatial variation of network denudation rate.

Keynote Presentation

Suzanne Linnane

Dundalk Institute of Technology, Ireland

Bio

Suzanne Linnane heads up the 'Water, Communities and Development' at Dundalk Institute of Technology, Ireland. She serves as the Education Sector representative on the Irish National Water Forum and is a member of its Education and Research working groups. Much of her current research work is based around integrated catchment management and source protection of drinking water sources for rural water supplies in Ireland and sustainable water provision in the developing world. All her projects have a strong stakeholder component and involve consultation with relevant parties throughout all stages of the process with a view to sustainability and policy implementation. As well as high-level research activities, Suzanne is passionate about Environmental Education and is the co-founder and coordinator of the All about Water and H2O Heroes School's outreach programmes.

Title

Water governance for future proofing – an Irish perspective

Abstract

Ireland's water bodies have been recognised as a resource since human settlement began with archaeological evidence suggesting that human habitations were deliberately sited close to rivers or lakes. Historically, Ireland's rivers, lakes and groundwaters were free from serious man-made pollution. This situation changed decisively in the second half of the 20th century and since the 1970s, in particular, Ireland began to experience a deterioration in water quality that has had significant implications for biodiversity and for drinking water supplies. As part of its obligations under the Water Framework Directive, Ireland prepares a River Basin Management Plan every six years which sets targets to address water quality issues including the protection, improvement and sustainable management of the water environment. Launched in 2009, Ireland's first plan covered the period from 2009-2014 and quantified the extent of deterioration of water quality at that point. Despite some progress over the years, overall water quality is again in decline and Ireland's waters are now subject to mounting environmental pressures with the situation described as urgent. Meeting the challenge of protecting and improving Ireland's water quality for the 3rd RBMP (2022-2027) will be a complex undertaking and will require the participation and cooperation of many stakeholders.

Keynote Presentation

Bas Roels

WWF Netherlands

Bio

Bas Roels (44) is an ecologist who worked for 12 years for the Dutch government as policy advisor nature with a focus on water management, infrastructure and climate adaptation. The policy paper ‘Natuurambitie Grote Wateren 2050’ was coordinated by him. The last 7 years he worked for WWF The Netherlands coordinating a Dutch rivers- and delta program in which a climate resilient future vision on these areas is composed in which nature based solutions are put central.

Title

Room for Living Rivers; the need to accelerate the implementation of nature based solutions in Dutch river management practice. An overview of urgencies and concepts

Abstract

Dutch rivers are as anthropogenic as can be. No wonder that in The Netherlands important first steps with developing (ecological) river restoration concepts have been made. Within the ‘Room for the River program’, these have been put into practice on large scale over the last 15 years. Still, ecological output is sub-optimal, mainly because key ecological concepts were not fully developed or not implemented to minimalize negative impacts on other river functions, such as shipping or to reduce costs. In the meantime, predictions show that the impact of climate change on peak rivers flows increases and The Netherlands is facing an increased water safety task. This challenges the realized nature restoration: already river forests have been removed. From this context, how can we move to a meaningful follow up of ‘Room for the River’? What is ecological urgent and relevant and which water management and river design concepts are feasible? WWF proposed some new concepts & ideas, both addressing ecological needs for river restoration as the other river functions.

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Session I

Flood Risk Management

The discharge magnitude of the 1374 millennium flood event in the Rhine river

Hieu Ngo[a,b], Anouk Bomers[b], Dennie CM. Augustijn[b], Roshanka Ranasinghe[b,c], Tatiana Filatova[d], and Suzanne JMH. Hulscher[b]

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[b] *University of Twente, Department of Water Engineering and Management, Drienerlolaan 5, 7522 NB, Enschede, the Netherlands*
[c] *IHE Delft, Coastal & Urban Risk & Resilience department, Westvest 7, 2611 AX, Delft, the Netherlands*
[d] *Delft University of Technology, Multi Actor Systems Department, Delft, 2628 CN, the Netherlands*

Keywords — historic flood event, hydraulic modelling approach, flood reconstruction, flood frequency analysis

Introduction

Reconstructions of the most severe historic flood events contribute to a better quantification of design discharges corresponding to large return periods. However, reconstructions of the peak discharges of these historic flood events generally have large uncertainties related to the historic topography and hydraulic roughness of the river channels and floodplains (Herget and Meurs, 2010; Lang et al., 2003).

Discharge magnitudes of historic flood events can be reconstructed by using the simple one-dimensional (1D) approach (e.g. 1D cross-sectional) (Herget and Meurs, 2010) or hydraulic modelling approach (van der Meulen et al., 2021). However, the simple 1D approach makes it difficult to account for uncertainties in historic topography and hydraulic roughness. Therefore, this study sets up a 1D-2D coupled hydraulic model to reconstruct the discharge magnitude of the 1374 flood event - considered the largest flood of the last millennium in the Rhine river - in which the river is modelled by 1D profiles and the floodplains are discretized on a 2D grid. The result will be used to evaluate the effect on the design discharge.

Methodology

An "inverse modelling" approach was used to reconstruct the discharge magnitude of the 1374 flood event. First, the 1D-2D coupled hydraulic model was set up with the historic topography of the main river and floodplains corresponding to the year 1374 extracted from a high-resolution palaeo-DEM for the Lower Rhine catchment for 800 AD (van der Meulen et al., 2020) (Fig 1) and the hydraulic roughness coefficient for land cover classes corresponding to the palaeo situation (van der Meulen et al., 2021). An uncertainty analysis was then performed with different river bed levels and hydraulic roughness values (Table 1) to estimate the influence of these uncertainties on the reconstructed peak discharge of the 1374 flood event. The upstream discharge wave was also varied, corresponding to a wide range of peak discharges (12,000-24,000 m^3/s). Next, the simulated water levels were compared with the flood mark (observed water level) corresponding to the 1374 flood event at Cologne to determine the appropriate discharge magnitude.

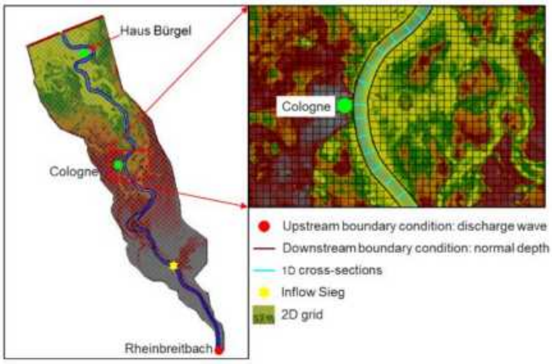

Figure 1. The model set-up for the study area (left side) and a close-up of the 2D grid (right side).

Table 1. Landscape classes and assigned Manning's n values. Source: van der Meulen et al. (2021)

Class	n_{min}	$n_{average}$	n_{max}
High grounds	0.1	0.1	0.1
River bed and banks	0.025	0.03	0.045
Proximal floodplain	0.06	0.07	0.08
Distal floodplain, high	0.04	0.05	0.06
Distal floodplain, low	0.035	0.04	0.055

Results and Discussion

The upstream discharge magnitude of the 1374 flood event was determined to be between 12,500 m^3/s and 22,000 m^3/s considering the combinations of the maximum and minimum roughness coefficient values with different river bed levels, with the 'best' estimate between 14,600 m^3/s and 18,700 m^3/s corresponding to

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the average roughness coefficient value ($n_{average}$) for all landscape classes.

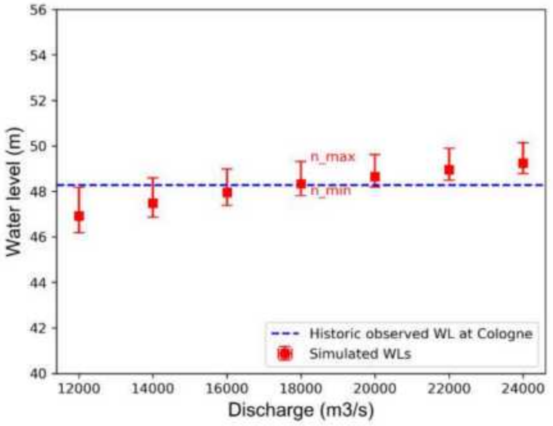

Figure 2. Water level (WL) at Cologne plotted against peak discharge. The uncertainty bands at peak discharge between 12,000 and 24,000 m³/s show results with all roughness classes set to minimum and maximum Manning's n values corresponding to river bed level = 800 AD-3 m. The red marker shows the WLs corresponding to the average Manning's n values.

The reconstructed discharge magnitude of the 1374 flood event corresponds to the study of Herget and Meurs (2010) (23,200 m^3/s, with an uncertainty range of between 18,800 m^3/s and 29,000 m^3/s) and this study were independently updated into the 12 reconstructed historic flood events in the period 1300-1772. Then these data were respectively combined with the systematic discharge data set covering the period 1772-2018 to create a continuous discharge data set covering the period 1317-2018 corresponding to each study by using a bootstrap method (Bomers et al., 2019). A flood frequency analysis was performed based on these discharge data sets to determine the design discharges and their 95% confidence interval for different return periods corresponding to each study based on the generalized extreme value (GEV) distribution function (Fig 3).

The results (Fig 3) show that updating the 1374 reconstructed discharge magnitude of this study into the historic flood events results in a significant reduction of 1,800 m^3/s (10%) in the design discharge and 1000 m^3/s (20%) in the confidence interval corresponding to a 100,000 year return period compared to using the 1374 reconstructed discharge magnitude of Herget and Meurs (2010).

Conclusions

The discharge magnitude for the 1374 millennium flood event was determined to be between 12,500 m^3/s and 22,000 m^3/s, with the 'best' estimate between 14,600 m^3/s and 18,700 m^3/s.

The reduction of the 95% confidence interval shows the importance of reconstructing historic flood events with high accuracy, contributing a more certain quantification of design discharges.

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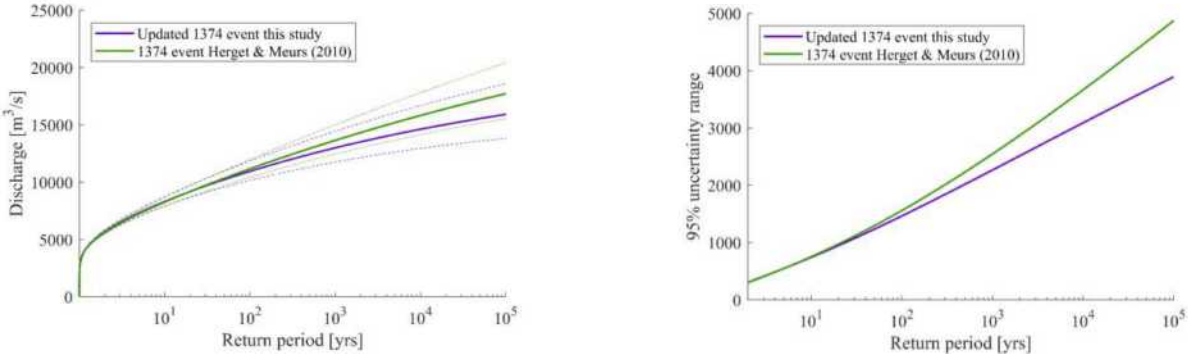

Fig 3. Flood frequency curves and their 95% confidence intervals of data sets corresponding to the reconstructed discharge magnitude of the 1374 flood event of Herget and Meurs´s study and this study.

Flood of July 13-15 2021: a new type of floods in Western Europe?

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Keywords — Flood typology, data analysis, tributary, international

Introduction

The flood event of July 13-15 2021 in Western Europe did not just surprise the inhabitants and the local authorities of the affected regions, also scientists were stunned to see such a catastrophic flood event occur, especially during summer (Cornwall, 2021). With economic losses running into billions of euros and over 200 fatalities (United Nations, 2022), the flood event exposes a vulnerable weakness in current flood risk management: flood risk associated with the smaller streams that form the tributaries of major rivers such as the Meuse and the Rhine. In the Mediterranean region and the Alps, similar sudden floods, known as flash floods, are common and specific warning systems have been developed (Marchi et al., 2010). Does the 2021 flood event force us to take a similar approach and include flash floods in our flood risk management plans or was the flood event not as unique as we perceive it to be?

Method

In order to understand the uniqueness of the flood event, context must be provided, both historically and spatially. A data analysis of the precipitation and discharge measurements combined with a detailed site description is a simple method for this purpose. An explorative approach for determining relevant parameters prevents a possible tunnel vision towards specific findings. Furthermore, it gives the research both a wide and deep layer of understanding. We select the most critical catchments, based on a heatmap from the flooding locations, of Germany, Belgium and the Netherlands as case studies. These are respectively the Ahr, Vesdre and Geul catchments. It must be noted that measurements of the event were rare due to several dysfunctional (and sometimes destructed) gauges. The consequential data gaps, combined with the often less accurate measurements of gauges during extreme events, introduce uncertainty in the analysis. Therefore, this abstract focuses on qualitative findings rather than precise numbers.

Results

of A common method to provide historical context of an event is to determine return periods. The frequency analysis of both precipitation and discharge measurements undeniably shows the rarity of the event, with the exception of several precipitation gauges. Return periods of a 100 years form the norm, but outliers over a 1000 years were found as well. As many values of precipitation and discharge had never been measured before, the significance of these results is reduced by the relatively short time period of these measurements, ranging from ten to ninety years (a problem already acknowledged by Rodier et al. (1984)). For the Ahr catchment, Roggenkamp et al. (2014) reconstructed historical peak discharges which show a similar event in 1910 and an even more extreme case in 1804. This centenary occurrence contrasts with the return period of over 10.000 years for the peak discharge in July 2021, as obtained from the available discharge measurements (Schäfer et al., 2021). Both the 1804 and 1910 floods occurred during summer. Seel (1983) provides the timing of more historical floods, which shows that just below 50% of all registered floods occurred during summer. These findings imply that the flood event in the Ahr of July 13-15 2021 may not have been as rare in size and timing as anticipated. Extending this conclusion to the catchments of the Vesdre and Geul is not possible due to a lack of data.

Historical context is only one insight in the uniqueness of the flood event, flood typology provides another. Merz et al. (2003) introduces five types of regional floods of which the potential summer flood types are: flash floods, short-rain floods and long-rain floods. The large extent of the precipitation area and its stationarity, due to the large cold core low over Western Europe, is a characteristic of a long-rain flood.

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In contrast, the hydrographs indicate a lag time (defined as the time between the centroid of the precipitation event and the moment of the peak discharge) of less than 24 hours. This fits the characterization of a flash flood (Merz et al., 2003). These mixed characteristics of the July 2021 flood event prevent an identification of the flood type, which highlights the uniqueness of the flood event. This may complicate flood risk management, as a new flood type weakens the common approach of flood risk analysis.

Besides historical context, spatial context helps to understand the local conditions in which these flood events occurred. Although the catchments are similar in terms of size, shape and mean annual discharge, considerable differences can be found in their slope (both regarding the overall landscape and the river channel bed), the mean annual precipitation, the geology and human interference in the river course. The importance of catchment characteristics is highlighted by the different runoff ratios. The total volume of precipitation of the Ahr catchment is only slightly higher than for the Geul catchment while the total volume of precipitation is twice as large for the Vesdre catchment. The peak discharges show a different pattern, with the Ahr's peak discharge of around 800 m^3/s, followed by the Vesdre with 600 m^3/s (Zeimetz et al., 2021) and lastly, the Geul with 100 m^3/s (Task Force Fact Finding Hoogwater 2021, 2021). This order of flood severity in the catchments, indicated by the peak discharges, aligns with the varying degree of financial damage and number of fatalities between the three catchments. The varying runoff response and thus potential flood behaviour may be caused by the different catchment characteristics described above, and illustrates the importance of spatial context in flood typology.

Conclusion and further research

There is no denying that the 2021 flood event was a rare and surprising event, as shown by the damage and number of fatalities. And indeed, the forcing of the flood event from the high precipitation resulting from the extensive cold core low, is a unique circumstance. However, the size and timing of the flood event is not entirely new. Floods of similar magnitude have occurred before the measurement record, and should be accounted for in flood risk analysis. Similar analysis is required for the Geul and the Vesdre catchments and possibly a generalization to Western Europe. Furthermore, the hydrological and hydrodynamic behaviour must be understood before possible measures can be considered. The high peak flows of this event complicate the implementation of structural measures. It may lead to a mentality shift away from the current philosophy that flooding must be prevented at all costs. Finally, the role of both urbanisation and climate change must be investigated to assess their impact on the return periods of similar events in the future.

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Effects of urbanization, deforestation and climate change on flooding in Cap-Haitien, Haiti

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Keywords: Hydrology, modeling, climate change, SWAT, SOBEK1D2D, Floods, Cap-Haitien, Haiti.

Introduction

Cap-Haitien, the 2nd largest city in Haiti (Figure 1), is exposed to all kinds of risks, including sea-level rise, climate change, earthquakes, erosion, urbanization, deforestation, and flooding (CECI,2017) (Figure 2). These natural hazards often turn into disasters due to a lack of good prevention and preparedness measures, management structure, and inadequate infrastructures and services (MTPTC,2015). Furthermore, the lack of urban planning and infrastructure and difficulties observed among local authorities in the application of laws and regulations have resulted in the gradual encroachment of flood-prone areas. This practice intensifies the risk of flooding, increasing the exposure of people, property, and infrastructure. Reducing this risk appears now to be essential for the economic development of the city of Cap-Haitien and the recovery of its urban and natural environment. So, our objective is to examine the impact of drivers such as deforestation, urbanization, and climate change on Cap-Haitien's recurring problems of river flooding.

Methodology

We interconnect separately built hydrological and hydraulic models. On the one hand, the hydrological model used is the distributed, process-based and continuous simulation tool SWAT (Soil Water Assessment Tool) developed jointly by the USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research, Texas A&M University. On the other hand, the hydraulic model used is a coupled SOBEK1D2D developed by Deltares, formerly Delft Hydraulics (Netherlands), based on the complete Saint-Venant equations. We applied the models to different scenarios of urban growth and population pattern, deforestation in the mountains, and climate change, basing the latter on the rcp2.6 and rcp8.5 scenarios for greenhouse gas emissions. We used a DEM of 30 x 30 m^2 with a global soil and land use map to delineate the SWAT Hydrological Response Unit (HRU) under the baseline scenario (actual land use), modified land-use scenario (10% of urban area increase), and climate change scenario. Additionally, we modeled events with different return periods in SOBEK1D2D, including the November 2012 event.

Figure 1. Panoramic view of Cap-Haitien City, Haiti. The Haut du Cap River flows from the right to the sea on the left.

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Figure 2. Floods in Cap-Haitien, February 2022

Preliminary results

The results show that urbanization-deforestation is the main driver of the sediment production and transport mechanism and that the hydraulic capacity of the Haut du Cap River is lower than the estimated peak flows for 5, 10, 50, and 100 years of return period jointly with the November 2012 event (Figure 3). Also, we show that many mountain ravines are the source of flash floods since the drainage system is clogged with all kinds of fine sediment upstream and garbage downstream, adding to the very short response time of their waves. Although uncertain, we found that climate change has an overall impact on the frequency of extraordinary events than on the peak flow given that a temperature increase between 1° C to 5 °C is expected in Cap-Haitien under both climate change scenarios rcp2.5 and rcp8.5. Additionally, drier conditions are expected annually for the period 2022-2040 than the baseline scenario (1979-2014) despite the low level of confidence and that climate change would have a significant impact on the future water availability of the watershed.

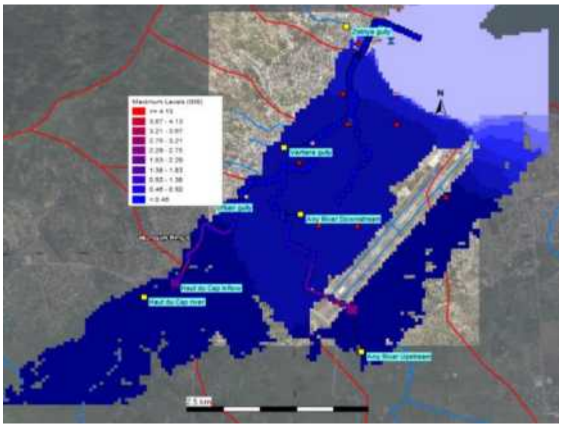

Figure 3. Flood extent of the November 2012 event

Conclusions and recommendations

The study concludes that, despite structural mitigation measures with drainage canal systems, a serious lack of governance has been playing a major role in the uncontrolled urbanization, lack of waste management system: main deep anthropogenic activities that cause flood threats. This study has data limitations and we think that serious water governance problems should be noted in the region. Therefore, it is recommended to install new climatological stations and to have continuous surveys of flow or water levels in strategic points of the city for a better understanding of how the Cap-Haitien hydrological system works and to anticipate better decisions.

Acknowledgment

The authors would like to thank Adri Verwey (Consultant) for his valuable contribution, advice, and above all for having made the hydraulic model available to us.

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River ice and flood monitoring from space: bridging research and operational practices

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Keywords — Remote Sensing, Earth Observation, River Ice, Floods, Flood Risk

Introduction

River ice jams are a major contributor to flood risk in cold regions, particularly in the fall and spring when the river freezes or ice sections break up, respectively. For example, a river ice jam along the Athabasca River in 2020 caused flooding in Fort McMurray, Canada, displacing 13,000 people and damaging 1,200 properties (Fig 1). River ice jams are notoriously hard to model and predict, which makes forecasting and early warning for this type of flooding, to facilitate risk reduction and mitigation measures, difficult.

Freeze-up in fall and break-up in spring can be a predecessor to ice jams and should therefore be monitored closely, in (near) real-time. When floods occur, monitoring is also critical for understanding how the flood extent evolves over time and how to most effectively implement emergency assistance, potentially saving lives and reducing the costs of such disasters (Oddo and Bolten, 2019).

Satellite remote sensing, often referred to as Earth Observation (EO), can be used to monitor rivers over large and remote areas. While ground-based monitoring stations and gauges remain vital instruments, they cannot capture the full spatial extent of a river or flood. Aerial surveys provide a good alternative, but these are relatively expensive, especially for continuous monitoring. For floods specifically, numerical models can be an excellent source of information, but are not readily available in all regions and can be costly to set up. In contrast, satellites orbit and monitor nearly all regions of the globe and can thus provide scientists, governments, and disaster response agencies with the information they need. However, there is a clear gap between research and operational practice, which is explored further in this paper.

Research

Both river ice classification (e.g. Puestow et al., 2004; Van der Sanden et al., 2021) and flood mapping from EO data sources (e.g. Schumann et al., 2009; Markert et al., 2020) have been active areas of research for the last two decades. The recent rise in the availability of EO data, cloud computing, and artificial intelligence (AI) and machine learning (ML) techniques are pushing this research further. For example, de Roda Husman et al. (2021) used a Random Forest model to classify river ice from EO data. Mayer et al. (2021) trained a Convolutional Neural Network and applied this on satellite data in Google Earth Engine (GEE; Gorelick et al., 2017) to showcase its potential for water and flood mapping. These are just two examples of many recent studies leveraging similar datasets, techniques and/or platforms, contributing to the greater scientific understanding of these topics and paving the way for new applications to reduce flood risk.

Practice

Organisations tasked with managing river basins and producing flood forecasts and/or early warnings typically have strong expertise in water resources, hydrology, and their watersheds in particular. However, they do not always have the technical expertise required to process and analyse EO data and the vast computational power required to do this at a detailed scale over large areas. The first issue can be overcome by setting up an automated processing pipeline that produces data ready for interpretation by end-users. This pipeline can also be integrated within existing operational water information and/or flood forecasting systems. A good example of this is the recent integration of EO data for river ice monitoring at several organizations across Canada (Kwant et al., 2020). Cloud-based solutions, which allow for providing data-as-a-service, are another option, which can also solve the computational constraints (e.g. Ramthun et al., 2021).

However, this assumes that either sufficient information technology (IT) infrastructure is present and maintained at the organisation, or that it possesses the financial means to use cloud environments. This is not always

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the case, especially at smaller organisations, or those in developing countries. Aside from these practical considerations, each organization will also have its own specific needs, particularly on operational aspects.

Conclusion

Exemplified by the cases above, we propose to not search for a single "best" approach but rather recommend flexibility when operationalizing EO data streams or services. This requires balancing operational constraints with new developments from recent research. Regardless of the chosen approach, those providing an application or service should help end-users develop the necessary capacity and make sure it is fully integrated within their operational systems and processes. We will dive deeper into this during our presentation and hope this will lead to a productive discussion on the topic.

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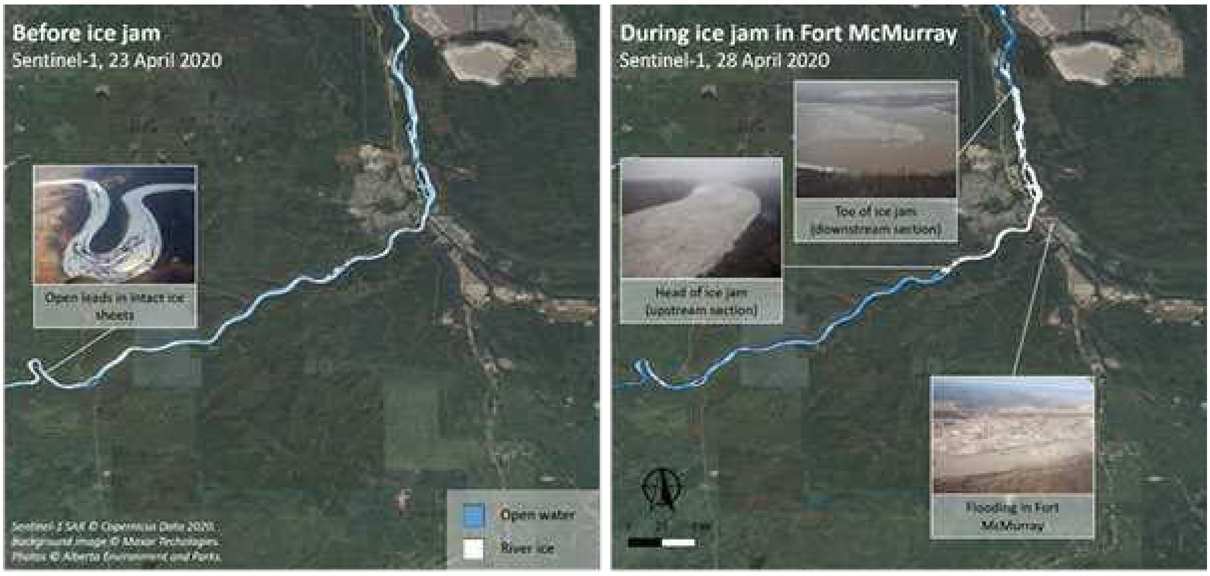

Figure 1: River ice jam flooding in Fort McMurray, Canada as seen from Sentinel-1 and dedicated aerial surveys. Contains modified Copernicus Sentinel data [2020]. Background image © Maxar Technologies. Photos © Alberta Environment and Parks.

Role of Albert Canal system in July 2021 flood: what can we learn from this?

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Keywords — Meuse River, flood risk management, flooding event

Introduction

In July 2021, the Meuse catchment was impacted by a severe flood. The highest discharge of the Meuse ever was recorded at Sint Pieter, with a value of approximately 3310 m^3/s (van der Veen and Agtersloot, 2021). Tributaries of the Meuse also suffered from severe floods, leading to serious damage in the entire catchment. The fact that this event happened during summer made it even more rare, as previous floods in the catchment usually occurred during winter (Tu et al., 2005). Another remarkable aspect of this flood was the situation at the Albert Canal due to the partly closed Monsin dam at the Meuse near Liège. Due to maintenance of this dam, it could not convey all the water coming from the river as only 2 out of 6 openings were fully available. Therefore, a significant part of the Meuse discharge (~700 m^3/s) was diverted into the Albert Canal at Monsin instead. The discharge and water levels in the canal were extraordinary, and this leads to the question how this exactly originated and what happened in the interaction between the canal and the Meuse River. An interesting question is also what would have happened in the Meuse River and the Albert Canal if the Monsin dam had functioned normally. Furthermore, the event poses the question what role the Albert canal could play in the future in alleviating flood risks in the Meuse River by diverting part of the Meuse discharge into the canal.

Objectives

The first objective of this study was to gain a better understanding of the interaction between the Meuse River and the Albert Canal during this event. A second objective was to implement the Albert Canal system in a SOBEK3-model, which can be used to predict discharges and water levels in the Meuse River. The third objective was to investigate what the hydraulic situation on the Meuse River and the canal would have been, if the Monsin dam would have functioned normally. The fourth and final objective was to examine the potential of the canal to reduce future flood risks in the Meuse River.

Study Area

The study area covers parts of the Belgian and the Dutch Meuse basin. The part of the Meuse River that was considered, lies roughly between the cities of Liège and Maastricht. The Albert Canal was considered from its origin at Liège up to just downstream of the first (of six) sluices in the Albert Canal at the city of Genk. The canal of Ternaaien, the Monsin canal and the sluices in these canals also played an important role during the July 2021 event, and are part of the study area. The canal Briegden-Neerharen and the Zuid-Willemsvaart are connected to the Albert Canal, but did not play a significant role during the event. Figure 1 gives an overview of the waterways considered in the study area.

Figure 1 Overview of the hydraulic situation in the study area

Research approach

In order to gain a better understanding of the interaction between the Meuse River and Albert Canal system during the event, observed water

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level and discharge data were obtained for both waterways. The observed discharge data at Eijsden were corrected because of the so-called backwater effect at this location, caused by the flow entering the Meuse River from canal Ternaaien. The timing of peak discharges and water levels were compared for several locations in order to gain insight in how the flood wave propagated through the system during the event. A special point of interest was the amount of water conveyed through the canal of Ternaaien. This discharge was estimated by comparing measured discharges at different locations on the Albert Canal. After this first analysis, the SOBEK3-model was used to simulate the event. In order to do this, the model was extended, as in the original model the Albert Canal system was included only through a boundary condition. The Albert Canal was therefore included up to just downstream of sluice Genk. The canal Ternaaien and the canal Monsin were important during this event, and were schematized in the model as well. Cross-sections for the canals were obtained from a previous modelling study of the canal system by Nossent et al (2016). The canal Briegden-Neerharen was included in the model through a boundary condition on the Albert Canal. The calibration and validation of the extended model was performed based on the July 2021 event. The validated model was used to investigate what the situation would have been if the Monsin dam had functioned normally. The final step of this study was to perform a scenario analysis. Here, model runs were performed for different peak discharges with varying recurrence times. The goal of this scenario analysis is to investigate how water levels and discharge on the Meuse could be lowered by diverting part of the discharge to the Albert Canal. Model runs where flow is conveyed to the Albert Canal were compared with model runs where all water flows through the Meuse River (normal situation). The comparison between these results gives an indication on the potential of the Albert Canal to reduce flood risks in the Meuse River.

Results

This study is part of an ongoing master thesis study. Therefore, not all results are available yet, such as the implementation of the Albert Canal and the scenario analysis. First preliminary results are shown in figure 2, providing observed and simulated water levels at the entrance of the Albert canal near Monsin. This figure shows that the developed model is capable of simulating water levels at this location well. The general pattern is followed closely by the model, and the error is relatively small, especially after the flood.

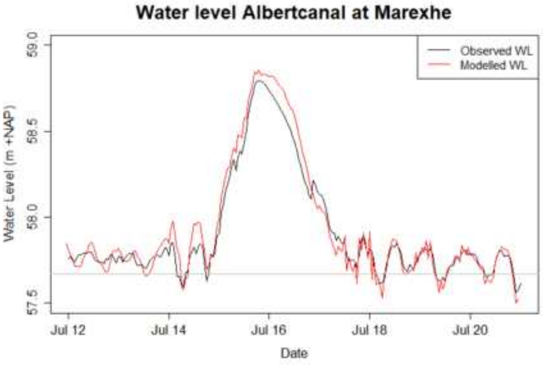

Figure 2 Modelled water levels compared to observed

The Nash-Sutcliffe-Efficiency (NSE) was also calculated for this model run. This NSE was found to be 0.939.

Ongoing research

As mentioned, the research in this study has not been completed yet. Currently, the calibration and validation of the model is still taking place. It is expected that this will be ready soon. The next step will be to simulate the situation in the study area that would have occurred if the Monsin dam was operating normally. This step will be followed by the scenario analysis, for which different scenarios will be examined regarding future peak discharges. It is expected that the work will be finished prior to the NCR-meeting.

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Assessing the performance of an LSTM neural network and a HAND model for long-term real-time flood forecasting

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Keywords — Flood forecasting, surrogate models, neural networks, LSTM, HAND model

Introduction

Floods affect more people every year than any other weather-related disaster, and can have terrible consequences (Verwey et al., 2017). As such, there is a need to predict flood events and assess corresponding flood risk. If an incoming upstream discharge wave is noticed, decisions such as evacuation or dike reinforcement have to be made in time and with sufficient certainty in factors such as locations of dike overflow or dike breaches. For this purpose, a real time flood forecasting system is desired, in which ensemble model predictions and uncertainty analysis of hundreds or even thousands of model runs allow for reviewing multiple scenarios (Chu et al., 2020).

To model flood dynamics, the most commonly used method is two-dimensional depth-averaged (2DH) hydrodynamic models. However, these models generally have long computation times of many hours or even days. As a result, the incoming discharge wave has travelled further downstream, leaving little time to evacuate the areas at risk. (Teng et al., 2017).

Surrogate models have been invented to speed up model run times via two strategies: lower-fidelity and response-surface surrogates (Razavi et al., 2012). Lower-fidelity models are still physically based, but use a simplified description of the system. Response-surface models are data-driven and do not contain physical descriptions of the system.

In recent years, neural networks have become the most popular type of response-surface model (Mosavi et al., 2018). However, neural networks have to be trained on a large data-set that is often gathered from a time-consuming 2D-hydrodynamic model, meaning that they are only valid for the specific situation modelled. Due to the dynamic nature of riverine systems, both from natural and human processes, the long-term usefulness and validity of neural networks in a real-time flood forecasting system is therefore questionable. Additionally, research using neural networks for flood water depth prediction has mostly considered relatively simple events of rivers spilling into floodplains. Inundation due to dike breaches remains an unexplored field of study.

Regarding lower-fidelity models, a model that is still being applied and developed is the Height Above Nearest Drainage (HAND) model, which only requires a digital elevation map of the area to calculate maximum water depths. Additionally, it does not require a long process of data gathering and training, making it suitable for easy updating in case of changing conditions in the river system. However, it cannot predict the propagation of the flood throughout the study area over time, which would be useful to decide which areas should be evacuated first.

In short, the research community finds itself at a cross-roads: continue investing in neural networks, or further developing lower-fidelity models. Therefore, the objective of this research is to expand the lower fidelity HAND model to include a time component of flood propagation, and compare its performance to that of a neural network.

The two models to be developed are evaluated against a 2D-hydrodynamic model made in HEC-RAS by Bomers (2021). 80 model runs that simulate the flooding after a dike breach for different discharge waves in the IJssel branch of the Rhine in the Netherlands are available.

Neural network – LSTM

A neural network consists of an input layer, which takes a set of data as input. In this case, it is a time series of discharge through a dike breach. This data is processed through one or more layers with neurons, that activate and pass on signals based on a weighting function to eventually produce the desired output.

Unlike such traditional feed-forward neural networks, LSTM networks incorporate results of previous time steps into the calculating of the current time step. As such, LSTM are a type of Recurrent Neural Network (RNN), and this is what makes them suitable for predicting time-series behaviour (Tewari et al., 2021).

In training, the neural network is given an input, and the corresponding output (both derived from the 2D-hydrodynamic HEC-RAS

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model), and it tries to find the relations and weights in and between each neuron that best reproduce these outputs from the given inputs. Such hyperparameters include for example the number of layers through which the signals pass, the number of neurons in each layer, and the dropout. Dropout involves the probabilistic removal of a few input data points per neural network iteration, to make the neurons more robust to the inputs and prevent overfitting to the data. Another important parameter in the training is the number of epochs, which defines the amount of times the neural network should use the dataset to update its internal structure.

HAND model

The development of the HAND model starts with the Digital Elevation Model (DEM) of the study area. From the DEM, properties like the slope are used to derive drainage paths from each cell to its neighbors, eventually flowing to the cells that make up the local drainage paths (Scriven et al., 2021). Each cell's topographic height above the drainage path is known as the Height Above Nearest Drainage (HAND) value. To calculate the maximum flood water depths, the model fills the study area up to the highest water level of the expected discharge wave. It is usually applied to river valleys that are relatively clearly marked by topographical boundaries (Figure 1).

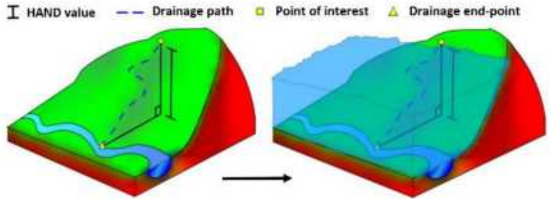

Figure 1 - HAND value on hillside (left) and corresponding flood level (right) (figure adapted from Scriven et al. (2021))

The HAND model only calculates maximum flood depths based on river water level, so in this study the HAND model will be expanded with a module that can take a volume as an input and divide it over the hinterland. To model "flow" over the hinterland, the flow will be allowed to travel with a certain distance through the local drainage paths. To determine this distance, flow speed data from the 2D-hydrodynamic HEC-RAS output will be used to create a relationship between flow speed and distance from the dike breach.

Preliminary results

Figure 2 shows the comparison of a 1000-epoch test run with the LSTM network against the 2D-hydrodynamc HEC-RAS output. It can be seen that the neural network floods the hinterland too quickly, so the flood propagation through time should still be improved. The final flood water depths, however, are already well-predicted by this network. More research into the effects of the hyperparameters is yet to be conducted, to find an optimal set of parameters and further improve the accuracy of the prediction.

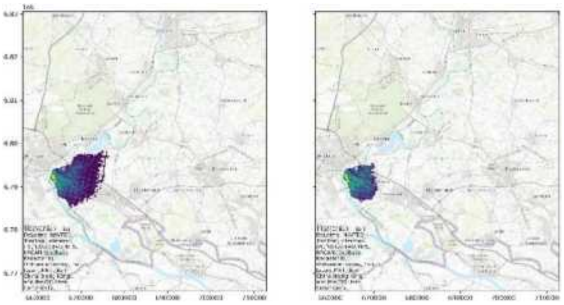

Figure 2 – (left) LSTM prediction of water depth 3 hours after breach. (right) HEC-RAS prediction of water depth.

The HAND model is expected to result in similar flood maps if it is successfully implemented and expanded. The proposed method is expected to make the HAND model applicable in river systems where the hinterland does not form a topographical boundary for the water, such as the Netherlands, where the hinterland is usually lower than the river.

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Geul River flooding reproduced with a Delft3D depth-averaged model

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Keywords — River, Flood, Valkenburg

Introduction

Due to heavy rainfall and steep slopes, on the 15th July 2021 the Geul River discharge rose extremely quickly producing a dangerous flash flood. As a result, the river inundated the city of Valkenburg (Figure 1) causing vast damages. Strategies to avoid future flooding in the area demand understanding and quantification of the effects of different measures. The design of interventions in the river requires knowledge on the role of several factors affecting flood dynamics. For instance, it is important to assess the role of floodplain vegetation to establish whether it is needed to manage it and how. For this, an appropriate numerical model, which includes the river's main channel and floodplains, becomes necessary.

To this purpose, a 2D model was created with Delft3D 4 suite covering the river from the border between The Netherlands and Belgium to Meerssen, close to the confluence with the Meuse.

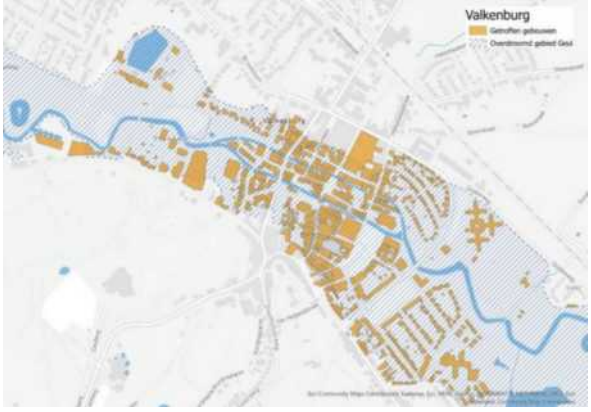

Figure 1 Affected and flooded areas in Valkenburg (Task Force Fact Finding hoogwater 2021 (2021)).

The Geul River

The Geul River is a right-bank tributary of the Meuse River starting in eastern Belgium at an elevation of 400 m a.s.l. (Figure 2). The confluence with the Meuse is located near Itteren, the Netherlands, at an elevation of 50 m a.s.l. The river is 56 km long in total and has a longitudinal slope of 0.02 m/m in its upper reach and of 0.0015 m/m in its downstream reach. The basin has a total surface of 380 km^2 with a precipitation of 750-800 mm/year in the area close to the confluence and of 1,000 mm/year, in its upper part (de Moor, 2007).

Figure 2 Geul River near the border between The Netherlands and Belgium.

The average river discharge is equal to 3.6 m^3/s and reached a maximum peak of 65 m^3/s.(Dautrebande, et al., 2000). However, the typical annual peaks vary between 20 to 30 m^3/s.
Flow rates higher than 13 m^3/s can generate local floods (de Moor, et al., 2007).

Available data

Discharge and water level measurements were provided by the Limburg Water Board at 26 stations along the Geul River and its tributaries, namely the Gulp, Eyserbeek and Selzerbeek. The most upstream available gauging station on the Geul is located in Cottessen, close to the Dutch-Belgian border, while the most downstream is at Meerssen.

The hydrographs from Cottessen and Meerssen stations had missing values around the peak of the July 2021 flood. The Water Board estimated that the peak discharge at Meerssen was around 85-90 m^3/s on July 15 at 10:00 (record value).

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Therefore, Rijkswaterstaat Zuid-Nederland reconstructed the hydrograph at Meerssen. (Figure 3) whereas we constructed a stage-discharge rating curve for the Cottessen station based on the available data during the flood. The latter curve was used to obtain the missing discharge values of the July 2021 event.

On another note, cross section measurements of the Geul River and its tributaries were provided by the Limburg Water Board. Finally, the elevation of the Geul's floodplains was obtained through the AHN4 digital terrain model (https://www.ahn.nl).

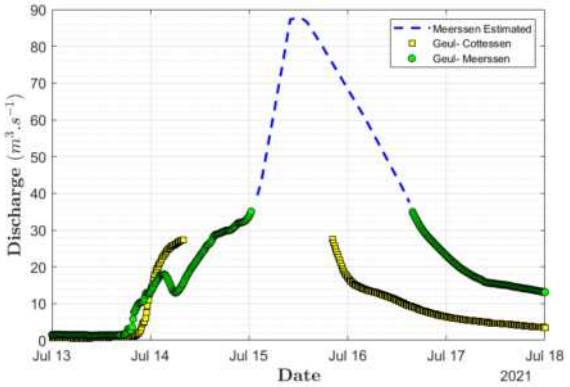

Figure 3 Hydrographs at Cottessen and Meerssen stations denoted in yellow squares and green circles, respectively. The dashed blue line represents the estimated hydrograph at Meerssen.

Delft3D 4 suite model

The model covers the Geul main channel and its floodplains along 34 km and includes all bifurcations and the final stretch of the tributaries. The model includes all buildings, water bodies and structures (weirs) that are present within the domain (Figure 4).

The main channel bed level is about 2.5 m lower than the floodplain level in the upper part of the river and 3.5 m lower in Valkenburg.

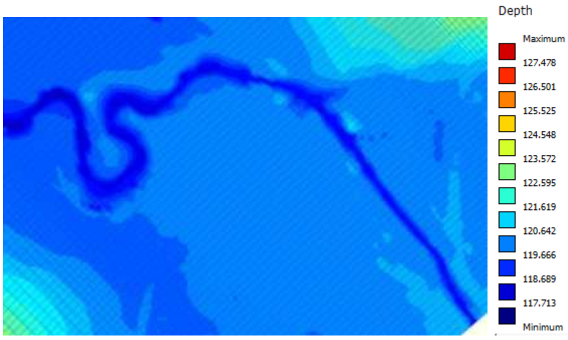

Figure 4 Model grid and elevation near the upstream boundary.

The boundary conditions are: hydrograph at the upstream end of the Geul, Gulp, Eyserbeek and Selzerbeek rivers, and water levels at the downstream end of the Geul (at the Meerssen station)

The roughness coefficients of the river and the floodplains are used for the calibration. Vegetation roughness is derived using the method developed by Baptist (2005).

Preliminary results

The water depth along the Geul River on the 28th of July 2012 is represented in Figure 5. It varies around 1 m and reaches 3.5 m in some pools. These preliminary results were obtained first by calibrating the model with a low discharge of 1.2 m^3/s at the Geul upstream boundary.

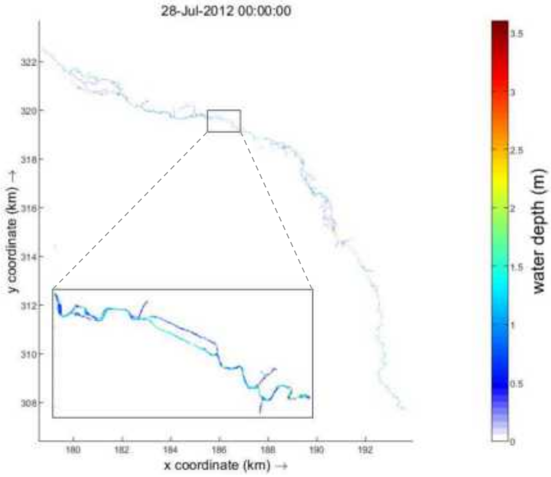

Figure 5 Water depth in the Geul River on July 28,2012, obtained through a Delft3D 4 suite model. The area around the Geul in Valkenburg is denoted by a black rectangle and magnified in the bottom left corner.

Future perspective

The calibrated model will be used to reconstruct the event of July 2021, evaluate the flooded areas, and analyse the role of floodplain vegetation on flooding in the area under several scenarios.

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Modelling open channel flow for the features of a flexible groyne

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Keywords — Groynes, River Training Works, 3D CFD modelling, Fluent

Introduction

Recent river programmes have shown that an integrated approach is required for improving multiple functions within the river such as safety against flooding, riverine nature rehabilitation and maintaining a navigational water depth (Havinga, 2020). Furthermore, rivers are under pressure by climate change, tight budgets for maintenance and management, and high demands from society. The Self-Supporting River System (SSRS) programme seeks therefore potential, renewable, and affordable measures to manage the river system. One of its innovations regards flexible groynes with steeper head slopes and a porous structure. In general, groynes maintain navigational water depth and protect river banks. They partly block the wet cross-section of a river, leading to flow separation downstream of the groyne. This generates large turbulent structures that increase Reynolds shear stresses and bed shear stresses, consequently leading to significant local scour (Koken, 2009; Duan, 2009). The most important processes for local scour are the horseshoe vortex system upstream, vortex shedding at the tip of the groyne and the large turbulent fluctuations in the mixing layer downstream of the groyne. Hence, investigations for improving alternative groyne configurations to decrease the maximum local bed shear stresses are interesting to analyse.

The innovative flexible groyne is a porous groyne made of concrete X-stream blocks. It differs from conventional groynes because it is permeable and allows increasing the steepness of its head and side slopes. Notwithstanding extensive previous research on different groyne configurations, little research has been carried out on permeability and head steepness. The present research aims to numerically quantify the effects of groyne permeability and head steepness on flow characteristics in an open-channel flow.

Methodology

We first reviewed existing CFD software packages to select a package suitable for modelling the flow around a porous, steep-headed groyne. The most critical implementations include non-hydrostatic effects, the large turbulent structures and the representation of the porous zone using a non-linear function. Fluent and OpenFOAM were found to be capable of implementing the required processes. From a practical perspective, Fluent was chosen for further modelling.

We validated the numerical model on three different experimental studies (Jeon, 2018; Leu, 2008; Yarahmadi, 2020). For turbulence closure we used a detached eddy simulation (DES) model and a $k-\omega$ shear stress transport (SST) model. These models adequately capture the separation flow according to literature and the manual. The DES model was found to reproduce mean flow velocities better. In addition, a comparison of algorithms for the pressure-velocity solving method showed that the PISO algorithm reproduced mean flow velocities slightly better than the SIMPLE algorithm. The validation focused on three critical aspects: the large turbulent fluctuations for a rectangular groyne, the coupled system of flow through porous media and free-surface flow, and the mean flow properties around a triangular groyne.

After validation, we applied the model to different configurations of a single groyne. Head slopes were varied between 1:1 and 1:3 and porosity was varied between $0\ \%$ and $60\ \%$ porosity. In addition, we modelled two configurations of multiple groynes, one representing conventional groynes and one representing the flexible groynes. We used the mean flow properties, turbulence properties and bed shear stresses for quantifying the effects of permeability and head steepness on the flow characteristics in an open-channel flow.

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Results

The validation showed that the numerical results agreed fairly with the mean flow velocities. Mean streamwise velocities were slightly overestimated. Most critical mean-flow properties were reproduced within an RMSE of $30\ \%$ and a PBIAS of $25\ \%$. Reynolds shear stresses were overestimated and shifted further downstream than the experimental data.

Groynes with $60\ \%$ porosity were found to decrease peak values of bed shear stresses by $5\ \%$ compared to impermeable groynes, as shown in Fig. 1. In addition, the Reynolds shear stresses and bed shear stresses at flexible groynes shifted downstream compared to impermeable groynes, due to the appearance of momentum exchange between the free-flow region and the flow through the porous structure. Decreasing the steepness of the groyne head from 1:1 to 1:3 showed minor decreases of the bed shear stresses.

Conclusions

The flexible groyne of the SSRS programme significantly affects the flow. The downstream shift of turbulence and bed shear stresses can be expected to shift the scour hole away from the groyne. This is favourable for groyne stability.

Recommendations

We recommend deriving relations for the effect of groyne porosity and groyne head steepness on flow characteristics by carrying out numerical simulations for more values of porosity and steepness. Including a sediment transport model is recommended for increasing the understanding of hydrodynamics and morphology around these flexible groynes.

Acknowledgements

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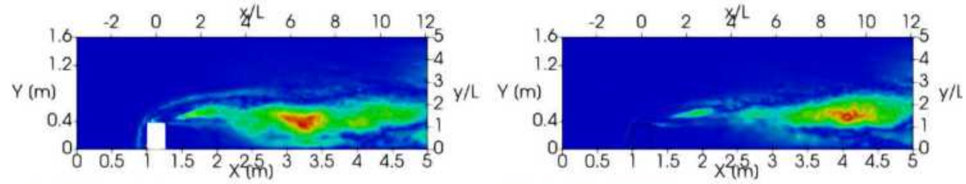
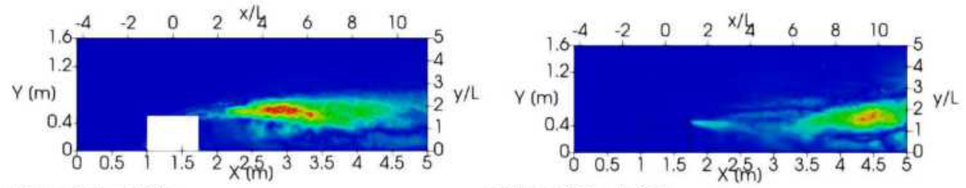


(a) Slope 1:1, Porosity 0 %

(b) Slope 1:1, Porosity 60 %



(c) Slope 1:3, Porosity 0 %

(d) Slope 1:3, Porosity 60 %

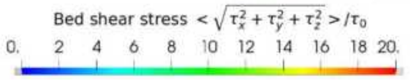


Figure 1: Bed shear stresses at the bed plane for the numerical model with single groyne configurations

The influence of floodplain geometry on riverbed elevation change within and between flood events

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Keywords — flooding, morphodynamics, floodplain dynamics

Introduction

Flood events can cause abrupt changes to river channel morphology over short time scales. The spatial variation in patterns of erosion and deposition can also be high, making it challenging to predict morphodynamic response from a given discharge. Back-to-back floods can additionally cause adjustments to bed elevation that do not recover between events and can affect future flood hazards; intra-flood erosion can reduce channel-floodplain connectivity (e.g. Guan et al., 2016), and in-channel deposition can reduce overall conveyance for floodwaves (e.g. Stover & Montgomery, 2001). Understanding where and why different regions are prone to high degrees of bed elevation changes during floods is thus important for forecasting flood hazards in subsequent events. Previous work suggests that spatial changes in local river geometry can affect river bed elevation change during floods (Van Denderen, 2014). Channel confinement has also been shown to be a predictor of reach-scale channel response to floods (Sholtes et al., 2018). Here, we analyze relationships between longitudinal gradients in river channel width and bed elevation change in the Waal River. This work seeks to broadly understand the degree to which along-channel variation in river channel and floodplain geometry can be leveraged to predict bed elevation change during floods.

Floodplain variation hypotheses

Gradients in floodplain width are expected to be an important control on erosion and deposition patterns during high discharge events because they can generate gradients in flow velocity and sediment transport capacity. An abrupt spatial widening of the floodplain causes a backwater effect during peak flows as flow depth adjusts to the longitudinal change in planform geometry (Fig 1a). The resultant gradients in both flow velocity and sediment transport capacity can cause abrupt deposition where the floodplain widens and abrupt erosion where the floodplain narrows (Fig 1b). This behavior differs from low-flows where the discharge is confined within a main channel with constant width. Thus, we hypothesize that peak changes in main-channel bed elevation during floods will correspond with peak gradients in floodplain width, with the direction of bed elevation change (i.e. erosion or deposition) dependent on whether the floodplain widens or narrows.

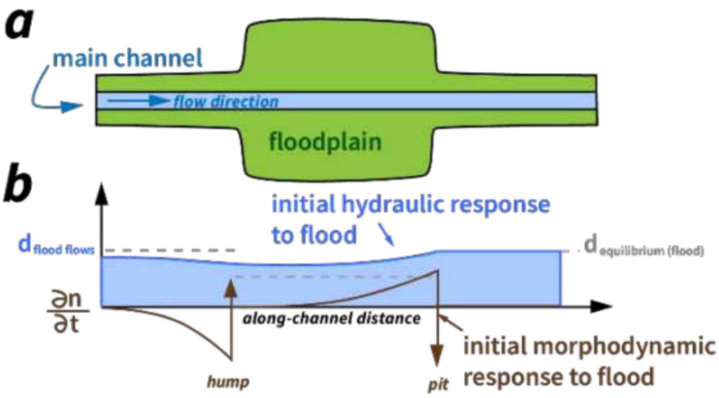

Figure 1. Example hypothesis of along-channel changes in floodplain width causing a backwater effect during flood events and initial morphodynamic response. ***a)*** *A planform channel schematic where the main channel has a constant width and the floodplain has relatively wide and narrow segments. Flow is from left to right.* ***b)*** *An expected hydraulic response for a flood which spills onto the floodplain is shown in light blue. The expected initial bed elevation change ($\partial n / \partial t$) is shown in brown. A hump forms where the floodplain rapidly widens and a pit is expected to occur where the floodplain rapidly narrows.*

Discharge & bed elevation analyses

We use high-resolution, biweekly bathymetry measurements from the Waal River in the Netherlands over the last 20 years to analyze bed elevation changes. A wavelet analysis proposed in Van Denderen et al. (2022) is used to isolate bed elevation changes on spatial scales of 300m-4km, those that are typically affected by discharge conditions on the Waal River. River bed variation as a function of discharge is analyzed at each location, and a linear fit is used to characterize the degree of difference in bed elevation changes between high and low flows (Fig 2b & c). The slope of this line is used to quantify bed elevation variation between high and low flows along-channel (Fig 2a). It is expected that the large differences in bed elevation change between high and low flows shown in Fig 2a will correlate with large gradients in local floodplain width.

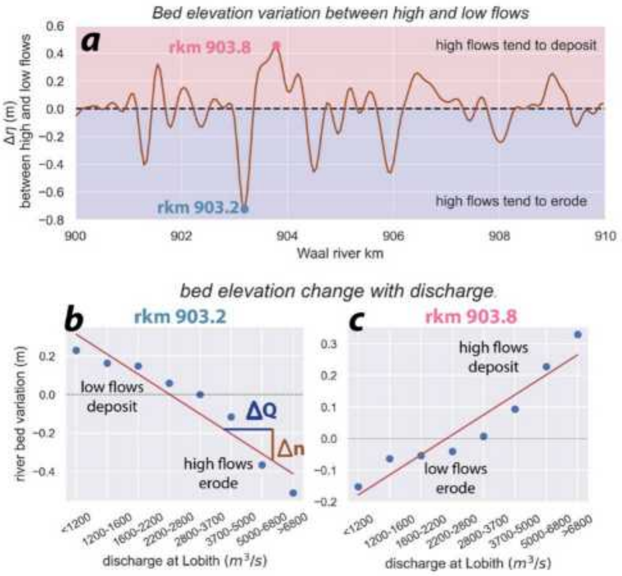

Figure 2. ***a)*** *An example section of the Waal River (river km 900-910) showing differences in bed elevation change between high and low flows (Δη) which vary along the channel.* ***b & c)*** *show example calculations of (Δη) for rkm 903.2 where high flows tend to erode and low flows tend to deposit and 903.8 where high flows tend to deposit and low flows tend to erode. Each plot shows river bed variation as a function of discharge at Lobith, where each data point represents bed elevation change for a range of mean daily discharge values obtained from flow duration curves for the data period, 2005-2021.*

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Sedimentation from the extreme summer 2021 flood along the Maas River, Netherlands

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Keywords — Maas River, Netherlands, 2021 summer flood, overbank sedimentation, floodplain deposits

Introduction

This study reports new field data for overbank sedimentation generated by the extreme flood event of summer 2021 along the Maas River, an intensively managed lowland river in the Netherlands. Flood duration was short (2-4 days) but flood magnitude was extreme. The event generated the highest discharge (3,265 m^3/s) recorded (at Eijsden, NL) in more than 100 years, and new flood stage records were established for several downstream stations.

The thickness (mm) of overbank flood deposits are reported for 108 field sites along a 198-km channel distance, from the NL-BE border to the downstream-most field location in the mid-delta. Field sites included a range of hydro-geomorphic settings typical of an intensively engineered lowland alluvial river, including low floodplain, high floodplain, channel bank, inset channel, and artificial flood basins recently created for the Room for the River flood management program.

Data and methods

Flood sedimentary deposits were sampled in August and September 2021 using conventional field sampling procedures (Heitmuller et al., 2016), which included identifying recent sediment deposited atop buried soil and organic layers using field texture, density, and differences in soil color (recorded). Sedimentation thickness (mm) of each of the 108 reported values is an average of three individual thickness measurements obtained within a ~0.5 m radius at each field site. Minimum floodwater height was measured by identifying silt and trash lines in vegetation and fencing at multiple locations, and ranged from 3.5-m to 0.3-m above low and high floodplain surfaces, respectively. Hydrometer analysis and wet sieving was conducted to determine particle size for 84 flood sediment samples. Field data observations and measurements were combined with a lidar DEM in a GIS to identify hydro-geomorphic settings per sample.

Results

Average flood deposit thickness was 19 mm along the Maas River, and mainly varied according to hydro-geomorphic setting: low floodplains (27 mm), high floodplains (3 mm), channel banks (18 mm), inset banks (12 mm), and flood basins (32 mm) (Fig. 1). Maximum sedimentation was associated with discreet sand sheets (305 mm), and most sand sheets were less than 30-m in width. Minimum sedimentation thickness was 0-mm at some locations, including several sites immediately along river banks. Floodplain stripping (erosion) at some low floodplain sites included reworking and deposition of large clasts (gravel, cobble). Pronounced lateral decreases in sedimentation thickness persist despite the height of the flood waters, and rapidly declines beyond about ~30 m from the channel bank. Lateral changes in particle size, however, are less abrupt, and along some reaches very fine sand was deposited to the distal margins of the embanked floodplain. Some laterally distant sites > ~200 m from the channel bank underwent high amounts of sedimentation (38 mm, 25 mm, 43 mm) with pronounced vertical fining (very fine sand to silt) of discreet laminae associated with slackwater sedimentation within basins engineered for the Room for the River flood management program.

In contrast to prior sedimentation studies a classic downstream-fining pattern does not exist (Fig. 2). Particle size (D50 mm) increases downstream. Average particle size (D50) increases from 0.04-mm near the NL-BE border to 0.13-mm downstream in the mid-delta (198-km). Similarly, particle sorting reveals a downstream spatial pattern, from moderately sorted to well sorted. The distinctive downstream pattern to flood sedimentary deposits for the 2021 extreme flood is likely due to upstream floodplain sequestration of silts whereas downstream flows remained competent to entrain sandy channel bed deposits. The overall thickness of the 2021 flood deposits are somewhat less than reported for flood events in 1993 and 1995. This may be due to the shorter duration of the 2021 flood event, as well as the persistent decline in Maas River sediment loads over past decades.

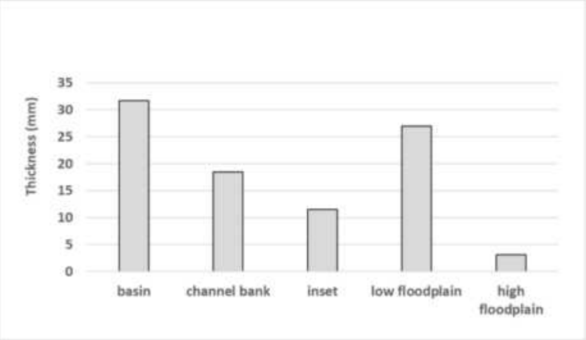

Figure 1. Maas River sedimentation from the 2021 flood event by hydro-geomorphic setting: flood basins, channel bank, inset channel, low floodplain, and high floodplain surfaces.

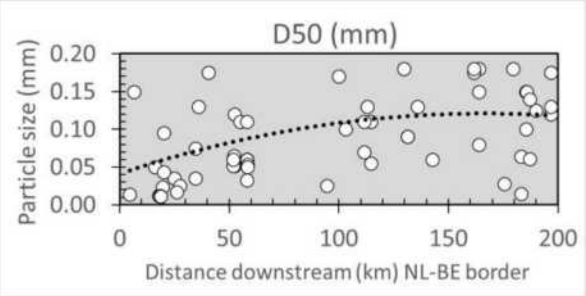

Figure 2. Downstream coarsening of median particle size (mm) of flood deposits along the Maas River from the 2021 event, BE-NL border (0-km) to mid-delta (198-km).

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Session 2

River Functions Under Pressure

Historic narrowing and deepening of the Rhine-Meuse estuary causes long term sediment deprivation

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Keywords — Estuaries, Long term morphology, Maps, River deltas, Anthropogenic influences

The Rhine-Meuse delta: a history of human interference

Humans interfere with their surrounding landscape as they migrate and settle. This is particularly prevalent in estuary and delta areas. In the Rhine-Meuse delta (RMD) the once natural estuary and delta area has transitioned into a densely populated urban zone, home to one of the largest ports in the world. Recently, it has been determined that the RMD is losing sediment annually, and at risk of drowning from future sea-level rise (Cox et al. (2021,b)). But how did the estuary develop to this point? Here we trace this history of human influence on the channels and morphology of the RMD including embanking, land reclamation, dredging and major engineering constructions which have created an urban delta.

The first widespread human interventions in the RMD began around 1000 when large-scale land reclamations and embankments started, fixing the courses of the Rhine and Meuse rivers, reclaiming their floodplains and halting any further avulsions. In the 13^{th} century, the city and port of Rotterdam were founded and rapid urbanisation began, with intermittent floods (including the Saint Elisabeth flood) halting or reshaping estuary development. From 1500-1700 extensive embanking and reclaiming continued. The Dutch East Indies company drove trade and shipping and dredging technology developed to find new ways to accommodate ships. From 1700-1900 new channels and canals were dug to allow for quicker shipping and better connections. From 1900 onwards, Rotterdam developed into the world's busiest port. This was accompanied by several major engineering works including the further new canals, the Deltworks and recently the construction of a large offshore port, the Maasvlakte 2. The most recent period has been focused on channel deepening and continuous dredging for navigation.

Methods

We use a hypsometric tool (see Leuven et al. (2018)) to determine past estuary morphology. This tool uses palaeogeographical and old maps and tidal range at the river mouth as basic inputs. The maps are used to determine width change through time, and then classic stability relations are used to indicate depth. This allows calculation of estuary width, depth and channel volume through time. Our analysis starts in 1500 BC using palaeogeographic reconstructions from Vos et al. (2020). In 1558, when the first accurate maps of the region begin to appear, we use the collection of georeferenced maps from the Utrecht University library. Tidal range has been constant for the period (see de Haas et al. (2019)), until the Deltaworks sealed off one estuary mouth in the 1970s, after which measured tidal range is used. We determined that the region can be split into two estuaries (see Figure 1) the main course of the Rhine river discharge to the the north and main course of the River Meuse discharge to the south. In total, 40 maps were used in analysis.

Results

Both estuaries have narrowed due to embanking and land reclamation. The RME estuary has rapidly narrowed by 85% since 1500 and the HVL estuary has narrowed by 65% since 1500. The RME estuary has been deepened by 94% while the HVL estuary has shallowed by 45% since 1500. This has led to an overall estuary volume change of -5.5Mm^3.
Initially, as the estuary formed and expanded (1500BC-1500, see table 1 and Figure 1), there is volume gain and sediment loss. Then, from 1500-1900 rapid embanking and land reclamation led to a loss of estuary volume and sediment gain. Since 1900 however, there has been volume gain (as channels are deepened for dredging) and sediment loss, a trend that is predicted to continue in the future.

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Table 1: Comparison of this sediment budget with previous sediment budgets for the RMD

Time period	Average sediment budget	Source
2000-2018	-2Mt/a	Cox et al. (2021)
2018-2085	-15Mt/a	Cox et al. (2021b)
1500BC-250BC	-1.9Mt/a	This research
250BC-1500AD	-2.86Mt/a	This research
1500-1900C	10.3Mt/a	This research
1900-2020C	-1.2Mt/a	This research

Long-term impact & conclusions

The RMD area has shown significant changes due to human intervention. The northern channels have been primarily affected by port and shipping developments starting in the 13^{th} century, meanwhile the southern part of the system has been changed mainly due to land reclamation and embanking. Our predictions for the future sediment budget of the RMD show the area will be changing more extremely than any other period in its 3500 year history, despite changes only occurring vertically (deepening) and not laterally (

Acknowledgements

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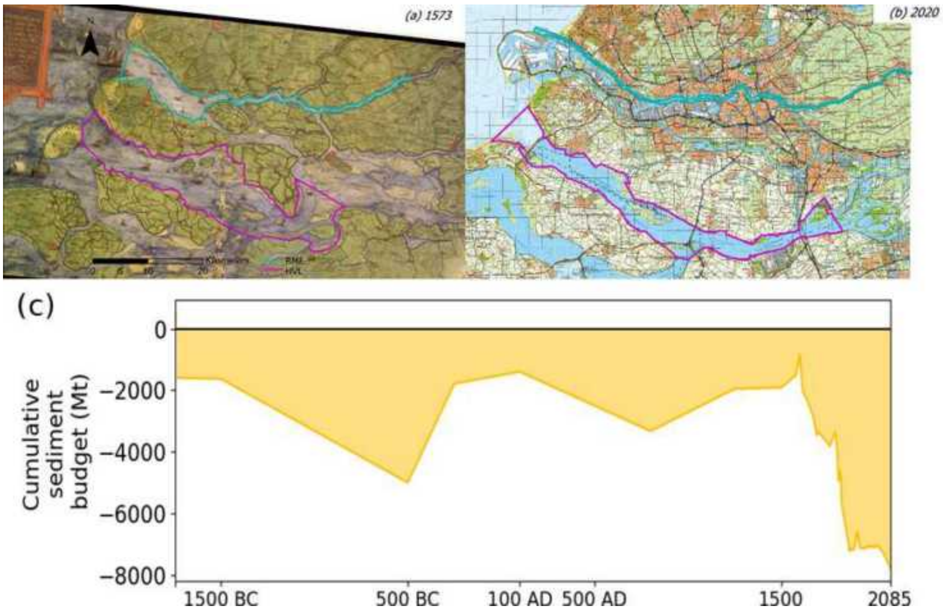

Figure 1: Map of the area in (a) 1573 and (b) 2020 where the northern estuary (RME) is marked in blue and the southern estuary (HVL) is marked in purple. Map (a) was supplied by the Utrecht University Map Library.Map (b) is the Top 250 map for the Netherlands. (c) is the cumulative sediment budget from 1500BC- present and future predictions until 2085.

Nature-friendly banks in the IJssel River - Measurements, analyses and recommendations

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Keywords — Nature-friendly banks, IJssel River, monitoring

Introduction

The EU Water Framework Directive guides and regulates targets on water quality and habitat diversity. Rijkswaterstaat (RWS) has already implemented hundreds of diverse measures in the Netherlands to comply with these ambitions. Nature-friendly banks (natuurvriendelijke oevers, NVOs, in Dutch) constitute one of those measures. They are created by removing existing protections (mostly riprap) up to a metre below average water level. While progress was made on understanding and forecasting the morphological development of NVOs exposed to flow and ship waves in regulated rivers (Duró et al., 2020; Duró, 2021), it remained unclear how NVOs respond to loads in unregulated rivers.

Figure 1. Nature-friendly bank at Welsumer Waarden in 2017, shortly after protection removal and excavation

RWS Oost-Nederland realised 14 new NVOs along the IJssel River in 2016 (e.g. Fig. 1). To prevent too much initial sedimentation in the fairway, the NVOs were pre-excavated during construction, with slopes between 1:10 and 1:3 (Fig. 2). A monitoring programme over 2016–2020 was implemented based on the conceptual model of Baar et al. (2014). The goal of this study was to evaluate the available data to explain differences in morphological evolution of NVOs along the Ijssel and generate generic guidelines for the selection and maintenance of NVOs in the upcoming years.

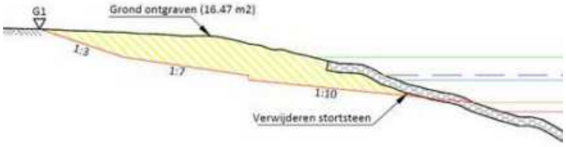

Figure 2. Example of initial profile design of NVOs

Methodology

We analysed field data of recent NVOs (built in 2016, hereafter "new" NVOs) and previously existing NVOs (hereafter "old" NVOs). The latter consisted of 14 locations, where protections had been removed since 1990s and includes banks that were never protected.

The monitoring programme included yearly topo-bathymetric measurements with LIDAR and sonar since 2016. Moreover, several field records along the NVOs, including photos, sediment characteristics, vegetation cover, and scarp morphology were taken in 2017 and 2020.

Different hypotheses describing the factors that may affect the NVO morphological evolution were evaluated. Parameters to confirm or falsify these included bank geometry (e.g. profile slope and length, see next), water level fluctuations, ship passages, position in the river stretch (straight reach, inner or outer bank), median grain size, presence of cohesive layer, and slump blocks. Three bank profiles were considered in each groyne field (Fig. 3), resulting in a total of 539 bank profiles.

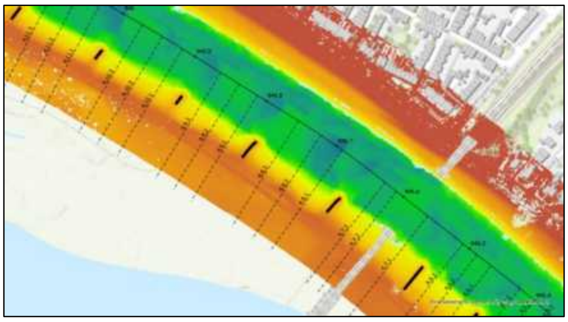

Figure 3. Location of three bank profiles per groyne field in elevation map

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Each bank profile was schematised according to a conceptual model with key features (Fig. 4). An algorithm was used to automate the detection of these points, based on slope changes, elevation and proximity.

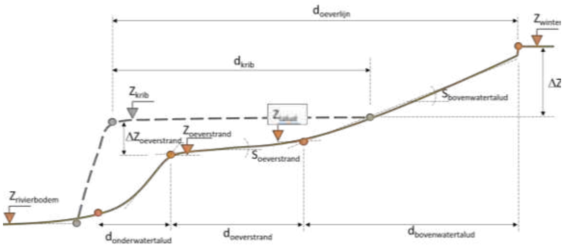

Figure 4. Schematized NVO profile between groynes

Results and interpretation

The four key points of the theoretical profile (circles in Fig. 4) were found in 45% of all analysed bank profiles, whereas another 20% had no clear inflexion point between the terrace and upper bank. The lack of elevation data at many cross profiles partially explains this. Circa 60% of the profiles missed one or more points, which were usually located at the terrace.

For those 65% of profiles, we compared several parameters in search of correlations and causality. Most profiles, however, did not present any clear correlation between potential erosion drivers and morphological changes. A likely explanation is that little morphological changes were observed at the pre-excavated NVOs after 3–4 years of development. Moreover, the new NVOs showed similar terrace and upper-bank slopes as old NVOs (e.g. Fig 5). This suggests that the initial profile of new NVOs closely resembled the long-term or equilibrium profile.

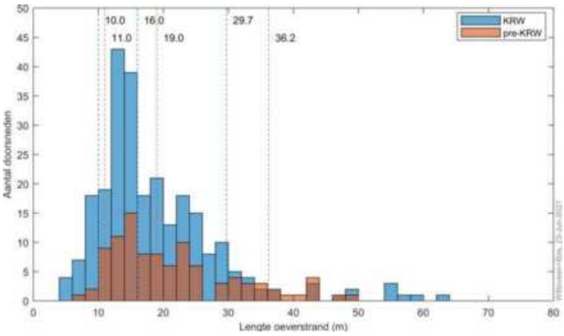

Figure 5. Terrace-length histogram for new and "old" NVOs

The observations indicated:

- Vegetated upper banks presented less morphological changes, on average;
- No relationship was found between median grain size at the terrace and the equilibrium slope;
- Direct sedimentation in the fairway at the location of the NVOs was limited;
- Analytical calculations showed potential indirect sedimentation as a result of the increased cross-section to be 3–10 cm;
- Recent NVOs with cohesive layers developed more slowly than banks without cohesive layers;
- Old NVOs with cohesive layers had a milder equilibrium profile than banks without cohesive layers.

Recommendations

We recommend improving the understanding of the morphological development of NVOs by:

- Continued yearly measurement of NVOs to gain a dataset that covers the full morphological development of the banks;
- Study of development of unprotected lower banks if this has ecological benefit;
- More detailed study of locations with deviating erosion patterns to formulate new hypotheses.

We recommend for future NVOs in the IJssel:

- Keep the usually submerged lower parts of the banks protected;
- Pre-excavate new NVOs to near-equilibrium profiles;
- Place pre-excavated material (if clean) upstream of NVOs as contribution to oppose large-scale channel bed degradation.
- Preferably locate new NVOs downstream of the Twente Canal, where ecology benefits from less ship traffic;
- Locate new NVOs at locations where direct or indirect sedimentation is no obstacle for navigation;
- Locate new NVOs in the upper IJssel if they need to counteract bed degradation.

We recommend further research on:

- Subsurface sand deposits that affect erodibility;
- Detection of cohesive layers at key elevations by soil cores per groyne field prior to selecting new NVO locations (those layers seem to affect erosion rates, e.g. at Welsumer Waarden).

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Basisrivierbodemligging - A reference river bed level - Application to the Meuse flood of 2021

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Keywords — River bed, Integrated River Management, Meuse 2021 flood, function exceedence, flood safety, scour holes

Introduction

Significant human intervention has taken place in the Rivers Rhine and Meuse. Due to an imbalance in the river system caused by these past interventions and by changes in the climate, important river-related functionalities as shipping, freshwater, nature, and flood risk management will sooner or later face difficulties. In order to accommodate various, sometimes conflicting, functions of the rivers sustainably, system choices are necessary. Therefore, a signaling instrument to visualize and analyze the (conflicting) demands of river functions for the river bed is now being established in the project BasisRivierbodemLigging (BRL, in English: Reference River Bed Level).

Objective

The BRL is a relatively new instrument under development and only limited concrete practical experience has been gained by its' application.

In July 2021, record high discharges were measured in the Meuse river. The flood caused severe damage to buildings and infrastructure. The study of the Task Force Fact Finding (*TFFF* (2021), see also the keynote of Nathalie Asselman) has shown that especially in the permanently free-flowing river section of the Grensmaas (Common Meuse) at least 22 scour holes of more than 3 meters developed. Four of these scour holes are even more than 10 meters deep. The scour holes have led to damage and risks, i.e. unstable riverbanks and infrastructure or insufficient coverage on top of pipes or cables in the river bed.

Using this case of the large-scale morphological changes on the Grensmaas during the Meuse flood of July 2021, it is possible to:

1. Learn which risks the BRL instrument signals well;
2. Identify which problems are not yet indicated by the BRL;
3. Test whether the BRL can be used as an auxiliary tool to quickly identify risk locations after a flood event or other large-scale morphological change.

Methods

The BRL instrument

Currently, the BRL instrument comprises a first set of river functions for which the demands or target values have been schematized as either 3D upper or lower limits for the river bed). For each of the river functions the function-exceedence-map shows whether this function has enough room with respect to the actual river bed.

Besides the individual maps, the BRL instrument also shows statistics for each function and it comprises several integral maps, i.e. the function conflict map that shows whether there is space for management between the minimal upper limit and the maximum lower limit.

Case study bed

The BRL identifies the (lack of) space between a river bed and function requirements. For this case study the difference in function-exceedence before and after the flood of 2021 is compared. Two case study beds were developed for the Grensmaas. The first, the river bed before the flood, is based on the AHN, LIDAR and multibeam soundings of autumn 2020 and spring 2021. The second river bed is formed by an update with multibeam soundings measured by the Measurement Service of Rijkswaterstaat after the flood. No update of the floodplains took place, because LIDAR measurements were not yet available.

Results

During the flood of July 2021 more than 20 deep scour holes developed in the river section between riverkilometers 34 and 40. Currently, the BRL comprises only one upper limit in this section, namely the function for *flood safety*. For this function the average bed level within a riverkilometer or floodplain is not allowed to raise above a threshold. Fig. 1 shows that the drop of the average bed level of the summerbed by the development of large scour holes has resulted in more space (more green

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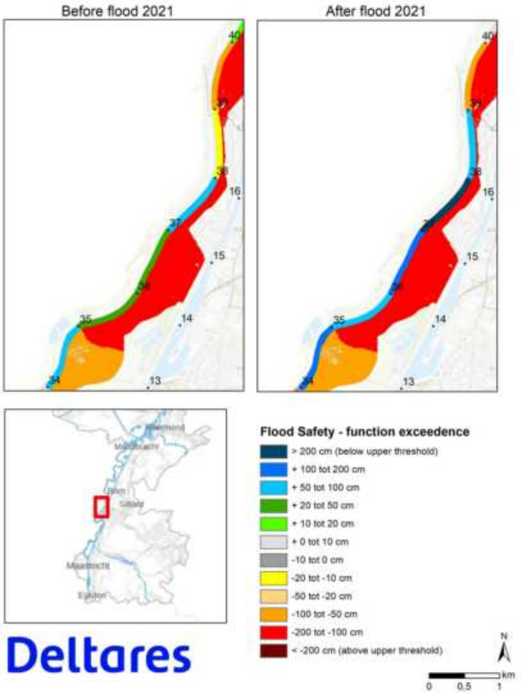

Figure 1: The function exceedence for the function flood safety *(high water levels) both before and after the summer flood of 2021.*

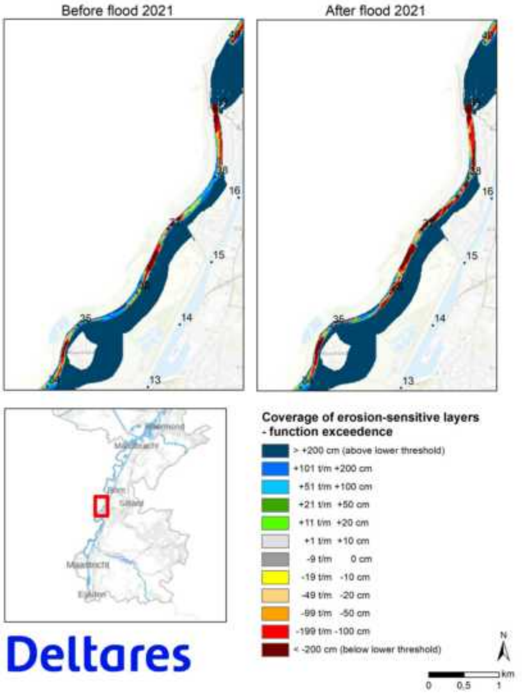

Figure 2: The function exceedence for the function cover on top of erosion-sensitive layers *before and after the summer flood of 2021.*

and blue colors) and a decrease in function exceedence (less red or yellow) for the function *flood safety*. The figure also shows that the floodplains show no change in function exceedence, because there is no update of the bed level measurements in the floodplains.

The BRL currently comprises multiple lower limits with coverage in the case study area: the *stability of embankments*, the *stability of banks*, the *cover above cables or pipes*, and the *cover on top of erosion-sensitive layers*.

The function *cover of erosion-sensitive layers* is especially interesting, because it is expected that erosion-sensitive layers easily erode when the coarse armour layer on top breaks through. Fig. 2 shows that the presence of only a small functional space or already an exceedence of the function *cover of erosion-sensitive layers* in spring 2021 often resulted in the development of scour holes and as a result large function exceedence after the flood. This figure thus confirms that many of the scour holes are formed because the fine sands on top of bed were easily eroded by the large flow velocities during the flood. This means that the BRL function *cover of erosion-sensitive layers* can be used to identify possible future erosion hotspots.

Conclusion

1. Most of the risk locations found by the Task Force Fact Finding or by Rijkswaterstaat Zuid Nederland were also identified by the BRL and the BRL even identified additional risk locations.
2. The results of the BRL are directly dependent on the quality of data used for the analysis. Not all risk locations were identified either because there were not always new measurements of the river bed available after the flood, or the dataset for the river functions was not complete for that location or the function is not yet been implemented in the BRL.
3. The BRL has proven to be useful for identifying risk locations. The presence of only a small functional space or functional exceeding for the function of *cover of erosion-sensitive layers* can be used to identify possible future erosion hotspots.

Acknowledgements

The BRL instrument is currently being developed and tested at Deltares in cooporation with and funded by Rijkswaterstaat.

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Vulnerability of villages in the Dutch Geul valley

Do we have to search for solutions within the water systems or floodproofing exposed livelihoods?

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Keywords — Flood risk, water systems, bottlenecks, vulnerability, HAND

Introduction

In July 2021, several European countries were affected by floods, including the Netherlands. The hotspot of damages in the Netherlands was located in the Geul valley. A first estimate by ENW shows damages of 200-250 million euros in the Dutch part of the Geul valley, which is about 50% of the total estimated damage in the Netherlands (Task Force Fact Finding hoogwater 2021, 2021). Historically, villages along the river in the Geul valley have to deal with floods and the associated risks. There are several urban centres along the Geul river and the inhabitants, buildings and infrastructure are vulnerable to floods (see figure 1). At the same time, urbanization often results in bottlenecks in the water system. Water and surrounding livelihoods conflict, but do we have to search for solutions within the water systems or floodproofing exposed livelihoods? In this abstract, a brief perspective of vulnerable inhabitants and bottlenecks in the water system is given. These are preliminary analyses and the objective of the broader research is to find effective measures to reduce flood risks in the Geul valley by using an integrated risk-based approach.

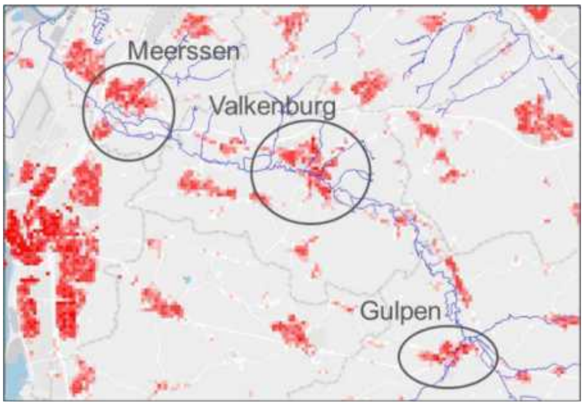

Figure 1. The Geul river and the villages that lay along the Geul are indicated in red. The redness indicates the density of the inhabitants.

Landscape perspective of vulnerability

To understand flood risk, we first quantify the vulnerable inhabitants in the Geul valley. Therefore, we make use of the height above the nearest open water combined with population data from CBS. Rennó et al. (2008) developed a quantitative topographic algorithm called HAND (Height Above Nearest Drainage). The application of the HAND descriptor is often used in hydrological modelling to classify different landscapes. This algorithm is implemented in the PCRaster and the HAND can be calculated based on only an elevation map, for instance, the AHN3. The present-day landscape of the Geul catchment is characterized by large, flat plateaus and deeply incised river valleys. These characteristics are visible in the distribution of the HAND (see figure 2). Within the valley, there is a large area with HAND values lower than 2 meters. The shape of the curve indicates the presence of floodplains that can inundate. In these lower areas, inhabitants are also settled (pink in figure 2). About 15% of the population in the Geul valley lives in areas with HAND values lower than 3m. We compared the vulnerable inhabitants according to the HAND analysis with the exposed inhabitants estimated by the Task Force Fact Finding hoogwater (TFFF) 2021 (red in figure 2). It can be seen that about half of the vulnerable inhabitants is barely affected by the summer floods, including the village Gulpen.

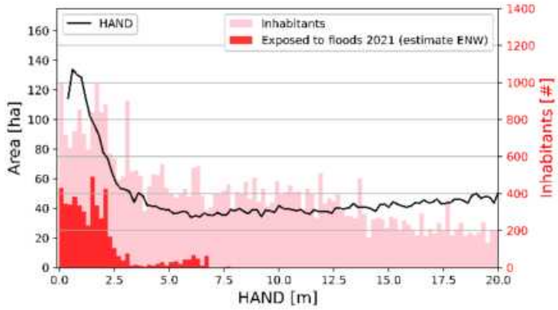

Figure 2. The black line shows the surface area of the HAND values in the Geul valley (left y-axis) and the pink and red bars show the distribution of the inhabitants by HAND (right y-axis). The stepsize of the HAND on the x-axis is 0.2m.

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Bottlenecks within the water system

The Geul river is a nearly undisturbed water system without embankments or canalization (de Moor et al. 2008). Klijn et al. (2018) proposed a method to assess the sensitivity of embanked rivers to discharge uncertainties. They expressed this sensitivity by the relationship between discharge and flood water level and quantified this by taking the difference in flood levels for subsequent discharge levels which differ by a factor of 10 in probability of occurrence. This measure is called the decimate or decimation height. The decimate heights in the Geul valley are calculated by using a hydrodynamic model which includes the inundation of floodplains. The decimate height is based on the 1:100 and 1:10 per year exceedance probability. Note that the corresponding discharge levels during the summer floods exceeded the 1:100 per year probability of occurrence and the severity varied along the different branches. The decimate heights along the unbanked Geul river show the presence of urban areas and obstacles like bridges that causes remarkable differences in the robustness along the river (see Figure 3). The river has limited room for flooding when it crosses villages, like Mechelen and Schin op Geul, where high decimate heights are found. Figure 4 shows an aerial image of Schin op Geul in which the decimate heights along the river are indicated by the coloured points.

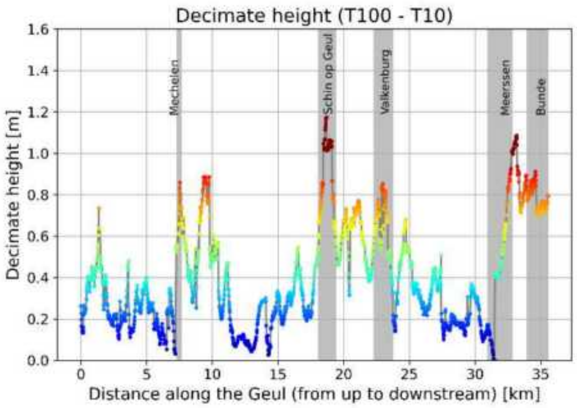

Figure 3. The decimate height along the Geul river. Several villages located along the Geul are indicated by grey areas. The colours correspond to the decimate height. Other branches in the catchment (Gulp, Selzerbeek and Eyserbeek) are not shown.

Future research

Appropriate design of the water system and the surrounding environment and the search for effective measures are necessary to protect livelihoods from floods. Conventional measures primarily focus on reducing the water levels by improving the water system (e.g. more room for the river or changing the rainfall-runoff process). The flood risk hotspots arise at places where rivers cross villages and space is being used by several spatial functions.

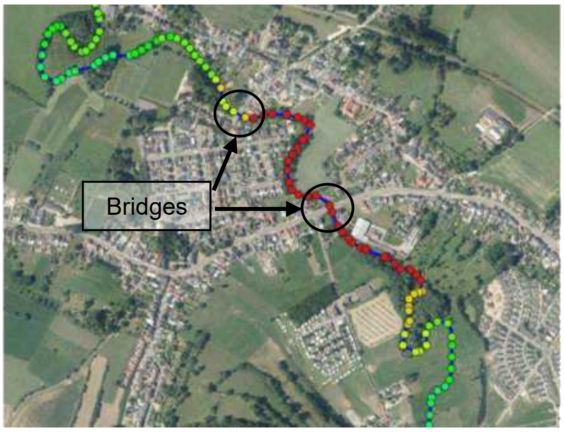

Figure 4. The decimate height at Schin op Geul. Two locations where bridges crossing the river are appointed. Red corresponds to large decimate heights and green to lower ones, like indicated in Figure 3.

It may be difficult to give more space to the water systems and other types of measures can reduce flood risks as well, like temporary and emergency flood-proofing. What are effective measures to reduce the flood risks in the Geul valley? As always, without humans, there is no risk. So, it would make sense to reduce flood risks by making livelihoods themselves more flood-proof or flood resilient, e.g. by reducing damages and improving flood recovery to get back on their feet more quickly. How to compare the effectiveness of different risk reduction strategies and what is an effective strategy to protect the village Valkenburg?

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Beneficial (re)use of local sediment as a means for sustainable river management

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Keywords — local sediment, sustainable management, functional design

Introduction

Continuous and ambitious projects are carried out in river areas worldwide in the context of flood protection, waterway management, nature development and mineral extraction. In many of these river projects, earthmoving is the major part. Among other things, it determines the costs, the CO_2 footprint and the environmental nuisance of such projects, and the spatial quality of the river landscape. Smart use of soil is therefore a key factor in sustainable river management. The subject therefore is starting to be progressively more present in policy. In the Netherlands, it has a prominent place in various knowledge and innovation agendas, such as the KIA Agriculture, Food and Water, the KIA Circular Economy, and the KIA of the Dutch Flood Protection Programme (*Hoogwaterbeschermingsprogramma*, HWBP). These articulate the need for practice-oriented research that contributes to sustainability and cost reduction of earthmoving, so that earthmoving is energy neutral by 2030, the costs per m^3 decrease significantly between 2020 and 2030 and that by 2030 there will be a healthy sediment and soil economy for circular material use. Therefore professionals are looking for new methods to realize these sustainability ambitions. However, a lot still has to happen so that they can be achieved in practice.

Dike Reinforcement with local soils

One of the many functions coming together in the river area is flood protection. The HWBP performs pilots to test innovations in order to develop new techniques or improve sustainability for flood safety. One of them is the pilot Dike Reinforcement with local soils (POV-DGG), which runs from 2018 until the end of 2022.

In soil-driven local design, the local material determines the design principle. Dikes are therefore functionally designed. The basic principle of functional design is that the suitable soil is not sought for a given standard dike design, but what a dike design could look like is considered and needed given the available material. Based on the composition of the soil, an estimate can be made of the behavior of the material. Subsequently, it is determined in which dike component or part these behavioral properties can best be applied.

The current practical knowledge gap

From the experience of the POV-DGG, various knowledge gaps can be identified with regard to the use of local sediment and soil for dike strengthening:

- Insight into the amount of soil and sediment that can be sustainably extracted from floodplains (in the context of nature development projects), so that the spatial quality of the river area can be enhanced.
- Insight into the properties and uses of this material, so that the link to its useful application in projects can be realised.
- Insight into the functional design of dikes using local soil, so that CO_2 emissions, environmental nuisance and costs as a result of transport movements can be reduced as much as possible.
- Best practices to locally match offer and demand of soil (combination of projects).

The challenge of determining the material properties

In order to stimulate soil-driven design with local land, it is important to give more room for preliminary research into available materials in the design process (Wiggers & Peters, 2021). However, the composition of natural sediments and soils varies largely per site and even within the same site. Moreover, small variations on the composition of the solid fraction can largely affect the mechanical properties of clay (e.g. Barciela-Rial et al., 2020; Barciela-Rial et al., 2022).

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Concluding discussion

Sustainable local (re)use of sediment contributes to a circular economy by reducing waste and regenerating natural systems (floodplains). It implies coupling of projects where soil becomes available, such as nature development projects, with those with soil is a needed material, such as dike strengthening. However such coupling in time is not straightforward, given the different administrations and stakeholders involved. Even though some tools are being developed (e.g. Besseling et al., 2021), they are still in an initial state and do not contain yet enough practical information that can be used directly in projects by different organisations. This is mostly because the different existing pilot tools have been developed by or for different organisations with different goals.

On the technical side, innovative functional dike design is needed. In case of lower mechanical performance of the local soil than traditionally used, it may imply, for instance, broader dikes. The prior determination of the mechanical properties of the local material is therefore required.

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Predicting the flow and transport of plastic debris in open waters

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Keywords — Megaplastic items, Finite-size effect

Introduction

Plastic debris of different sizes, shapes, densities, polymer compositions, and mechanical properties have been observed in the riverine, estuarine and marine environments, worsening the ecological and aesthetic values of the environment (*Derraik*, 2002). Moreover, accumulated plastic waste can be an important contributor to urban flooding (*Honingh*, 2020). Therefore, removal and disposal of plastic debris from the aquatic environment is an urgent issue to be addressed.

For that, it is important to know the trajectories and accumulation zones of plastic waste in order to capture them within the water system before they reach the ocean and to identify accumulation hot-spots. In general, there are three steps in prediction of plastic debris transport using a numerical model i.e. 1. to construct an underlying flow hydrodynamic model, 2. to simulate the material transport associated with the flow and 3. to account for the influence of plastics on the flow. The latter is important particularly for zones of accumulation near structures, such as floating debris carpets.

While most research efforts focused on large-scale plastic accumulation and transport as case studies (*Kubota*, 1994; *Neumann*, 2014), a few studies emphasize local processes of plastic debris, including vertical distribution of plastic particles (*Zaat*, 2020; *Kooi*, 2016), rising and settling velocities (*Chubarenko*, 2016; *Khatmullina*, 2017; *Kuizenga*, 2021) and its wave-induced motion (*Alsina*, 2020). To the author's best knowledge, current models for prediction of plastic debris transport assume a highly simplified geometry of plastic items, while making use of parameterization of the physical processes (*Besseling*, 2017), therefore pointing out the need for further research.

Size and inertial effects

Generally, the underlying hydrodynamic is simulated using Navier-Stokes equations and turbulence closures, however, the simulation of particle trajectory is still a difficult task due to its representation in the numerical model.

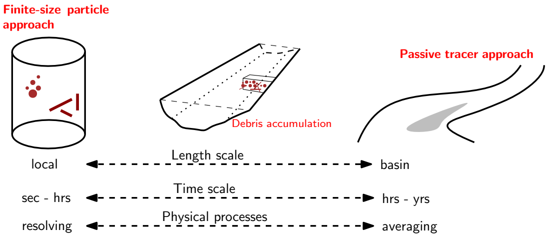

Figure 1: Finite-size particle approach and passive tracer approach currently used for small-scale analysis and large-scale applications, respectively. Simulation of debris accumulation exists halfway of the spectrum.

If the particles are assumed to travel with the flow i.e. negligible inertia, the passive tracer approach is commonly used for particle tracking. However, when inertia and buoyancy become significant, its trajectory should be considered separately from the underlying flow, which leads to a coupling between the particle shape and its net transport (*Dibenedetto*, 2018). This means that in such cases the finite-size particle approach should be applied instead. In this research, the latter approach will be applied for particle kinematic.

Fig 1 summarizes the two approaches and their applicability ranges of length scales, time scales and physical processes. Simulation of debris accumulation at halfway of the spectrum needs to account for not only inertia and buoyancy of plastic items, but also its size and orientation, as explained below.

In the finite-size particle approach, particles smaller than or equal to the Kolmogorov length scale are considered as point-mass, i.e. the so-called point-particle method. However, plastic items larger than this length scale should not be modelled as point particles because of their significantly large size, which otherwise can cause non-physical results (*Loth*, 2009). Hence, a method that accounts for variation of hydrodynamic forces around the plastic item should be applied (*Loth*, 2009), including particle orientation, particle-particle interaction and interactions with banks and structures. In this research,

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since large plastic items will be considered, the concept of “megaplastic” is introduced.

Megaplastic

Based on the apparent physical properties and expected distinct behaviour of some plastic items, the term **megaplastics** is defined for significantly large sizes of plastic debris $>$ 5 cm that are affected by added mass caused by the entrapment of water, air and sediment. These megaplastic also interact with structural components and entangle with other items, a behaviour that may not be observable with smaller macro or micro plastics. It is hypothesized that megaplastic can cause larger-scale physical damages such as flooding, landscape deterioration, while particles smaller than macroplastic (around 5 mm) can induce chemical and biological hazards to ecosystem. It is noted that due to cascading fragmentation, nano-, micro-, and macro-plastic can be seen as later stages of megaplastic degradation.

Future work

Interaction of hydrodynamic and particle dynamic will be studied using numerical simulation and experimental methods. More specifically, more emphasis will be put on plastic debris accumulation at hydraulic structures (e.g. carpet and gate formation at racks), incipient motion, remobilization and settling phenomenon, since these processes also play an important role in waste-removal strategy.

It is believed that this research output will also contribute to a better understanding of the behaviour of smaller items, using improved parameterization of their behaviour in 2D models.

Acknowledgements

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Final evaluation of longitudinal-training-walls pilot in the river Waal

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Keywords — River training, river Waal

Introduction

Rijkswaterstaat Oost-Nederland launched the idea of a new system of river training. It replaces the existing system of a single main channel between groynes by two parallel channels, separated by a longitudinal training wall. Expected benefits included reduction of overall bed incision, improved navigability, improved ecological conditions, and more safety against flooding.

To test this new system, Rijkswaterstaat implemented a pilot with three longitudinal training walls in the river Waal between Wamel (km 911.5) and Ophemert (km 921.5) in the years 2014-16 (Figs. 1 and 2). Before, during and after implementation, an extensive monitoring and research programme was executed by the WaalSamen partnership consisting of Rijkswaterstaat, Koninklijke BLN-Schuttevaer, Sportvisserij Nederland, Hengelsportfederatie Midden-Nederland, Deltares, and the universities of Nijmegen, Wageningen, Delft and Twente. In 2020, Rijkswaterstaat commissioned Deltares to evaluate the results from the monitoring and research programme. Part of the evaluation was subcontracted to HKV, Witteveen+Bos, MARIN and Bureau Waardenburg.

Method

The effects on hydraulics and morphology were assessed by analysing field data (De Jong et al., 2021) and carrying out numerical simulations (Paarlberg et al., 2021). The field data comprised water level registrations, flow velocity measurements and bed topographies derived from bathymetric surveys. The effects on how vessel used the waterway were assessed by analysing AIS data (Indah-Everts and Hermans, 2021). The effects on ecological conditions were studied by a broad array of biotic and abiotic field surveys (Collas et al., 2020). Surveys and interviews were used to assess how stakeholders and the local population experienced the pilot with the training walls (Verbrugge and Van den Born, 2021).

Figure 1. Location of pilot of longitudinal training walls in the river Waal.

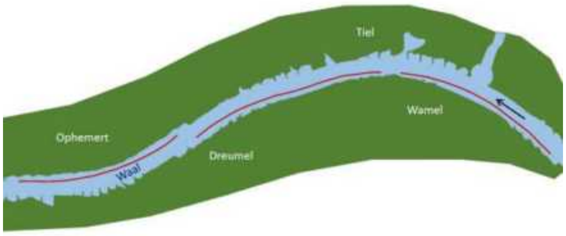

Figure 2: Three longitudinal training walls between Wamel (km 911.5) and Ophemert (km 921.5).

The data were used to evaluate the consequences of the new system for safety against flooding (Asselman and De Grave, 2021), navigation (Van der Mark and Van der Wijk, 2021), nature (Collas et al., 2020), freshwater supply (Van der Vat, 2021), public acceptance (Verbrugge and Van den Born, 2021), and morphological response in the light of maintenance and long-term sustainability (Chavarrías et al., 2021). Zuijderwijk & De Jong (2021) explored possibilities for optimization. Huppes (2021) reviewed the applicability of longitudinal training walls to other reaches of the Dutch Rhine branches.

Results

The new system was found to improve navigability at low flows if applied in reaches of least available depth. Moreover, it was found to sustain long-term navigability by countering the ongoing overall incision of the river bed. After implementation of the pilot, the waterway continued satisfying the international navigability standards. Yet a paradox was that, despite improvement of navigability during droughts and on a long term, skippers still saw the system with longitudinal training walls as an encroachment of the waterway in their day-to-day experience.

The pilot substantially improved the quality of nature in the reach of the training walls. The walls lowered design flood water levels at least as much as the groyne lowering previously planned in this reach. A modestly positive effect was found on freshwater supply during droughts.

Local inhabitants and recreational boaters were positive about the training walls from the start. The experience of inhabitants and sport fishers became more positive in the course of time, but inland waterway skippers remained skeptical. Participation of stakeholders in the monitoring and research programme was found to have increased support and appreciation for the pilot.

Conclusions and recommendations

The system tested in the pilot opens perspectives for integral solution of several river problems. It performs better than the old system with groynes thanks to spatial diversification through separation of functions. The pilot generally confirmed the expectations about the potential of the new system. No unforeseen negative impacts have surfaced. The new system does not solve all river problems completely, but it offers more space for further improvements in the future than the old system (Mosselman et al., 2021).

Figure 3. Inlet sill at upstream end of the longitudinal training wall at Wamel.

Rijkswaterstaat and Deltares jointly identified three points of further attention: (i) regulation of flow and sediment transport by modifying inlet sills (Fig. 3); (ii) operation and maintenance; (iii) the inland waterway (Mosselman & Buijse, 2021). We recommend addressing these points by continued monitoring and close consultation of the inland waterway transport sector.

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Tidal response to polder construction in the Pussur-Sibsa estuary

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Keywords — Land Reclamation, Tidal Amplification, Idealized Modelling

Introduction

Intertidal areas impose a strong control on the hydrodynamics in estuaries and tidal inlets. Widespread reclamation of the intertidal zone in the Pussur-Sibsa estuary (PSE), Bangladesh, led to substantial tidal amplification (*Pethick and Orford*, 2013; *Van Maren et al.*, 2022) and radically shifted discharge patterns throughout the estuary. In some places, severe bank erosion followed, whilst in other areas shipping is disrupted due to rapid shoaling. The exact mechanisms behind the observed changes in the PSE are still unclear. In this contribution, we employ an idealized process-based model to investigate the effects of widespread land reclamation on hydromorphodynamics of the PSE.

Field Site

The Pussur-Sibsa estuary (PSE) is a multi-channel subsystem of the larger Ganges-Brahmaputra-Meghna Delta and connects to the Ganges River through the Gorai River. The Sibsa River (western branch) and the Pussur River (eastern branch) join approximately 30 km from the seaward boundary. Prior to their definitive confluence, the Sibsa and the Pussur are connected through four transverse rivers. The Pussur river receives most of its fresh water from the Gorai River, which draws 10-20% of the Ganges discharge. The Sibsa river, on the other hand, only receives fresh water from local precipitation. In the 1960's and 70's, a significant portion of the intertidal planform and peripheral rivers were embanked. Prior to the embankment construction, all discharge from the Gorai found its way to the ocean through the Pussur branch (*NEDECO*, 1967). Half a century later, a substiantial part of this fresh water flow is diverted to the Sibsa branch through the connecting channels (*Bain et al.*, 2019). It seems that the gross tidal prism of the Sibsa has significantly increased.

Methodology

An idealized numerical model resembling the mainstem Sibsa river was constructed to investigate the hydrodynamic changes following a loss of intertidal area along an elongated tidal channel. First, the hydrodynamics of a near-equilibrium tidal channel with extensive intertidal storage is investigated (Figure 1). Next, the response to a series of interventions is explored. Model simulations were carried out using the depth-averaged version (2DH) of Delft3D-flow, and all input files were prepared using MATLAB.

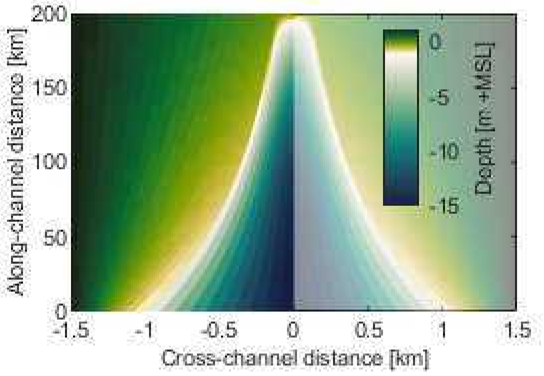

Figure 1: Bathymetry of the idealized numerical model. The lighter shades on the right-hand side denote the area where the flow is not computed directly, but is instead derived by mirroring the results from left-hand side.

The location and extent of embankment construction can vary substantially. Hence, we started simulations with different sections of the intertidal area removed from the model domain. In Bangladesh, land reclamation started inland and shifted progressively towards the coastline. In the PSE, embankment construction stopped 60 to 80 km from the coastline, to preserve the Sundarbans mangrove area. In many other estuaries (e.g. the Western Scheldt in The Netherlands), land reclamation development followed an opposite pattern. It started at the coastline and gradually moved landward. Both cases were included in the simulations, but only the former is shown in this abstract.

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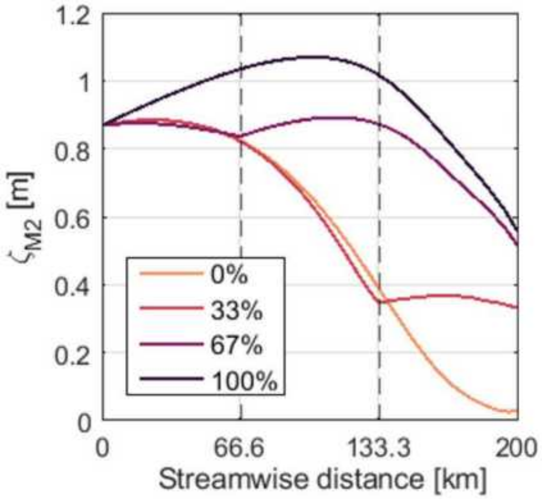

Figure 2: Along-channel profiles of the amplitude of the M2-constituent for simulations with varying degrees of embankment of the intertidal area. Embankment construction starts at the seaward boundary.

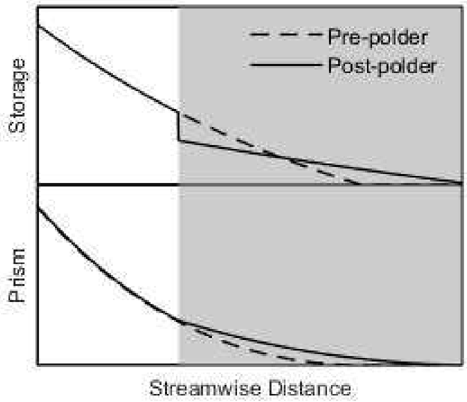

Figure 3: Conceptual profiles of the intertidal storage volume and tidal prism before and after partial embankment of the intertidal area. The grey area denotes the embanked section.

Results

When sections of the intertidal area are removed from the model domain, the tidal amplitude increases within and landward of these sections (Figure 2). Embankment of intertidal area causes a large portion of intertidal storage to be lost. However, the tidal amplification that follows enlarges the intertidal storage within the channel. This increase in intertidal storage is composed of two components: a local increase of the tidal range and stronger landward intrusion of the tidal wave. Consequently, the loss of storage area within the intertidal zone, following its embankment, is more or less completely compensated for by an increase of storage within the channel (figure 3)

Removal of the intertidal area enhances wave propagation in the channel. At the start (or end) of an embanked section, the wave celerity can suddenly increase (or decrease) up to 6 m/s. Especially the removal of the intertidal area near the shallow landward end of the channel, significantly reduces travel times from the inlet to the landward boundary. Embankment of the most landward 33% of the intertidal area reduces the total travel time with 4 hours and 20 minutes.

Discussion and Conclusion

The response of a tidal system to reclamation of its intertidal area can be complex and counter-intuitive. Because the morphological response of the channel seaward of a reclamation is slow, the loss of intertidal storage on the intertidal platform can be compensated for through tidal amplification, and a landward expansion of the tidal influence. As the compensated intertidal storage is situated landward of the lost storage, the tidal prism within and landward of the embanked sections increases, ultimately resulting in channel erosion. Drastic increases of the tidal wave celerity following embankment of the intertidal area may bring the tidal wave closer to or further from resonance conditions. Earlier polder construction in the Sibsa basin resulted in a shift of the intertidal storage into the Pussur, hereby allowing the Sibsa to capture discharge from the Gorai. This study highlights the unexpected changes to water levels and tidal discharges that may proceed from land reclamation, decades after the reclaiming activity took place.

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Plastic transport through the Dutch rivers

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Keywords — Macroplastic, microplastic, plastic soup, pollution, hydrology, floods

Plastic pollution in terrestrial and aquatic ecosystems is a growing threat to environmental health and human livelihood (van Emmerik & Schwarz, 2020). Rivers are assumed to be major pathways for land-based plastic waste towards the oceans (Meijer et al., 2021). However, a growing amount of evidence suggests that most plastics never make it into the sea, and rather accumulate within river systems for years, decades and potentially even longer (van Emmerik, Mellink et al., 2022). Long-term and consistent observations are therefore key to improve the understanding of transport and retention dynamics, to identify sources and sinks, and to assess potential risks (van Emmerik, Vriend et al., 2022). We present key findings from a one-year intensive monitoring campaign of floating macroplastics in the Dutch Rhine, IJssel and Meuse rivers. Measurements were done monthly at upstream and downstream locations of each river. Additional observations were done during the annual peak discharge in February and the Meuse flood event in July. We assessed the spatial and temporal variation of floating plastic quantities and composition at the national scale. We demonstrated that floating plastic transport is significantly higher downstream than upstream. Further spatial variations were hypothesized to be related to the complex river network, locations of urban areas, and tidal dynamics. Floating plastic transport during the February peak discharge was higher than under normal conditions. During the Meuse flood in July a four- to sixfold increase was found. For the first time, we demonstrated the strong response of floating plastic transport to peak discharge events. For four out of five tested locations, we found a strong positive correlation between floating plastic and discharge, further confirming the important role of hydrology as driving force of plastic transport dynamics. Finally, we estimated the floating plastic mass transport for the upstream and downstream locations of all three rivers. Despite the match with previous model results (Meijer et al., 2021), our estimates emphasize the large uncertainties in plastic mass transport locally, regionally, and globally. We demonstrate the cardinal role of hydrology in plastic transport dynamics. However, we also emphasize the need for exploring other factors that may explain the observation spatiotemporal variation in floating plastic transport (Roebroek et al., 2021). Our study aims to contribute to both advancing the fundamental understanding of plastic transport dynamics, and the establishment of long-term and harmonized data collection at the river basin scale.

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Real-time monitoring of the rivers Boven-Rijn and Waal to support dredging operations

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Keywords — Dredging, river morphology, real-time monitoring

Introduction

The river Waal is an important shipping route connecting the harbour of Rotterdam with the hinterland. Obstructions in the navigation channel have a large financial impact on the economy of the Netherlands. Continuous dredging is needed to ensure sufficient water depth and channel width for navigation.

From July 2021, Heijmans carries out the maintenance work with subcontractor Martens en Van Oord (MvO) for a minimum of 5 years. For dredging operations, MvO is supported by De Jong Zuurmond. HKV develops a monitoring system to collect and process all relevant morphological data in near real-time: a Digital Twin of the navigation channel of the rivers Boven-Rijn and Waal. This system provides continuous insight in the morphological development of the riverbed and the dredging activities for both the contractor and Rijkswaterstaat (client). The Digital Twin offers unique opportunities to get a better insight in riverbed morphology while optimizing dredging operations.

A Digital Twin for real-time insight

The Digital Twin is set up in Delft-FEWS. This software is originally developed as flood early warning system (FEWS) and can store and process huge amounts of data as scalar or grid time series. We configured this powerful software to meet the needs of monitoring the riverbed dynamics and dredging operations.

The system is fully automatic and runs predefined workflows automatically in a set interval. Logs and alerts are automatically created based on the incoming data and triggered workflows. Therewith the system fits the needs of the contractor to deliver automatically (weekly) maps of the riverbed compared to the required bed level to Rijkswaterstaat without the interference of staff. Missing or erroneous data streams are detected in real-time to allow for proper response.

To meet the contractor's needs, two interfaces are developed. The Delft-FEWS interface with full access to the database and a huge variety of functionality (see Figure 1). Next to this, a web-based dashboard (see Figure 2) is developed to provide easy access, but also limited in the amount of data shown and functionality.

Data sources

Within the Digital Twin relevant data sources are collected and processed to support dredging operations and perform (trend) analysis:

- Measured and forecasted water levels and discharges at Rijkswaterstaat measurement locations.
- Multi-beam measurements of the riverbed in a 1x1 m spatial resolution carried out by the contractor in set intervals: per week for so-called dredging Hotspots and per 8 weeks for the entire river Waal.
- Daily single-beam measurements of Covadem on a 10x10 m spatial grid.
- Daily grids of the dredging operations (suction hopper and ploughing) carried out by the vessels of the contractor.
- Least Available Depth measurement performed by Rijkswaterstaat (in Dutch: MGD = Minstgepeilde Diepte).
- Various more or less static sources, such a navigation channel geometry, fixed layers, typical flow patterns, grain-size distributions and river dune statistics.

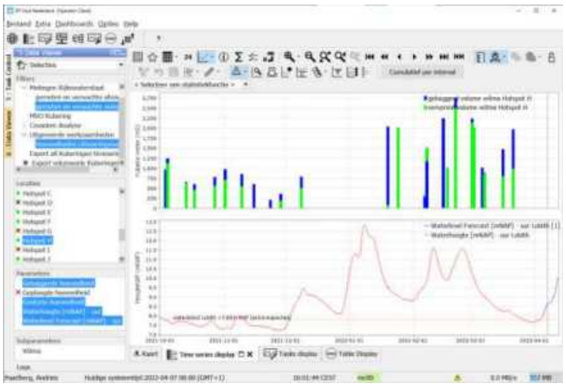

Figure 1: The Delft-FEWS interface of the Digital Twin showing the dredged and dumped volumes together with observed and forecasted water level at Lobith.

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Optimizing data flows

To enable data (trend) analysis, the data needs to be consistent and error-free as much as possible. This sets certain requirements on soft- and hardware, but also on the data collection processes on the maintenance vessels, including human actions involved. Most importantly, dredging operations need to be performed safely. Together with the (sub)contractors and Rijkswaterstaat, we are optimizing the data collection process to minimize 'human errors' and to detect possible errors in data in an early stage, by processing and visualizing the data in real-time.

Results so far: insight in river dynamics and related dredging operations

The Digital Twin is operational for half a year and has already shown to be valuable:

- We ensure collection of consistent data sets which is beneficial for both the contractor and Rijkswaterstaat;
- The system gives a solid base for real-time monitoring of potential bottlenecks allowing for data-driven dredging without compromising on contract requirements;
- We have continuous and real-time insight into several data sources such as high-resolution multi-beam measurements and low-resolution, but high frequency single-beam measurements;
- Insight in Least Available Depth (Figure 3) that provide insight in the development of potential bottlenecks;
- We obtain insight in the efficiency of suction dredging/dumping (e.g. with hopper) and ploughing, and thereby create a consistent and complete and consistent database of dredging activities.

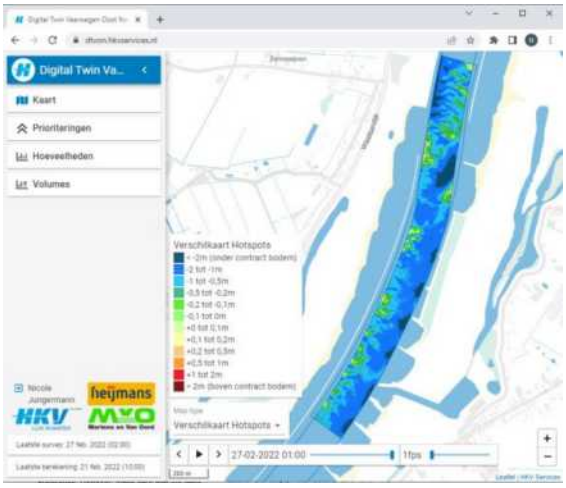

Figure 2: Difference map shown in the dashboard of the Digital Twin.

Future developments

The Digital Twin gives a lot of insight the river behaviour and how dredging operations influence this behaviour. By gaining more and more real-time insight in river behaviour and its relation with dredging operations, we aim towards efficient maintenance of the required bed level, thereby reducing the CO_2 footprint of the river maintenance. The Digital Twin provides a basis that can be easily extended with new data sources and insights in the morphological development of the river such as dune height predictions. There are several ideas to enrich the system with new data sources or optimize the data we have in the system. Think of using new opportunities in data collection (GPS, sensors), but also combining several data sources to reduce uncertainty or enlarge spatial coverage (e.g. increase spatial coverage of Covadem-data using multibeam measurements).

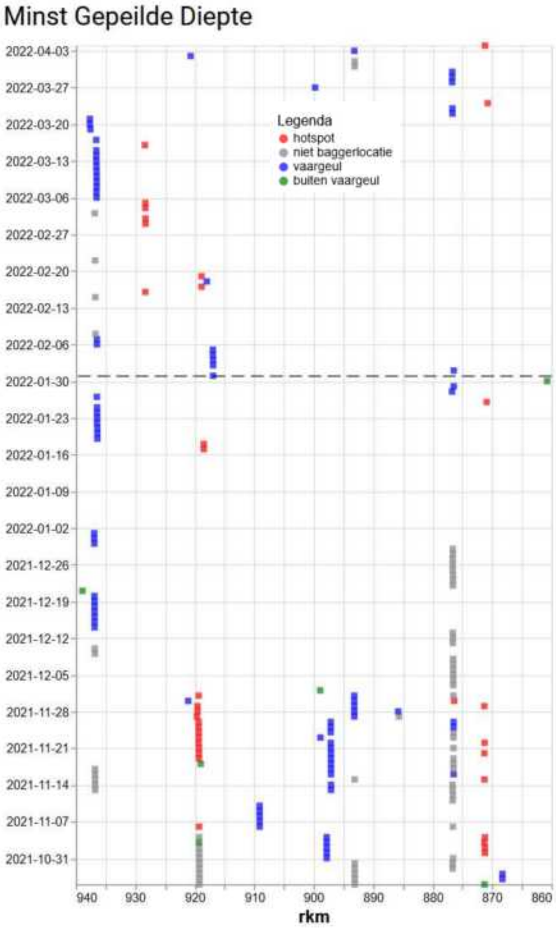

Figure 3: Visualisation of the Least Available Depth (Minst-gepeilde Diepte) along the Boven-Rijn and Waal.

River Bar Downscaling with Bed Sills and Bottom Groynes: A Numerical Study

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Keywords — River Morphodynamics, Bar Removal, Bed Sills, Bottom Groynes, Structure Configurations

Introduction

Alluvial low land rivers are often characterized by the presence of bars. These are large sediment deposits that affect the river cross-section by creating shoal and pool areas. The existence of bars in a river can lead to undesired effects on human activities and structures, such as hindering of navigation, blockage of water intake, and endangering the safety of the existing hydraulic structures as a result of flow concentration in some parts of the river cross-section, i.e. pool areas (Teraguchi, et al., 2011). Suppression or downscaling of bars can be possibly obtained by using bottom structures like bed sills, (structures across the entire river width with a level equal to the average elevation of channel bed) and bottom groynes (Figure 1). The advantage of using this type of structure to manage bars lies in their low level, which does not hinder river navigation and fish passage.

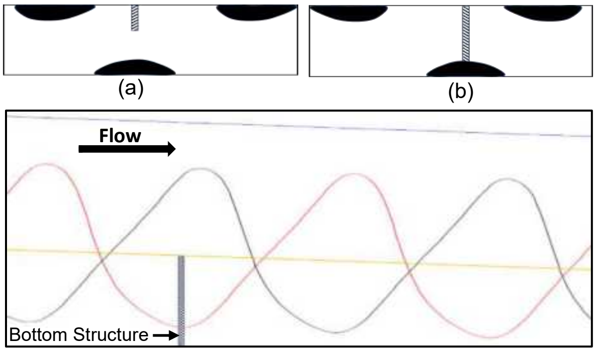

Figure 1 a) Plan view of Bottom Groyne, b) plan view of Bed Sill, c) Longitudinal profile. Blue line: water level, black line: right bank bed level, red line: left bank bed level, yellow line: average bed level.

This study investigates the effects of using bottom structures with various configurations (length, location, and number) on alternate bar-size reduction.

Methods

To achieve the goals of this research, a 2DH morphodynamical model of a straight alluvial channel with alternate bars was set up using the Dleft3D code, version 4. To have a realistic virtual river, characteristics of the Waal River, in the Netherlands, were imposed to the model, starting from the work of Duró (2014).

The virtual river has a uniform discharge of 1600 m^3/s (bankfull discharge of the Waal River), a Chèzy coefficient of 55 $m^{1/2}/s$, a longitudinal slope of approximately 10 cm/km, and uniform grain size with D_{50} of 1 mm.

These morphodynamic characteristics lead to the formation of alternate bars close to resonance (Crosato and Mosselman, 2020). The model grid consists of 16 and 384 cells covering a (250 m wide) and 15 km long river reach, the cell dimensions being about 15 m and 39 m in the transverse and longitudinal direction, respectively.

Preliminary model runs allowed selecting the numerical representation of bottom structures using Delft3D. Various scenarios are studied with the model:

- Two base-cases without any instream bottom structures represent cases of steady bars (hybrid alternate bars, as in Duró, et al. (2016)) or migrating bars (free alternate bars).
- Various scenarios with numerical structures representing bed sills or bottom groynes.
- Different configurations regarding structure's location, length (in the transverse direction), and number.

Preliminary Results

Two-base cases were generated. Hybrid bars were obtained by placing, a permanently emerging groyne obstructing 50% of the channel width near the upstream boundary (Figure 2). The groyne was enough to generate both morphodynamic instability, leading to the formation of alternate bars, and forcing, stabilising the bars while making them longer and steady.

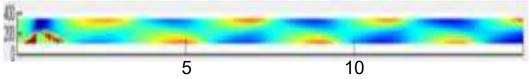

Figure 2 Plan view of bed level in steady bars base case

Free migrating bars were obtained by introducing a small random perturbation in the transverse distribution of the inflow at the upstream boundary. This was enough to create morphological instability leading to the formation of migrating bars (Figure 3).

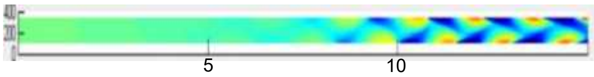

Figure 3 Plan view of bed level in migrating bars base case

The results of the preliminary runs to establish the best numerical representation of the structures clarified that the combination of inserting a numerical sub-grid structure called “2D Weir” and “non-erodible bed layer” does not alter the geometrical characteristics of the bars that form further downstream, which is according to theoretical expectations (Crosato and Mosselman, 2020) since these structures cause some extra forcing to the system without altering its morphodynamic characteristics.

The numerical “2D weir” computes the energy dissipation due to the presence of the structure and the “non-erodible bed layer” allows reproducing the morphological response to the rigid structure having a given top level.

About the scenarios with structures, preliminary trials were done to study the effects of different configurations on bar formation:

Location

Figure 4 shows that placing a bed sill at the pool deepest point of a hybrid steady bar affects the downstream bar amplitude more than placing the structure at other locations with respect to the same bar. The effect extended to a distance of approximately 1.5 times the bar wavelength and to a much lesser extent also upstream.

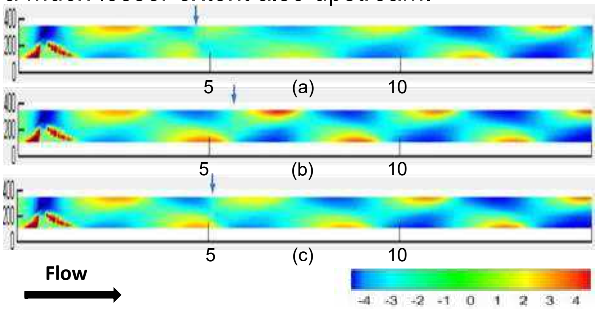

Figure 4 Plan view of bed level with different location of bed sills for hybrid alternate bars, a) pool deepest point, b) cross-over section, c) pool end section. The original hybrid bars are shown in Figure 2.

Length in transverse direction

Three different lengths (100%, 50%, and 33% of the width) were tested. Figure 5 shows that the bottom groyne covering 33% of the width maximizes downstream bar reduction. The bar amplitude decreased by 70% of the initial base-case scenario for a distance of 1 to 1.5 bar wavelength downstream and locally also upstream.

Number

Placing two structures at distances of 0.5, 1, 1.5 bar wavelengths does not increase the effectiveness in reducing downstream bar amplitude.

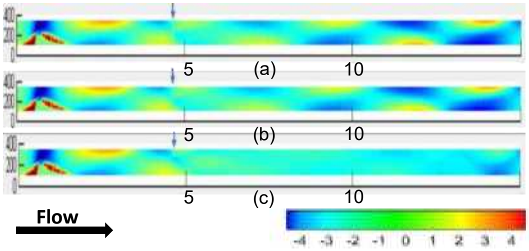

Figure 5 Plan view of bed level with different structure lengths, a) 100% of channel width, b) 50% of channel width, c) 33% of channel width.

Conclusions and recommendations

In Delft3D, the effects of bottom structures can be simulated using the combination of a sub-grid structure “2D Weir” and a “non-erodible bed layer”.

Preliminary results indicate that bottom structures might be effective in reducing alternate bar amplitude for a certain length downstream and can therefore be used to locally mitigate the negative consequences of bars. However, the investigation requires further studies, for instance by considering different bar regimes.

It is recommended to carry out additional physical experimental studies to clarify the feasibility of using this research outcome and obtain the required effects on real cases.

Acknowledgements

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Towards scaling up sediment nourishments in the Dutch Rivers

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Keywords — Integrated River Management, riverbed management, sediment nourishment

Introduction

Problem description

Within the Dutch river branches there is ongoing erosion of the main channel bed (Ylla Arbós et al. 2021) and as a result lowering of the water level during droughts. This causes bottlenecks for among other: navigability, fresh water supply and ground water levels.

Soft riverbed management (by means of nourishments) is proposed frequently within the Integrated River Management (IRM) program. Germany has set an example with multiple nourishments in the Oberrhein since the 1970s and in the Niederrhein since the 1990s (Ylla Arbós et al. 2021). In the Rhine branches, a pilot is performed with nourishments in 2016 (Figure 1) and 2019.

However, knowledge of effects and impacts from nourishments in the more dynamical lower parts of the Rhine branches, and how to implement and control it effectively is limited.

Figure 1. Sediment nourishment pilot project in the Boven-Rijn. Source: Sieben et al. (2016)

Motivation

End 2021 Rijkswaterstaat asked Witteveen+Bos to assess the interests, criteria, opportunities and risks of river-sediment management by nourishments. The knowledge gaps identified in the assessment enable defining pilot sediment nourishments that make the Rhine branches future-proof.

Outline

This abstract describes the context of river-sediment management by nourishments within IRM, the challenges in implementation such riverbed management and how a pilot can contribute to fill the knowledge gaps.

Method

The assessment mentioned is based on available documents and interviews with experts from departments of the Ministry of Infrastructure and Water Management as well as from the sectors of inland shipping, sediment mining and contracting.

Integrated River Management (IRM)

Context

The IRM program develops a future-proof river system that supports multiple functions and can be managed sustainably. The discharge capacity and the geometry and sediment management of the main channel play a central role in this, as far as flood safety, fresh water supply, river-related nature and navigability is concerned.

Causes of bed degradation

Bed degradation in the Dutch rivers is for a large part resulting from normalization of the rivers since about 1850 (Ylla Arbós et al. 2021 and Frings et al. 2019). Narrowing of the main channel, construction of dikes and groynes and bend cutoffs have reduced the flood risk and improved the navigability. However, the increased sediment transport capacity induced a smaller (equilibrium) bed gradient by bed degradation. Dredging and sediment mining have accelerated this significantly.

Mitigation of bed degradation

Bed degradation can be mitigated by:

- Eliminating or reducing causes of erosion by renormalization: lowering groynes or new side channels accompanied by longitudinal dams will change the normalized river geometry and reduce a cause of bed degradation. However the expected impact on bed levels is small, slow and may induce erosion at other locations. This impact could

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be enlarged and accelerated by combination of sediment nourishments and/or facilitation of riverbank erosion.
- Compensating measures by river-sediment management based on dedicated sediment extraction and application for replenishing and influencing the riverbed in the main channel. Compensating sediment deficits by nourishment counteracts the impact of erosion (Czapiga et al. 2022). Successful examples are the Niederrhein nourishments and the nourishments at the Dutch coast compensating for coastal erosion.
- A combination of both strategies combines benefits, should increase effectivity for all river functions. The river-sediment management component in such a combined strategy represents an economical no regret flexibility. It enables accomplishing stability on a short term, while developing a gradual river-relandscaping at large scale.

Challenges in implementation

The key challenges for developing soft riverbed management are obtaining specific knowledge on effectivity and impacts and sustainability.

1. Specific knowledge

Knowledge needs to be developed on where and how to nourish which sediment. Key questions are: “How does this sediment behave at a specific location under certain conditions?” And, “what effort is required, initially and in management and maintenance, to achieve the intended effect and to control side effects?”

This requires insight into the physical system and its functionalities, in sediment sources and their characteristics, designing and performing nourishments, and their impact.

2. Sustainability

How can soft riverbed management be carried out sustainably? Important issues are:
- Circularity: for example by dredging sediment from the main channel and nourishing it upstream. How well does this strategy fit the objectives?
- CO2 footprint: Since transportation of sediment contributes significantly to the environmental impact of river measures (Van Kouwen and Van Vuren, 2021), how can this be optimized?

Acquiring knowledge by pilot

A pilot is an essential step to acquire this specific knowledge (together with other studies) about performing nourishments the impact on the river system and it side effects.

From a sustainability perspective, a pilot of nourishment in the Midden-Waal, using material from the downstream part of the Waal and/or material that becomes available from maintenance work elsewhere. This conforms the work-with-work principle with material that remains in the system. This makes it circular and provides insight into supply-oriented management with available sediment.

If such a management is not adequate, there is reason to develop a demand-driven sediment management through a pilot with pre-specified sediment.

Conclusions

Riverbed management requires an integral strategy considering the physical system and all functions.

At current, there is a knowledge gap on how to nourish effectively, sustainable and without side effects in the more dynamical lower parts of the Rhine branches. A pilot that focusses on circularity, effectivity and unhindered shipping during and after the actual nourishment is considered essential to develop the required knowledge. We need to know at which location which sediment source is suitable for nourishments. This prepares us for scaling up soft riverbed measures in IRM.

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Inventing a hydraulic river modelling approach to simulate high flow and low flow conditions

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Keywords — Hydraulic river modelling, High and low flow, Roughness calibration,

Introduction

Global climate change affects all aspects of river processes. It is expected that discharge extremes will occur more often in the future and that the possibility of having discharge extremes in terms of high and low flows in a shorter period will increase too. More specifically, for the Rhine River in Germany and the Netherlands, high discharges in winter are expected to become more severe, whereas low flows will occur more often and over a more extended period in summer and autumn. Given these changes in climate conditions, the question arises whether it is possible to have an integrated hydraulic modelling approach to simulate high and low flows in rivers.

One of the advantages of a single model for low and high flows is the tendency towards integrated river management. For example, the implications of measures targeted to high flows should not have negative consequences for low flow conditions and vice versa. Currently, the calibration procedure is one of the reasons to employ two separate models instead of one calibrated model.

Calibration means minimizing the errors between simulated and observed water levels by modifying model parameters for a specific situation. These errors could be caused by e.g. uncertainties in the input data and mesh discretization in hydraulic models. The primary purpose of this study is to develop a single model with one calibration approach that could simulate the water level accurately for different discharge ranges. In this regard, the first step is to study the current state of hydraulic calibration approaches applied in the literature. The second step is to find a suitable model set-up for such a model. The third and fourth steps are finding the most promising calibration approach and how this calibration approach can be improved such that a hydraulic model can be calibrated and applied for varying discharge conditions and finally validated for an entire hydrograph.

Existing calibration methods

Hydraulic models are generally calibrated by changing the roughness parameter of the main channel and/ or floodplain since the actual value of the roughness under different circumstances is generally unknown (Xu et al., 2017). Another reason to calibrate the roughness is that the model results are sensitive to the roughness.

The main roughness calibration approaches used in the literature are categorized into two groups. The first group calibrates the roughness and adjusts one value for specific discharge ranges as boundary conditions (usually high flows), and then the model simulates different discharge ranges (Bomers et al., 2019, Pappenberger et al., 2005). In these models, the accuracy of the simulation results decreases as the difference between the boundary condition used for calibration and validation increases (Berends et al., 2016).

The second group calibrates the roughness separately for different discharge ranges. The calibrated roughness values per discharge range are used for the validation and simulation (Bessar et al., 2020, Domhof et al., 2018, Warmink et al., 2007, Yossef et al., 2018). The results of these models have a higher accuracy for a broader range of discharges. Different calibrations for different discharge values are like having different model setups. It is impossible to simulate different discharge ranges continuously with such models, and the results are not comparable.

Method

The Waal River (a bifurcation of the Rhine River) in the Netherlands is used as a case study (Fig.1). The Delft-FM 2DH model, developed by Deltares, is used as a starting point for this research.

The first step is providing a model mesh set-up with a minimum effect on the calibration result. The mesh is the most uncertain part of the model set-up and can affect the simulation results significantly. Mesh resolution affects river bathymetry discretization, and

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consequently discharge capacity and simulated water levels. In this regard, an optimum mesh for both high and low flows is constructed, considering the balance between mesh resolution and computational time.

Secondly, the model with the newly developed mesh is calibrated on high flows with different existing calibration methods, and the performance is evaluated for low flow conditions, and vice versa, to identify which calibration method provides the most reliable results for each discharge range. Lastly, the best performing calibration method is improved by e.g. including seasonal floodplain roughness variations and bedform dynamics, such that high and low flows are simulated accurately throughout the year.

Expected results and application

The main result of this study is a hydraulic model with a new calibration method to simulate varying flow conditions accurately. One of the applications of this model is to evaluate the effects of river interventions, considering the effect of preceding discharge events on current conditions in long-term simulations. With the help of this model, there will be room for future to consider the effects of new interventions to mitigate both high and low flow conditions.

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Figure 1. Case study a reach of Waal river from Pannerdensche to Zaltbommel.

Trends in suspended sediment fluxes across the Rhine river basin (1997-2014)

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Keywords — Rhine basin, Suspended Sediment, Load

Introduction

Suspended sediment transport is a vital process in healthy river systems. Rivers with a high suspended load carry large amounts of material providing multiple positive effects for entire river basins. It is estimated that about 90% of river sediment is transported in suspension (Turowski et al., 2010). Fine sediments contribute to the creation of habitat for aquatic species, easily bond to nutrients and form essential building material for river banks, floodplains and eventually for river deltas (Walling & Webb, 1996). In the past decades, the delivery of suspended sediment from many river basins to deltas has been decreasing (Dunn et al., 2019; J. Syvitski et al., 2022), including the Rhine basin (Asselman et al., 2003). This has resulted in disturbances of the sediment transport regime such as erosion and aggravated flood protection (Ylla Arbós et al., 2021). Particularly in the delta river engineering works such as dredging and sediment mining, the overall decrease of sediment has caused the sediment budget to become negative with several negative effects for ecology and morphology (Cox et al., 2021).

The decreasing flux of sediment, the primary building material of deltas together with sea level rise will create a major threat to river ecosystems and people living in deltas. A quantitative temporal and spatial understanding of sediment distribution upstream of the delta is essential to quantify eventual total sediment delivered to the delta. It enables sustainable watershed management including the design of strategies that attenuate or reverse decreased sediment delivery.
In this study, we aim to quantify the temporal and downstream changes in annual loads of suspended sediments in the Rhine river basin during the past decades to identify major sources and sinks of sediment.

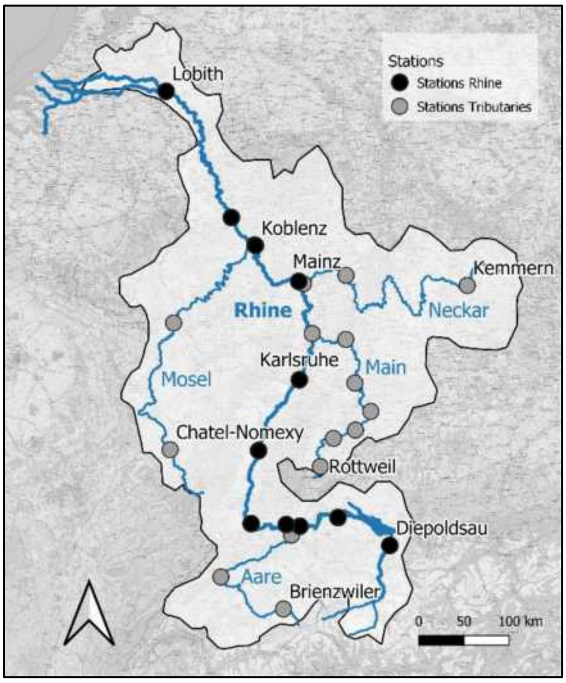

Figure 1: Study Area Rhine basin

Method

.
For our study, we used fortnightly or monthly measurements of 27 suspended sediment monitoring stations and corresponding daily discharge measurement stations along Rhine river and its four major tributaries (Fig. 1): the Aare, Neckar, Main and Mosel for the period of 1997-2014. Annual suspended loads were estimated by the rating curve method. The sediment rating curve method uses a log regression between measured suspended sediment concentrations and river discharge (Asselman, 2000; Syvitski et al., 2000; Walling & Fang, 2003).

$$SSC = a\,Q^{b} \tag{1}$$

$SSC = suspended\ sediment\ concentration$
$Q = discharge$
$a = the\ rating\ coefficient$
$b = the\ rating\ exponent$

For each year and each station, we determined a two-fold rating curve with a scale-break between the low and high discharge domain as

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proposed by Hoffmann et al. (2020) using a 5-year moving window. The scalebreak was established at the arithmetic mean discharge. These rating curves were subsequently used to calculate daily suspended sediment loads, which were summed to annual loads.

Results & Conclusions

Our results indicate that overall, the calculated suspended sediment loads in the 1997-2014 period show an increase in downstream direction (Fig. 2). The major tributaries deliver considerable amounts of sediment to the Rhine river. However, the Rhine river also encompasses sections where the difference in loads between consecutive stations is negative, thus, where sediment is retained. This occurs in the section of Lake Constance after the Alpine section between Diepoldsau and Oehningen, the impounded section between the Weil am Rhein and Karlsruhe, and the furthest downstream section between Bad Honnef and Lobith.

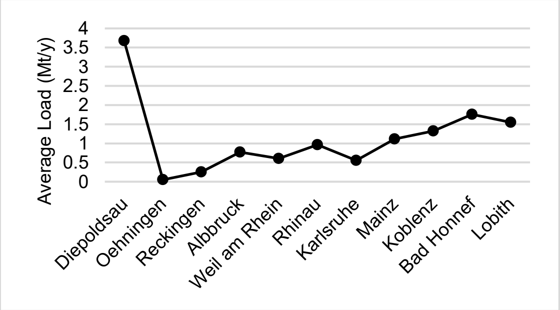

Figure 2: Average Loads Rhine river stations (from up- to downstream)

At most monitoring stations, the suspended sediment loads in the Rhine river show a consistent decreasing trend between 1997 and 2014, although the most upstream station of the Rhine River, the stations along the Aare River, and the upstream stations downstream the confluence of the Aare River show an increase in load. This sediment was most likely delivered from the Alps or the Swiss Plateau. The suspended sediment loads in the downstream reach of the Rhine river downstream from Karlsruhe show a consistently negative trend. In the Neckar, Main and Mosel tributaries, a similar pattern of a negligible change in suspended sediment loads in the headwater stations and a substantial decrease in load in the downstream stations is observed. This suggests that the decline in suspended sediment loads is primarily caused by engineering works and human interventions in or along the river channel.

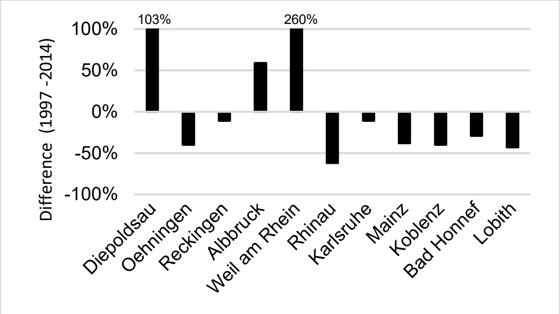

Figure 31: Difference in loads at Rhine stations (1997-2014)

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3

River Morphodynamics and Sediment Management

Modelling strategies for low flow dune behaviour

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Keywords — River Dunes, Low Flow, Modelling

Introduction

River dunes are dynamic bed forms which propagate in alluvial river beds, formed by the interaction between the flowing water and the erodible bed. Propagation speed and shape of these dunes depend on the sediment type in the bed and on the governing flow conditions. During low flow, dunes can decrease the navigable water depth while during high flow they increase the roughness and therefore result in increasing water levels. Understanding river and being able to predict dune behaviour, can therefore help to improve river bed management, especially in a changing climate where extreme river discharges, both high and low, are expected to occur even more (*Douville et al.*, 2021).

Initial dune growth, starting from a flat bed, shows linear behaviour. However, when a dune field is present on the bed, further development of the dunes is non-linear and also shows transitions linked to changes in sediment transport stage. For example the transition to upper stage plane bed is linked to the transition to suspended transport (*Naqshband et al.*, 2016). This transition to upper stage plane bed, occurring at extremely high discharges, has been studied extensively, while studies dune development during low flows in rivers are scarce.

A dune development model that may be used for predicting dunes must be able to simulate dune behaviour for both high and low flows well. We first give a short introduction into the dune behaviour during low flows in rivers, and then we introduce the dune model that will be used to simulate this behaviour and show how this model performs.

Low flow dune propagation

To better understand the behaviour of dunes during low flow situation, dunes were studied in a 16 km long stretch of the Waal River (river kilometres 894-910) over a period of 10 years by *Lokin et al.* (2022). This has shown that during low flow the relation between dune height and dune length is negative, e.g. the dunes become longer when the flow velocities drop towards low flow (Figure 1). This dune lengthening is related to diffusive behaviour; as the relative strength of gravition on sediment particles respective to the drag force by the current becomes more important for dune propagation towards low flows with mostly bed load transport. This causes the dunes to propagate in a diffusive manner (*Lokin et al.*, 2022).

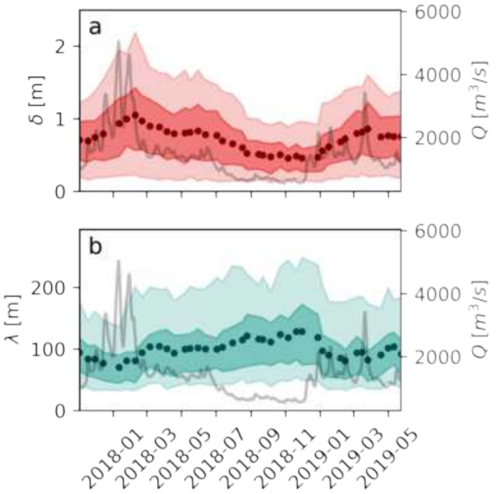

Figure 1: Dune height and length changes during a period between November 2017 and May 2019 in the Waal River, including a period with extreme low discharges. a) Dune height (δ, dots), with the 50% (dark band) and 90% (light band) confidence intervals, and the discharge at measuring station Tiel (grey line). b) Dune length (λ) with the 50% and 90% confidence intervals, and the discharge at measuring station Tiel.

The dune model

To simulate dune behaviour we use the dune development model initially developed by *Paarlberg et al.* (2009). This model simulates dune behaviour using separate flow and sediment transport modules. The flow is solved using the 2D vertical averaged shallow water equations assuming hydrostatic flow. For the sediment transport two transport formulations are currently available. The model has periodic boundary conditions such that the model

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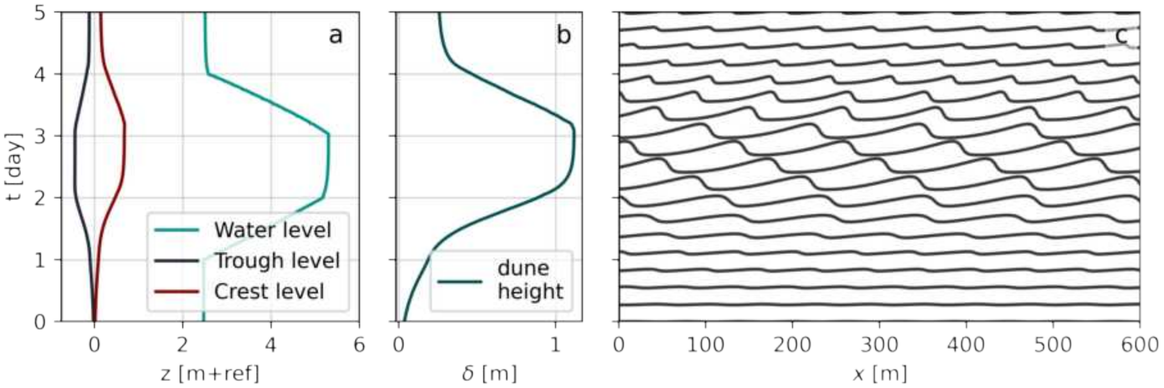

Figure 2: Dune development during a synthetic discharge wave with discharge varying between low and bank full in the Waal River. a) Development of the dune trough level, crest level and the water level. b) Dune height. c) Development of the dune shape.

domain covers one dune, which is actually an infinitely long train of identical dunes. The domain length is determined using a numerical linear stability analysis, in which the domain length is equal to the fastest growing mode.

This model is able to simulate dune height fairly well (Figure 2) and the general shape is representative for the dunes found in the Waal River: rounded off crests and a low angle lee. Dune height also lags the development of increasing and decreasing discharge, where dune height reaches its maximum half a day after the discharge is at its maximum.

Future model improvements

As the general dune shape and height are simulated fairly well, the simulated dune length does not yet follow the dune length found in the data. In the simulation the dune length is calculated with the linear stability analysis whenever the water level has changed by 5% with respect to the last timestep the lenght has been determined. The dune length, and consequently the model domain, is then instantaneously set to the newly determined length. This results in shorter dunes than found in the data and no effective lag in dune length adaptation, while this lag has been found in the data. Although dune height is well simulated, the model still need to be improved to simulate dune lengthening during low flows.

Conclusion

Dune lengths increase as discharges drop in the regime from median to low flows. This behaviour is likely related to the transition towards a mainly bed load dominated transport stage, where dunes propagate diffusively. Although the presented dune model is able to simulate the dune height fairly well, the simulated dune length development does not yet correspond to the data. The dune length is determined without accounting for the dune that is formed during previous higher discharges, this has to be implemented in the model to accurately simulate dunes during extreme low flow.

Acknowledgements

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Massive morphological changes during the 2021 summer flood in the River Meuse

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Keywords — flood event, river morphology, impact measures

Introduction

In July 2021, an exceptional flood developed in the River Meuse and its tributaries. High rainfall intensity lasted for several days in a number of sub-catchments in Belgium, Germany and the Netherlands, causing devastating floods. In the River Meuse, the peak discharge was highest since measurements started in 1911. At St. Pieter the maximum discharge was 3260 m^3/s with a return period of about 120 year. The flood event was particularly exceptional because floods normally occur in winter. During the flood, which lasted for 5 days only, flow velocities probably exceeded 5 m/s (based on numerical simulations) and unprecedented morphological changes occurred, especially in the permanently free flowing river section, referred to as the Common Meuse. Scour of the riverbed and river banks caused damage to infrastructure like ferry landings and pipe lines crossing the river. Morphological changes of this intensity and magnitude during extreme events are only sparsely reported in literature.

Objective

The objective of the study was to improve understanding of the morphological processes during extreme floods, by focusing on the Common Meuse. Here, the riverbed surface is composed of gravel and the longitudinal bed slope is five times steeper than the downstream canalized river.

Methodology

Post-event, multibeam echosoundings were done to reveal the morphological changes in the riverbed. Field measurements were carried out to assess the sand deposits on the floodplains (Fig. 1). Airborne lidar measurements after the flood were applied to validate and enrich these data.

We analysed the volumes and composition of the floodplain deposits in relation to the riverbed material, morphological changes in the main riverbed, sinuosity of the river and the flooding intensity of the floodplains.

Figure 1 Field work by Wageningen University and Research on sediment deposits, location Bosscherveld, August 2021.

Results

The echosoundings showed that in a section of 15 km long, more than 20 deep scour holes developed in the riverbed, with depths sometimes exceeding 15 m (Fig. 2).

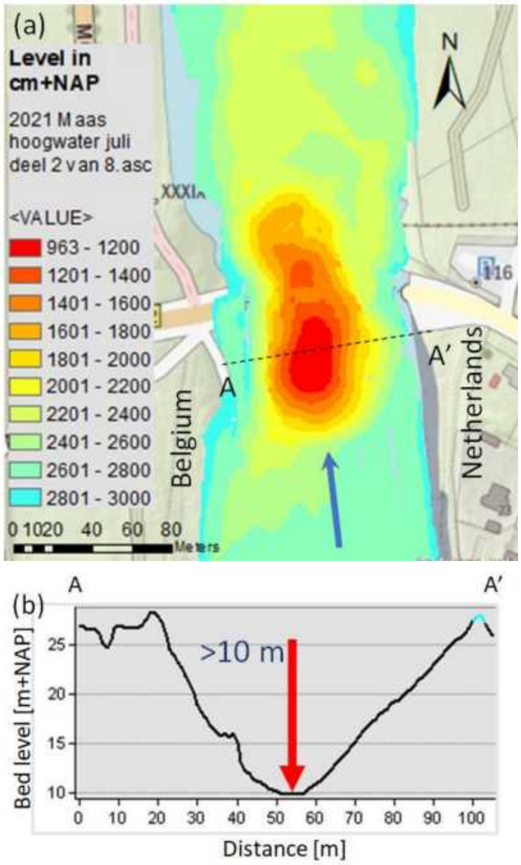

Figure 2 (a) Erosion on the Common Meuse at the location Berg. (b) cross-section A-A'. Source: multibeam measurements RWS-CIV, July 2021.

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Over 400,000 m³ of sediment eroded from the scour holes. On the floodplains at least 170,000 m³ of sand was deposited. The composition of these deposits in the reach directly downstream of the erosion holes, was identical to the fine sand found in the erosion holes after the flood.

Discussion

We expect that the massive morphological changes were caused by rapid erosion of fine sand layers underneath a thin layer of gravel on the riverbed (Meijer et al, 2011). We believe that the high flow velocities during the event caused the breaking up of the coarse armour layer on top of the riverbed and the consequential mobilization of the thin gravel layer. The fine sands underneath the gravel were quickly eroded when that happened, creating the deep scour holes.

Our analysis suggest that the main ingredients for thinning of the gravel layer on the riverbed are ongoing gradual channel incision up to 2 cm/yr, the vertical composition of the riverbed and altered flow conditions.

- Previous river training works, weirs and sediment mining created a supply-limited river system and an eroding trend.
- In the Meuse valley, several tectonic faults are found. In uplifting areas, known as horsts, the gravel layer on the riverbed is relatively thin (Meijer et al, 2011), as the river continuously erodes the rising riverbed.
- Room for the River measures carried out since the 1995 flood event, lowered flood levels, but also increased flow velocities in river reaches that were not or only marginally widened (see Figure 3).

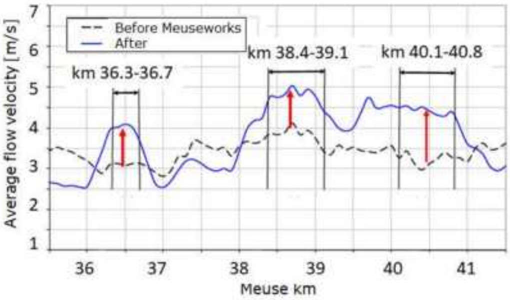

Figure 3 Change in maximum average flow velocities due to MeuseWorks (Room for the River programme for the Meuse River) under flood conditions. Source: Meijer & Vieira da Silva (2007).

A large portion of fine sediments released from the riverbed underneath the gravel layer was deposited in comparatively wide floodplains located further downstream. Compared to the floods of 1993 and 1995, the volumes of sand deposited on the floodplains of the more downstream reaches appeared to be relatively small. This can be explained by the short duration of the flood wave in 2022, the large wave damping and thus shorter duration of flooding of the floodplains. The curvature of the river, height of the banks and concentrated flow directed towards the floodplains appear to determine locations of the main sand deposits and their composition. At locations with lower floodplains and large secondary flood channels (Ooijen-Wanssum) coarser sand deposits were found (Fig. 4).

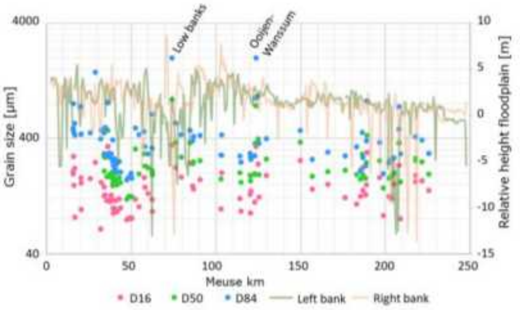

Figure 4 Characteristic grain diameters (D16, D50 and D84) sand deposits and relation to elevation of floodplains (bank) and secondary channels. Source: Beijer et al, 2021.

The unprecedented morphological changes may have a decisive impact on the morphological trends as well as on stability of infrastructure and flood safety. Climate change and ongoing river bed erosion may cause that these morphological processes occur more frequently in the future, also in other river sections, requiring new river management strategies to avoid catastrophes.

Acknowledgements

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Best Practices for Longitudinal Training Walls to mitigate channel bed erosion

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Keywords — Morphodynamics, River Engineering, Longitudinal Training Walls

Introduction

A recent pilot project in the Waal River sought to mitigate long-term riverbed erosion with longitudinal training walls (LTW). Groynes were removed and replaced by three walls that split the river corridor into a primary and an auxiliary channel. Each wall contained an entrance weir, wall notches, and an exit outlet. During floods, the wall is overtopped. Field data show that after five years, the engineered walls reversed some erosion in the primary channel by diverting water discharge from the primary channel toward the auxiliary channels (*Czapiga et al.*, 2021). Here we analyze these data to explain which factors can be of aid in LTW water and sediment partitioning and how our findings influence design practices to mitigate channel bed erosion with LTWs.

Morphodynamic Controls

Mitigation of channel bed erosion is achieved by increasing the river equilibrium slope (*Czapiga et al.*, 2022). LTWs accomplish this by decreasing discharge in the primary channel without removing the bed material load. As a result, how water and sediment are partitioned between the channels is critical to the success of an LTW project. Fluxes of water and sediment between the primary and the auxiliary channels depend on geometries of the entrance weir, the wall, and the auxiliary channel. Analysis of the pilot project showed that auxiliary channel width controlled discharge partitioning during flood flows (*Czapiga et al.*, 2021). Conversely, sediment fluxes into auxiliary channels were mostly controlled by weir geometry and were unrelated to wall or auxiliary channel geometry (*Czapiga et al.*, 2021). These observations lead to four specific design factors as detailed below and in Figure 1.

Results

Entrance Weir Geometry

Entrance weirs have no positive effect on erosion mitigation, as they do not influence water discharge partitioning during floods and may extract bed material load from the primary channel, which hampers mitigation. However, weirs extract water at low flow, which is important for ecological reasons. Thus, entrance weir should be designed to extract enough water at low flows and to limit the amount of water diverted into the auxiliary channel during floods.

Auxiliary Channel Geometry

Once the wall is over-topped, more water can enter the auxiliary channel than it can discharge. In other words, the discharge capacity of the auxiliary channel, which is set by channel geometry, controls discharge partitioning during floods. Expanding these channels, either by widening, as illustrated in Figure 1*B*), or deepening (i.e. dredging) removes more water from the primary channel and thus likely enhances erosion mitigation.

Slope of the Wall Crest

The LTW pilot project saw significant sediment accumulation in the primary channel during floods (*Czapiga et al.*, 2021). These deposits were located where flow rapidly entered the auxiliary channel and flow velocity suddenly decreased. Sediment deposited in the primary channel where sediment transport capacity suddenly declined. While deposition in the primary channel is one of the objectives of a LTW project, localized deposits may hamper navigation. Such depositions can be dispersed by making the auxiliary channel inflow more gradual. As a result, sediment transport capacity in the primary channel gently decreases and sediment deposits over a broader area. This can be achieved with a wall crest slope steeper than the adjacent primary channel bed slope (Figure 1*C*), such that upstream portions of the wall are inundated by less water and auxiliary channel inflow is more gradual.
The expected deposition location also changes with discharge level. The largest floods inundate the entire wall and a deposit forms in the primary channel just downstream of the entrance weir. Lower magnitude floods only inundate the downstream part of the wall, so deposition in the primary channel is shifted downstream where flow exits the primary channel.

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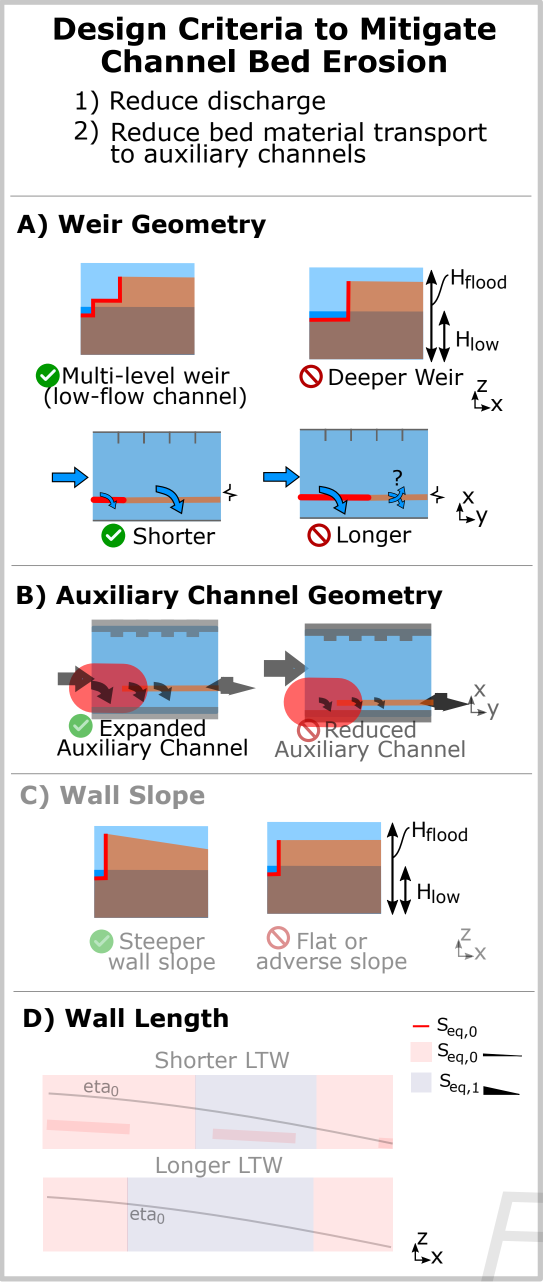
Both effects tend to elongate the deposit and reduce its height. While we schematize this effect via wall crest slope alone, a full design must consider notch location and geometry as well.

Wall Length

The magnitude of mitigated erosion increases with LTW length (Figure 1*D*). An eroding river continues eroding until it reaches an equilibrium state characterized by a lower slope. LTWs increase equilibrium slope in the primary channel. Long LTWs increase the region with the increased equilibrium slope, but also reduce erosion in the reach upstream. This occurs because the upstream end of the LTW section aggrades more as LTW length increases. The upstream reach then responds by aggrading to maintain its desired channel slope.



Conclusions

Based on the analysis of field data collected to monitor a pilot project for 5 years, we provide four main design criteria for LTWs: 1) Design the entrance weir to divert water at low flow for ecological purposes and to limit water diversion during floods, 2) expand or deepen auxiliary channels to reduce discharge in the primary channel during floods, 3) increase the slope of the wall crest to disperse the deposit during floods, and 4) increase LTW length to improve mitigations both in the primary channel and in the reach upstream.

Acknowledgements

This study is carried out as part of the Water2015 project 14508 ”Long-term bed degradation in rivers: causes and mitigation”, which is funded by the NWO Domain Applied and Engineering Sciences (AES, The Netherlands). There are no conflicts of interest.

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Linking hydraulic roughness to dune slipface angle: a RANS numerical model study

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Keywords — Numerical Modeling, River Dunes, Hydraulic Roughness

Introduction

River bedforms occur in a wide variety of shapes and sizes and the challenge is to quantify the hydraulic roughness of these bedforms. The quantification of the hydraulic roughness is important for river modelling, which is an important tool for river management. The slipface angle of dunes is one aspect that has a large influence on the hydraulic roughness of dunes. One process that controls this is flow separation and the associated turbulence behind the dune (Kwoll et al., 2016; Lefebvre and Winter, 2016). However, the relationship between slipface angle, flow separation, turbulence and hydraulic roughness is still not fully understood. Therefore this relationship is investigated in this study.

Methods

A Reynolds Averaged Navier Stokes (RANS) numerical model is constructed in OpenFOAM for turbulent flow over three sequential fixed dunes in a flume (fig. 1), based on flume experiments of Westerman (2021); Van Wijk (2021). Different characteristics of the flow are investigated: flow separation, Reynolds stress and turbulence. These characteristics are linked to the shear stresses on the bed: form shear stress, τ_{bf} and friction shear stress, τ_{bs}. Non-dimensional bed shear stress is calculated as:

$$\tau* = \frac{F_{tot}}{L_{dune} * b * \tau_0}, \tag{1}$$

where F_{tot} (N) is the total form or friction force over the dune, L_{dune} (m) the length of the dune along the bed, b (m) the width of the flume and τ_0 (N/m^2) the bed shear stress for a flat bed. Hydraulic roughness is quantified using the Chézy value, which is calculated based on the total bed shear stress:

$$C = \sqrt{\rho g \frac{u^2}{\langle \tau_b \rangle}}, \tag{2}$$

where u (m/s) is the average velocity, h (m) is the water depth and $\langle \tau_b \rangle$ (N/m^2) is the spatially averaged total bed shear stress over one dune.

Results

Comparison with the measurements shows that the constructed model is able to capture the main flow processes, such as turbulence and flow separation. Also the calculated Chézy roughness values match with the Chézy values that were determined from the lab experiments. For slipface angles below 10^o no flow separation is present and friction stresses are dominant (fig. 2). For higher slipface angles, the adverse pressure gradient behind the dune causes the boundary layer to separate from the bed and pressure drag becomes dominant (fig. 2). As a result, also the turbulence in the wake behind the dune increases. Total forces are independent of slipface angle in absence of flow separation, but increase with increasing slipface angles from 15^o to 25^o, to become stable again for slipface angles above 25^o. Based on the total forces, the Chézy value can be calculated. The effect of the flow separation on hydraulic roughness is clear, however there is variation between the different dunes and discharge conditions (fig. 2).

Discussion and conclusions

The slipface angle of dunes influences the hydraulic roughness by controlling the area of the flow separation. However, the variation in hydraulic roughness can not solely be explained based on the slipface angle. The results suggest that other factors such as the discharge and channel geometry around the dune also influence the hydraulic roughness of a bedform.

Future work & Acknowledgements

It is recommended to further investigate the initial development of the flow separation zone and the changes in the boundary layer and turbulent wake behind the dune at the start of flow separation. The authors would like to thank Peter Westerman and Jur van Wijk for for providing and later on clarifying their data set. Furthermore Wout Veelenturf and Ferry van Tilburg are acknowledged for their help in constructing the model.

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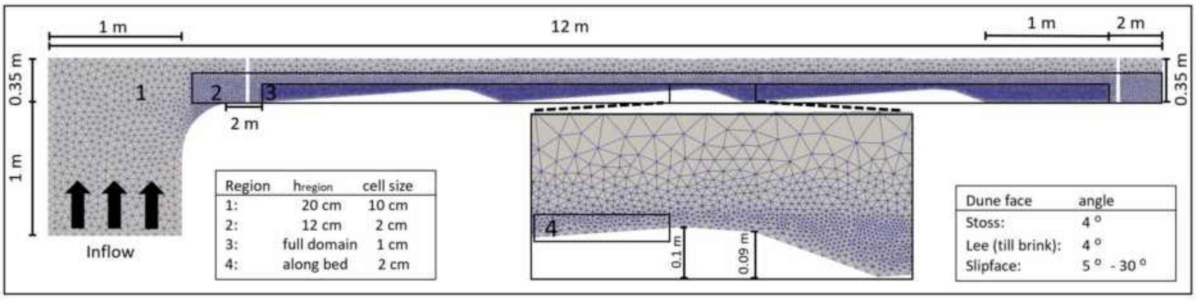

Figure 1: Schematic figure of the geometry and mesh of the flume with fixed dunes. Two parts of the flume are cut out to save space. The four mesh size regions are indicated and details are given in the text box, region four is only indicated for a small part of the bed, but it extends along the whole flume bed.

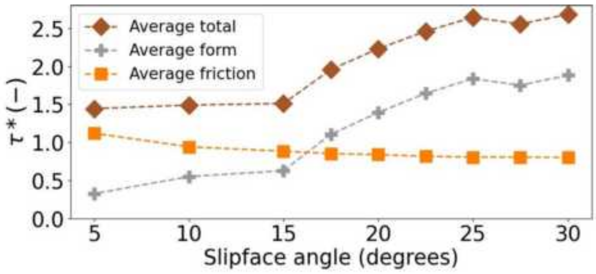

Figure 2: Form, friction and total forces averaged over the three dunes expressed as normalized bed shear stresses for high discharge conditions $(Q = 0.072m^3/s, S = 3.4mm/m\ )$*.*

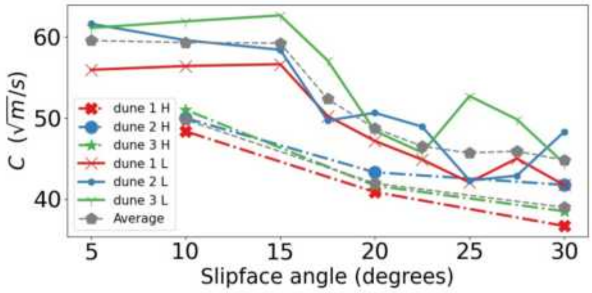

Figure 3: Calculated Chézy values for different slipface angles. Data are from high (H: $Q = 0.072m^3/s, S = 3.4mm/m$ *) and low (L:* $Q = 0.130m^3/s, S = 1.0mm/m$*) discharge conditions for dunes 1,2, and 3. The included average is the average per condition.*

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Mid-Century Channel Response to Climate Change in the Lower Rhine River

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Keywords — Climate Change, Channel Response, Lower Rhine River

Introduction

Most of the world's large rivers are heavily engineered, and for centuries, human intervention has modified the channel characteristics of rivers worldwide (Best, 2019). Today climate change adds to these pressures, as it alters river controls through sea level rise and changing precipitation, thereby modifying the hydrograph and sediment supply (Verhaar et al., 2010). Both climate change and human intervention will be important drivers of future channel response.

Here we consider the Lower Rhine River, defined as the 300-kilometer reach of the Rhine River between Bonn (Germany) and Gorinchem (the Netherlands), including a bifurcation close to the German-Dutch border (Pannerdense Kop). The Lower Rhine River is a paradigmatic engineered river that has been impacted by interventions for centuries, both for flood safety and for navigation, and has also been intensively monitored. Decades of field data on water discharge, water and bed level, and bed surface grain size illustrate that human intervention has governed channel response over the past century (e.g., Ylla Arbós et al. (2021); Quick et al. (2019)). Our goal is to assess how channel response to climate-related changes in the river controls compares to channel response due to (future) human intervention, focusing on changes in channel bed elevation, bed slope, and bed surface grain size over the next century.

Method

Given the large spatio-temporal scale of our study, as well as the uncertainty associated to climate and intervention projections, we set up a highly schematized 1D numerical model of the Lower Rhine River based on available field data. We calibrate it against the temporal change of discharge partitioning at the Pannerdense Kop bifurcation, considering three ranges of water discharge ($<$1500, 1500-2500, and $>$2500 m^3/s), and against erosion rates over the period 1990-2020.

We perform 100-year model runs for different scenarios of climate change and human intervention, and compare the results to a do-nothing scenario (i.e., a reference case in which the river controls remain as they are, and no further human intervention is carried out). In this paper we consider the following controls and scenarios: (a) upstream water discharge, 5 scenarios (KNMI, 2015); and (b) upstream sediment flux, 3 scenarios based on Frings et al. (2014)'s measured sediment flux data and associated uncertainty. The translation of these climate scenarios into suitable boundary conditions for the numerical model is discussed in Ylla Arbós et al. (2021).

Preliminary results

Model runs up to 2050 provide insight on the mid-century channel response to climate change. We focus on bed elevation change.

Figure 1 shows the spatial difference in bed level over the period 2010-2050 for different water discharge and sediment flux scenarios, with the reference scenario (i.e., the base case) included for comparison. We observe generalized bed incision in all cases, except for the reach between river km 820-860, and the lowermost 15 km, where the river bed aggrades. The incision is more pronounced downstream of river km 860 (i.e., the Dutch Rhine). In this reach, incision decreases in the downstream direction, which implies that the main channel slope decreases. Upstream of river km 860 (i.e., the German Rhine), bed incision is milder. In the German Rhine, bed incision increases in the downstream direction between river km 640-750, and decreases in the downstream direction between river km 750-860, suggesting and increase in concavity. Overall, the behavior is in line with historical observations of bed level change in the Lower Rhine River and relates to an ongoing slope adjustment in response to channel narrowing (Ylla Arbós et al., 2021).

For all water discharge scenarios, the predicted incision is enhanced up to about 20%.

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The scenarios consist of higher peak flows in the winter and lower base flows in the summer, which explains the increased incision rates, given that higher discharges (leading to river bed incision) are more relevant for morphodynamic change than lower discharges. Incision rates are relatively similar across water discharge scenarios in most of the domain, with slightly higher differences in the uppermost 60 km. Regarding sediment flux scenarios, higher sediment fluxes reduce the predicted incision up to 40%, while lower sediment fluxes increase it by a similar amount. The influence of changes in the sediment flux is limited to the uppermost 60 km during the considered period.

Some localized aggradational/degradational spikes are observed throughout the domain, for both the reference case and the climate scenarios. These spikes are related to the presence of fixed layers, and while in practice localized aggradation would likely be dredged, no intervention is considered in these runs.

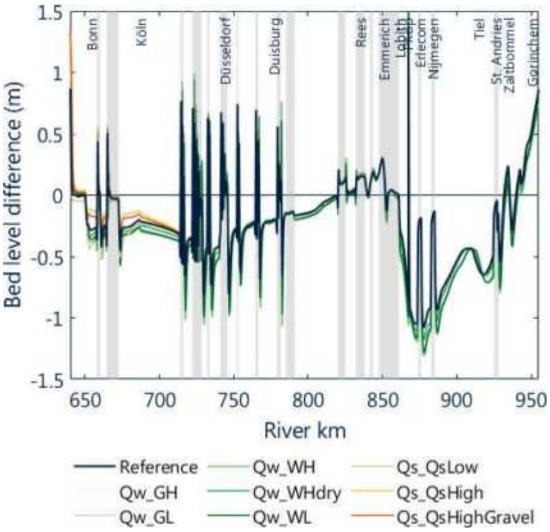

Figure 1: Bed level difference between over the period 2010-2050 for different scenarios of water discharge (Qw, following KNMI (2015) nomenclature) and sediment flux (Qs, following Frings et al. (2014) estimates). Gray areas indicate the presence of fixed layers.

Discussion and conclusions

Model runs of mid-century channel response show that the ongoing bed incision in the Lower Rhine River is enhanced up to 20% for all the water discharge scenarios. This is because these scenarios foresee increased peak flow rates, which are dominant in terms of channel response, and lead to river bed incision. Increased sediment fluxes reduce the predicted incision by up to 40%, though this effect is limited to the uppermost 60 km in the period of interest. For longer simulation times, the effect of a changing sediment flux will likely migrate further downstream.

Both historic data and the results of this study suggest that human intervention has played, and will keep playing a key role regarding channel response. In the past, this was mostly through channel narrowing (Ylla Arbós et al., 2021). In the present and future, this is more related to sediment management and river maintenance policies (e.g., fixed layers, Figure 1).

Future research will extend the period of analysis to 2100, and will consider scenarios for the remaining boundary conditions (downstream base level, sediment partitioning at the bifurcation), as well as for human intervention. This extension will include maintenance dredging, as very pronounced aggradation peaks are difficult to deal with numerically, but also not realistic.

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Residual sediment transport in a stratified estuarine channel

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Keywords — Estuary, Sediment transport, data analysis

Introduction

After major storm surge protection works in the Rhine-Meuse Delta, referred to as the Delta Works (Vellinga et al., 2014), the New Waterway has become the only remaining open channel connecting the estuary to the North Sea. Like in many harbour areas, continuous deepening of this channel for navigation purposes has led to strong stratification and often salt wedge conditions, which likely has a strong impact on the marine sediment import. The sediment balance for various fractions is highly uncertain (Cox et al., 2021). Based on field measurements and sediment transport modelling, we aim to unravel the mechanisms controlling residual sediment fluxes in highly stratified estuarine channels, by focusing on the New Waterway.

Methods

A measurement campaign was set up consisting of two 13-hour surveys, one during spring tide and one during neap tide. Flow was monitored continuously based on a vessel-mounted ADCP, at an along-channel transect (~3 km) and a cross-channel transect (~300 m). A measurement frame was equipped with a LISST-100x, a Seapoint turbidity meter and a CTD probe. Suspended sediment samples are collected every hour at three depths, next to water temperature, salinity and turbidity.

Results

The ADCP-measurements show a clear distinction in flow magnitude and direction between the upper fresh water layer and lower saline layer, confirming the high degree of stratification especially during neap tide. After low water slack, most suspended sediment is found in the lower half of the water column. Suspended sediment concentrations (SSCs) increase during the flood acceleration phase, suggesting local resuspension during this phase of the tide. When reaching high water slack, SSCs decrease with flow velocity. At high water slack, the ADCP-backscatter profiles indicate settling of the suspended sediment on top of the pycnocline. During the ebb phase, SSCs increase again, and the water column is better mixed compared to the flood phase. Preliminary results of the grain size analysis indicate coarsening of the suspended sediment at the end of the flood acceleration and ebb acceleration phases. Ongoing analysis of these data and numerical modelling of SSC will provide more insight in the suspended sediment transport processes under various degrees of stratification.

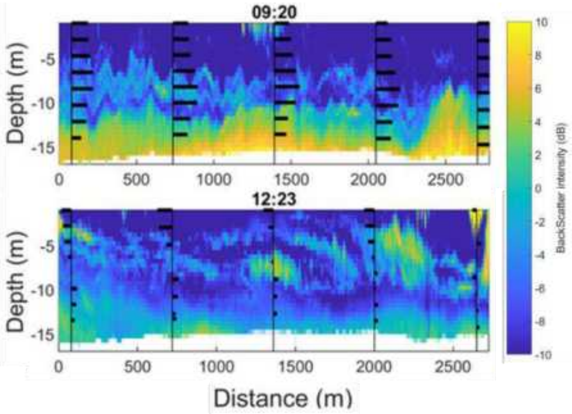

Figure 1. Two flow- and backscatter profiles recorded along the New Waterway during neap tide. Left panel: during the flood phase, sediment is concentrated in the lower half of the water column and the velocity maximum is located around the pycnocline as observed in De Nijs et al. (2011). Right panel: around HWS, suspended sediment settles around the height of the pycnocline.

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Channel Bed Erosion Characteristics in the Upper Dutch Rhine Bifurcation Region

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Keywords — river bifurcation, Rhine River, bed erosion, long term morphological change, Pannerdense Kop

Introduction

Flow and sediment partitioning in the Upper Dutch Rhine bifurcation region largely influences flood risk management, navigation, and freshwater supply. Generally, water discharge partitioning at a bifurcation has a dynamic relationship with local morphological development at the bifurcation region (Kleinhans et al., 2013). Therefore, knowledge about morphological development at a bifurcation region is important. This abstract focuses on the local channel bed erosion characteristics at the Upper Dutch Rhine bifurcation area. The knowledge can be used to signal trends in the partitioning of water and sediment and prepare mitigation measures to maintain a safe situation.

Method

The bed level of the Bovenrijn and its bifurcates were measured using single beam echo sounders roughly until 2000 and multi-beam echo sounders since then. We used a 5 km long moving average window, and the window does not cross the bifurcations. This allows us to assess the discontinuities in bed level at the bifurcations. Details of data treatment (including harmonizing single beam and multi-beam measurements) are available at Ylla Arbós et al. (2021).

Results

Channel bed of roughly the first 10 km of the Waal and Pannerden Channel bifurcates downstream of the Pannerdense Kop has eroded 2 to 3 times more than the surrounding area over the last century (Fig. 1a and b). The Bovenrijn has also eroded about 1.5 m close to the Pannerdense Kop since 1934.

We assessed the difference in bed level compared to the bed level averaged over the period 1958-1962. There seems to be an erosion wave along the Waal starting at the Bovenrijn and the upstream end of the Waal (Fig. 2a). The erosion appears to intensify around 1990, likely due to the intense dredging activity during that period (Visser, 2000) and gradually migrated downstream up to Nijmegen. For the Pannerden Channel, the erosion intensified roughly in the 1980s and travelled downstream up to IJsselkop (Fig. 2b). Another erosion wave originates at the IJsselkop along the IJssel river, spanning up to De Steeg.

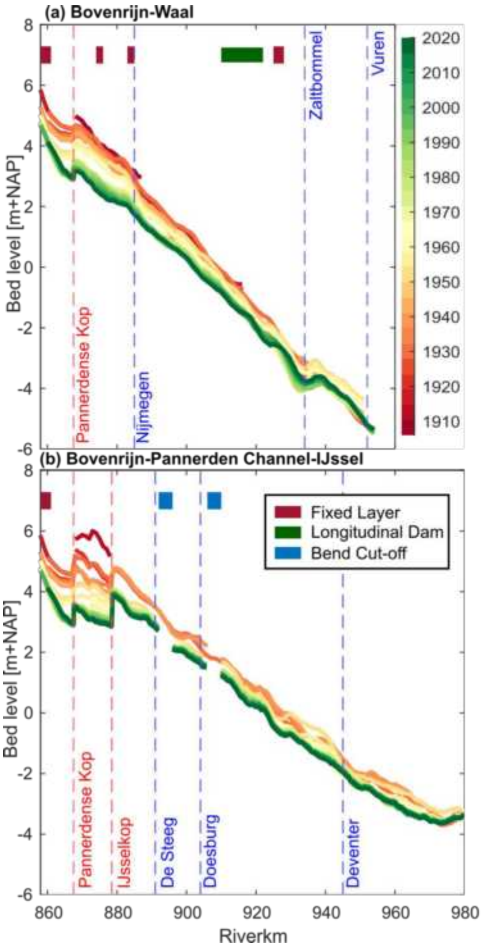

Figure 1: Longitudinal profile of bed level along (a) Bovenrijn-Waal and (b) Bovenrijn-Pannerden Channel-IJssel.

It is important to note that the erosion rate in the bifurcation region has reduced over the last two decades. The erosion rate in the upstream end of the Waal has lowered to approximately 1.5 cm/yr in the last two decades (Fig. 3a). In the same period, the Bovenrijn has aggraded

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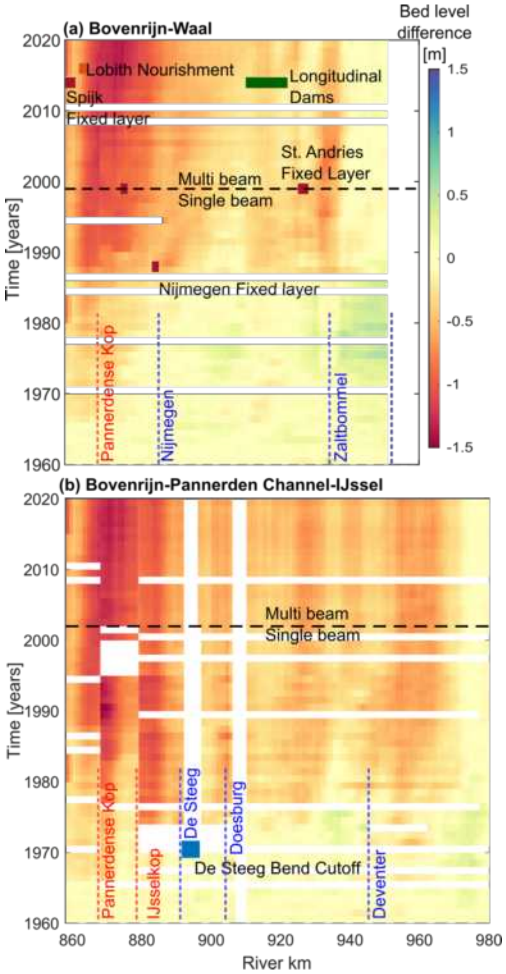

Figure 2: Space time plot of bed difference along (a) Bovenrijn-Waal and (b) Bovenrijn-Pannerden Channel-IJssel relative to the bed level averaged over the period 1958-1962.

up to 1 cm/yr at some parts close to the Pannerdense Kop, compared to about 4 cm/yr erosion in the period between 1971-1990. Particularly for the upstream end of the Pannerden Channel, the erosion rate has dropped from 5.5 cm/yr in 1971-1990 to roughly 0.5 cm/yr in the last two decades (Fig. 3b).

The current situation has led to a difference in erosion rates between the upstream part of the Waal and Pannerden Channel. The erosion rate difference causes the depth of the Waal to increase faster relative to the Pannerden Channel, hence attracting more water. In addition, the difference in erosion rate promotes the development of inlet step at the bifurcation that influences sediment partitioning of bed material load (Bolla Pittaluga et al., 2003).

The reduction in erosion rate in the bifurcation region is associated with a gradual coarsening of the bed surface texture previously observed in this region (Ylla Arbós et al., 2021). The coarsening is likely associated with the downstream migrating gravel-sand transition and sediment nourishments in the Niederrhein (Ylla Arbós et al., 2021).

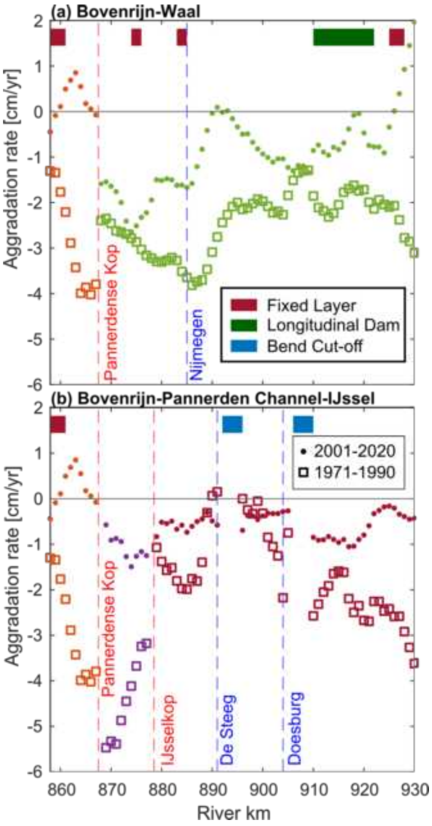

Figure 3: Comparison of bed aggradation rates between 1971-1990 (squares) and 2001-2020 (dots) along (a) Bovenrijn-Waal and (b) Bovenrijn-Pannerden Channel-IJssel

Acknowledgements

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The effect of longitudinal training dams and groyne lowering on river dunes

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Keywords — River dunes, Longitudinal training dams, Groin lowering

Introduction

Rivers have several important functions in society, such as transport, recreation, and ecological functions. River dunes are present on the riverbed of many alluvial rivers and have an effect on the roughness of the riverbed, hereby affecting water levels. After the (almost) floods in 1993 and 1995, the Room for the River program was initiated. The Room for the River program aimed to improve flood conveyance by giving rivers in the Netherlands more space. Room for the River measures change the way discharge is distributed over the river profile; the main channel, groin fields, flood plains and secondary channels. Therefore, these measures can have an effect on the characteristics of river dunes. The aim of this research is to assess the effects of river interventions on the characteristics of river dunes.

Method

In the Waal River the bed level of the main channel is measured on average once per two weeks with multi-beam echo sounding (MBES). Bed level measurements from 2005 to 2020 are used in this study. Three study areas were chosen in the river Waal, a section in the Middle Waal (rkm 894-911), Lower Waal (rkm 934-944), and a section with longitudinal training dams (LTD) (rkm 914-921.5). These three sections allow for the analysis of the effect of groin lowering and LTD construction.

From each measurement river dunes have been identified using the method developed by Lokin et al. (in prep.). The method identifies river dunes using a wavelet analysis with Morlet wavelet function, similar to Gutierrez et al. (2018). Dune crests and troughs are identified from a smoothened riverbed profile, such that superimposed bedforms are ignored. The method from Lokin et al. (in prep.) can also determine dune celerity. Dune celerity is determined using spatial cross-correlation between two consecutive measurements. The displacement is determined from the largest spatial cross-correlation between the measurements. Dividing the displacement by the time between two measurements provides the dune celerity.

To identify the differences in dune characteristics before and after the construction of an intervention, the average dune characteristics in the study areas per measurement were plotted against the five-daily average discharge at Tiel. Isotonic regression was used to aid the analysis (De Leeuw et al., 2009).

Results

The results are shown in the figures in this abstract. Fig. 1 shows the average dune height (Fig. 1a) and length (Fig. 1b) in the LTD study area plotted against the five-daily average discharge for the centre of the main channel.

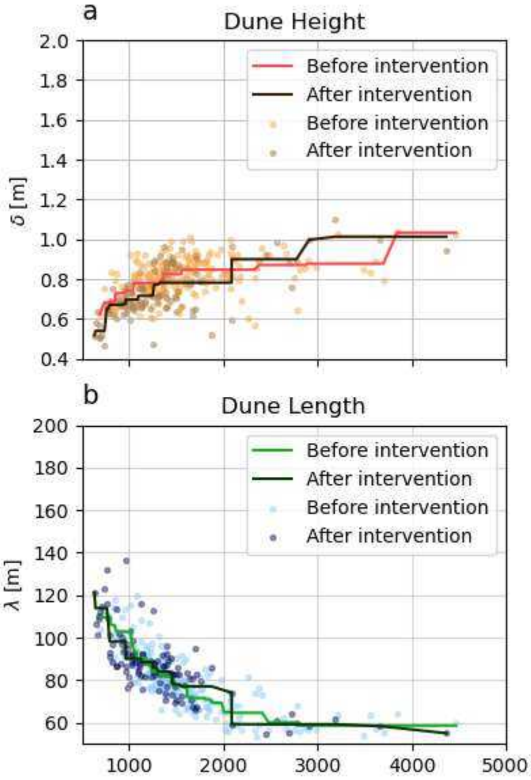

Figure 1. Average dune height (a) and dune length (b) in the LTD study area plotted against the five-day average discharge.

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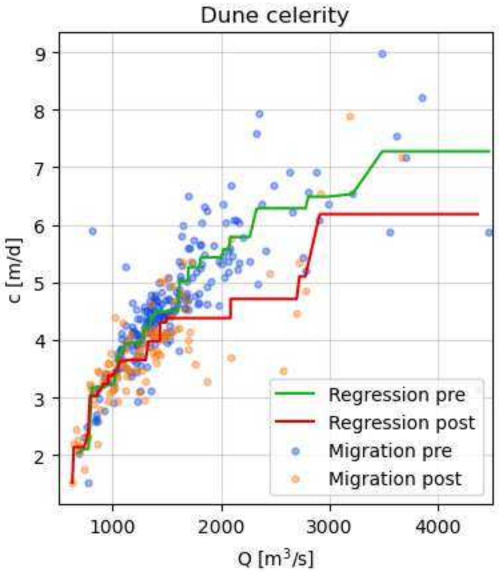

Figure 2. Average dune celerity in the LTD study area plotted against the five-day average discharge.

Fig. 2 shows the average dune celerity in the centre of the main channel for all three study areas plotted against the five-day average discharge.

Longitudinal training dams

Fig.1 shows that LTD construction leads to slightly smaller average dune heights for discharges below 2000 m³/s and larger average dune heights for discharges between 2100 m³/s and 3600 m³/s. The figure does not show a clear difference in dune lengths, the differences shown by the regression analysis around a discharge of 2000 m³/s are likely caused by limited data around those discharges after LTD construction. Fig. 2 shows that LTD construction lead to reduced dune celerity for discharges larger than 1100 m³/s.

Groin lowering

Groin lowering in the Middle Waal was observed to lead to larger average dune heights for discharges larger than 1900 m³/s at the centre of the main channel. The average dune celerity decreased after groin lowering for discharges larger than 1300 ³/s. In the Lower Waal groin lowering leads to slightly different results. Average dune lengths decreased after groin lowering at the centre of the main channel for discharges larger than 1200 m³/s. Dune celerity did not show a clear change after groin lowering.

Conclusion

The results show that the characteristics of river dunes have changed after groin lowering and LTD construction. LTD construction leads to slightly milder dunes for discharges below bankfull and steeper dunes for discharges larger than bankfull. Thus, for discharges below bankfull river dunes further contribute to lower water levels by LTD construction. However, for discharges above bankfull, river dunes are steeper and increase the roughness of the riverbed. Therefore, for discharges above bankfull river dunes could reduce the effectiveness of LTD construction to lower the water levels.

Groin lowering leads to steeper dunes for discharges larger than 1900 m³/s and 1200 m³/s in the Middle Waal and Lower Waal, respectively. Thus, river dunes could increase the roughness of the riverbed for larger discharges, possibly reducing the effectiveness of groin lowering to lower the water levels. The research also indicate river dunes can respond differently to groin lowering at different locations, potentially caused by differences in sediment grain size.

Reduced dune celerity caused by groin lowering in the Middle Waal and longitudinal training dam construction indicates reduced amounts of sediment transport. This is beneficial for the river Waal, as it mitigates the long term observed seen in the river Waal.

Acknowledgements

This research is a part of the research program Rivers2Morrow (2018-2023). Rivers2Morrow is financed by the Dutch Ministry of Infrastructure and Water Management. All measurement data were made available by Rijkswaterstaat. Our words of gratitude for collecting and sharing this data go out to technical staff of Rijkswaterstaat. We also thank Pepijn van Denderen for sharing accurate metadata of the measurement data. The primary author wishes to thank Lieke Lokin, Jord Warmink, and Suzanne Hulscher for their supervision on his master's thesis, from which the primary results are shown in this abstract.

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Effects of Suspended Sediment Transport on Bar Characteristics

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Keywords — Bars, Suspended sediment, Delft3D

Introduction

Bars are large sediment formations in rivers that emerge at low flow (Figure 1). Bars can be forced, free, or hybrid (Duró, et al., 2016). Free and hybrid bars form due to morphodynamic instability of the river bed. Hybrid bars are stabilized by hydrodynamic forcing and are thus steady. Most bar instability analyses are based on bedload transport, which implies quick adaption of sediment transport to the local flow conditions (Engelund, 1970). However, the transport of sediment in suspension does not immediately adapt to the local flow conditions since it presents time and space lags in its response. It is therefore believed that this influences the characteristics of the river bars. Theoretical work on the effects of sediment suspension on free alternate bars is based on linear simplifications of the equations and has led to opposite conclusions.

Figure 1 Alternate bars: Rhine River (Left), Experimental flume of Tewolde (2015) (Right)

The goal of this research is to investigate the effects of suspended sediment on bar formation, distinguishing hybrid bars from free bars, using a 2D numerical model. The study is complementary to the experimental work of Tewolde (2015) who studied hybrid alternate bar formation in the laboratory with two sediments having the same granulometry but different density to obtain either bedload or suspended load. Tewolde (2015) found that hybrid bars are damped if suspended load transport is dominant, but their wavelength seems unaffected by the transport mechanism. To fulfil the study's goal, a virtual alluvial straight channel with constant width and non-erodible banks is set up using the Delft3D code. Starting with a flatbed and different boundary conditions, the flat channel bed develops into a train of alternate bars. The characteristics of the virtual channel are an upscaled version of the experiments. The numerical results are then compared to the experimental ones.

Methods

The water depths in the experimental flume of Tewolde (2015) had the order of centimeter, which makes it difficult to reproduce them numerically. For this, it was necessary to upscale the experimental channel by keeping the same flow characteristics (Froude number), bedload mobility (Shields parameter), degree of suspension (Rouse number), and 2D morphodynamic response (bar mode and interaction parameter). Suspended sediment transport is affected by the spiral flow that forms around bars. For bedload, it is important to include the effects of gravity on sediment transport direction. The model is set up to include all this, at the scale of a real river. Calibration is carried out by modifying the bed slope effect (bedload) and the spiral flow effect (suspended load) on Run 1. Validation is carried out on Runs 2 and 3 (Table 1), reproducing the first 6 laboratory tests of Tewolde (2015).

Research scenarios

The investigation scenarios simulate bar formation with different percentages of bed and suspended load to complement the laboratory experiments of Tewolde (2015). For each scenario, the simulation is carried out either by imposing a groyne near the upstream boundary to generate hybrid bars or without a groyne and with a random inflow perturbation to generate free bars.

Table 1 Research scenarios. Each run includes the simulation of either hybrid or free alternate bars

Simulations	Discharge (m^3/s)	Width (m)	Sediment Type
Run1 bedload	155	50	Gravel (1cm)
Run2 bedload	179	50	Gravel (1cm)
Run3 bedload	205	50	Gravel (1cm)
Run1 sus. load	155	50	Sand (0.4mm)
Run2 sus. load	179	50	Sand (0.4mm)
Run3 sus. load	205	50	Sand (0.4mm)
50%bed+50%sus	155	50	Gravel +Sand
33%bed+67%sus	155	50	Gravel +Sand

Preliminary Results

The upscaling procedure allowed establishing the size and the discharge of the virtual channel (Table 1). To achieve the same sediment mobility and degree of suspension the virtual channel is made by two sediment components: gravel with a D_{50} of 1.0 cm for bedload, computed with the formula of Ashida–Michiue (1974); sand with a D_{50} of 0.4 mm for suspended load, computed either using the formula of Van Rijn (1984) or with an advection-diffusion approach.

The most important parameters to compare the results of calibration and validation with the results of the flume experiments are the bar wavelength and the bar amplitude. The advantage of the model lies in the possibility to study a longer channel minimising the effects of the boundaries, which were causing large uncertainty in the interpretation of the experimental results. The results of bedload calibration are shown in Table 2. The model is then validated on Run 2 and Run 3. The results are shown in Figure 2 and Figure 3. Figure 3 shows the entire model domain, much longer than the experimental one.

What next

The model is currently run to reproduce also the suspended sediment cases. The work is therefore still ongoing and the results of suspended sediment effects are not provided yet.

Table 2 Bar characteristics in the flume and the model (bedload cases)

Bar characteristics		**Experiment**	**Experiment (upscaled)**	**Model**
Run 1	Wavelength (m)	2.1	525	520.8
	Amplitude (m)	0.0123	3.075	2.24
Run 2	Wavelength (m)	2.25	562.5	562.5
	Amplitude (m)	0.0105	2.625	2.41
Run 3	Wavelength (m)	2.86	715	760.4
	Amplitude (m)	0.009	2.25	2.58

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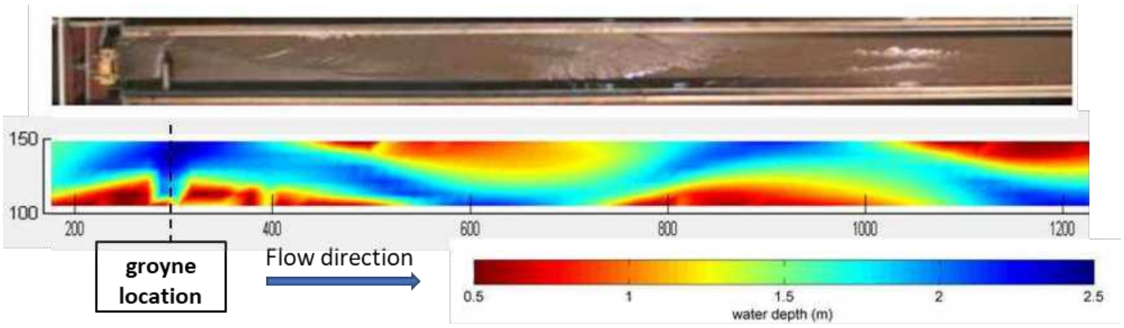

Figure 2 Run2 (bedload). Experiment (top) and model results (bottom).

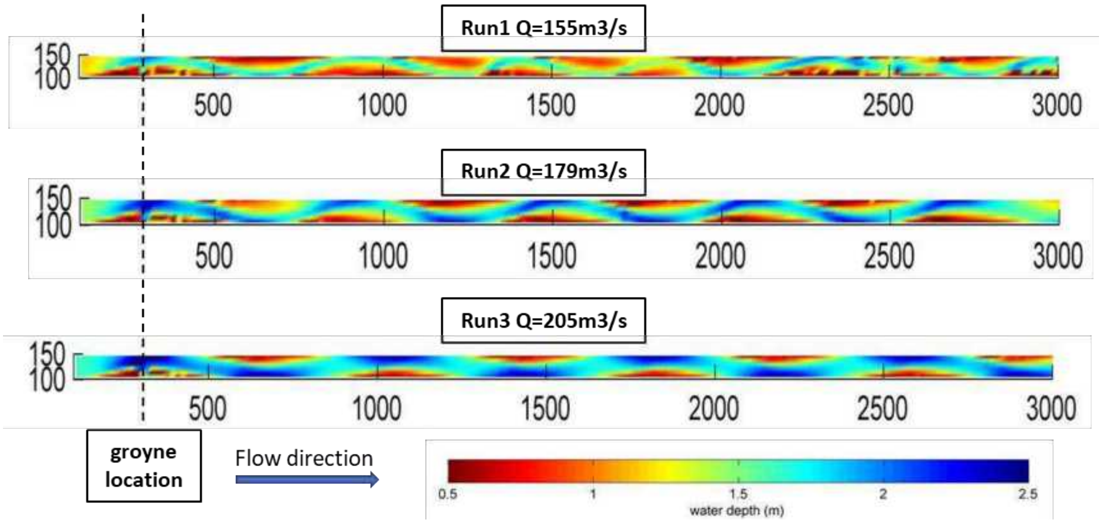

Figure 3 Results of model calibration and validation for bedload.

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Near-field of an experimental turbidity current triggered by an impinging water jet – a preliminary assessment

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Keywords — physical modelling, water injection dredging, sediment management

Introduction

The construction of dams in rivers impacts the environment at small to large temporal and spatial scales, and the impacts caused by the changes in sediment fluxes are a major concern. Although efforts have been made to develop more sustainable sediment management techniques, their poor predictability often hinders effective application. With this research, we aim at quantifying key sediment and hydrodynamic processes of an idealized and reduced-scale version of the water injection dredging technique, which can be applied to sustain sediment bypassing through dams. The application of this technique consists of (Winterwerp et al 2002) a) water injection into the bed, typically by a moving boat equipped with a jet array; b) mobilization and suspension of sediment from the bed; c) formation of a turbidity current that can transport sediment to distal areas by natural means. The processes involved in the application of this technique are commonly divided into spatial units, here defined as: injection and impact zone (position A, Figure 1), near-field (position B, Figure 1), and far-field (positions C, D, and E, Figure 1). Within a framework to link the momentum and sediment fluxes between two of these areas, injection and near-field (e. g. Sequeiros et al 2009), the first preliminary results on the near-field characterization of a laboratory experiment are here presented.

Methodology

The experimental setup (Figure 1) consists of a 4 m long, 2 m deep, and 22 cm wide flume; a hydrodynamic diffuser device exiting in a rectangular shape 3 cm high and 20 cm wide, approximately reproducing 2D jet boundary conditions; and a one meter deep deposit (ρ_{bulk} ~ 737 kg/m^3, i.e. 737 kg of sediment per m^3 of deposit) built with lightweight sediment ($\rho_{sediment}$ = 1581 kg/m^3; D50 = 0.222 mm[1]) and constant slope (α = 0°). To measure velocity and concentration profiles, four Ultrasonic Velocity Profilers (UVPs), one Acoustic Doppler velocimetry (ADV), and two Conductivity Concentration Meters (CCMs) were placed at four longitudinal locations. For the experiment presented in this piece of work, the jet boundary conditions were: discharge = 3 l/s and impinging angle = 45°.

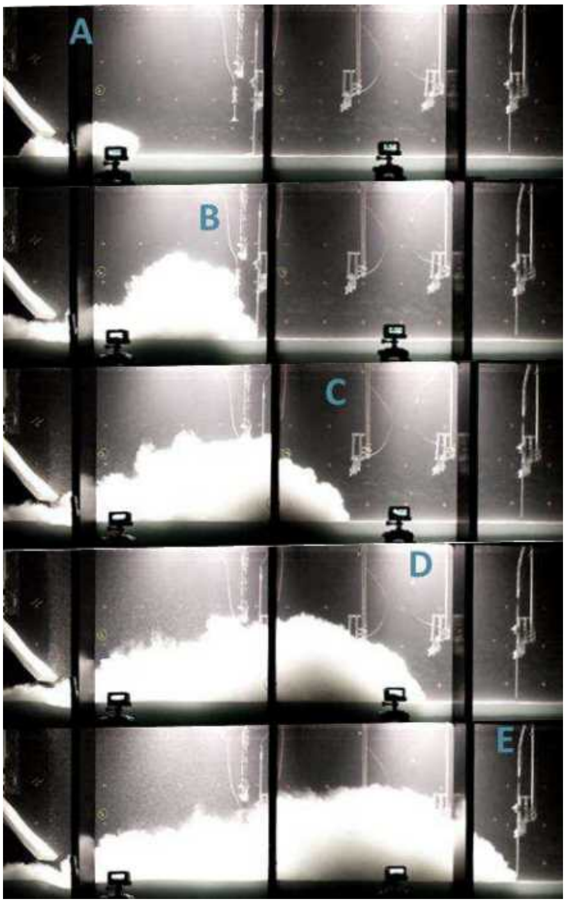

Figure 1. Snapshots of the experimental setup instants after the experiment started (A), and after approximately 5 (B), 10 (C), 15 (D) and 20 (E) seconds after the first snapshot.

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[1] Approximately, 4% of the grain sizes are between 0.150 - 0.180 mm, 76% between 0.180 - 0.250 mm, and 19% between 0.250 - 0.300 mm.

Preliminary results

In Figure 1, the development of the turbidity current after the jet impingement is shown in a sequence of snapshots (A to E). Downstream the near-field, the head of the turbidity current travelled with a velocity of ~ 8.5 cm/s. The impact zone at approximately the instant when the snapshot E was taken is shown in greater detail in Figure 2. Roughly, an erosion rate of 40 g/s (across the width of the flume) at the impact zone, triggered a turbidity current with a mean velocity profile at the near-field as shown in Figure 3.

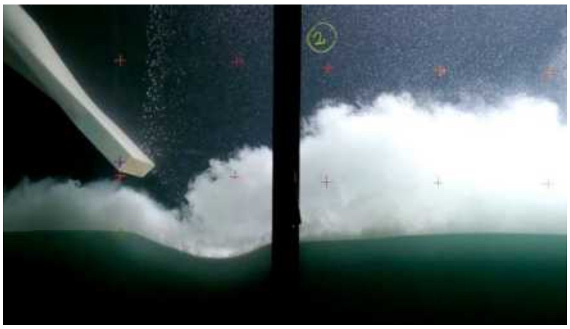

Figure 2. Scour result after approximately 23 seconds from the start of the experiment (snapshot E, Figure1).

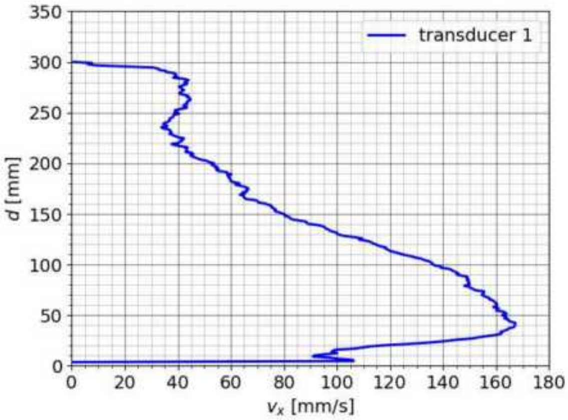

Figure 3. Mean velocity profile at position B (Figure 1). The velocities were averaged from t ~ 7 s (snapshot B, Figure1) to t ~ 23 s (snapshot E, Figure 1) from the start of the experiment.

Current and future work

Current and future research aim to characterize the near-field turbidity currents triggered in various initial (bed slope) and boundary conditions (jet discharge and impinging angle) and to link these near-fields with the injection characteristics.

Acknowledgments

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An interactive atlas of river morphodynamics

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Keywords — River morphodynamics, wavelet transform, RWS Wavelet Tool

Introduction

The bed level in the navigation channel of the Waal River is measured biweekly. This gives a unique dataset that describes the morphological behaviour of the river. We use a wavelet transform, a filtering technique that is able to determine bed level changes on various spatial scales, to analyse this data and explore relations to causes of bed level changes. With this method, both small-scale and large-scale bed-level changes can be visualised separately. Results show that different causes for bed-level changes can be disentangled such as interventions (Van Denderen et al., 2020), discharge fluctuations (Van Denderen et al., 2021) and the normalization measures of the past (Huthoff et al., 2021). This provides new insight in the behaviour of the river and offers opportunities for design and construction of new interventions with minimal negative morphological effects as well as valuable insights for the river manager.

The extensive dataset and complex methodology make it impractical for daily usage and less accessible for a wider group of users. Therefore, we developed a digital and interactive atlas for bed-level changes at different spatial scales that can be used to quickly evaluate local and large-scale bed-level changes. This RWS Wavelet Tool (RWT) is developed in Dutch and based on the results of the TKI Deltatechnologie research project (UTW01).

Wavelet method

A wavelet transform identifies wavelengths or frequencies in a wave-like signal. A wavelet transform can be compared to the better-known Fourier transform. A Fourier transform decomposes a wave-like signal into sinusoidal waves with different frequencies that are periodic and do not decay. This allows for determining the main frequencies that occur within a signal. This is not a problem for, for example, analysing tidal records in which the main tidal components always occur at the same frequencies. In the case of analysing bed levels, spatially varying conditions along the river, e.g., flow velocity, channel geometry and sediment characteristics, can result in large variations of the dominant frequencies in space. In contrary to the Fourier transform, a wavelet transform can reveal the wavelength of bed level changes and its spatial variation along the river.

The wavelet transform results in a wavelet power spectrum (wavelet power as function of frequency and space), from which the signal can be reconstructed resulting in the original signal. In addition, we can reconstruct the signal for a selection of wavelengths and thereby use the wavelet transform as a filtering technique.

The RWS Wavelet Tool (RWT)

Figure 1 shows a screenshot of the digital and interactive atlas, i.e., the RWS Wavelet Tool (RWT). The RWT can be controlled by three sliders with which a selection is made from the database and the figures are generated. The three sliders control the study area, the time period and the wavelengths. Four figures are generated:

1. The bed-level profile. This is the reference bed level (time-averaged between 2005-2014) and the bed level associated with a selected discharge category.
2. The bed level variation in time
3. The bed level variation with discharge, this shows the average bed level per discharge category in which cat. 0 corresponds with a discharge at Lobith <1200 m^3/s and cat. 7 with a discharge >6800 m^3/s.
4. The rate of bed-level change shows per discharge category the average bed-level change.

The bed level variation in time (2) can be used to identify bed level changes and the migration of bed features in time. The bed level variation with discharge (3) shows the range between which the bed level varies for various discharge levels. With this figure the bed-level

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development in the river is shown as a function of the occurred discharge levels, which is especially useful for shallow areas that can hinder navigation. The rate of bed-level change (4) can help to derive the time scales over which these shallow areas develop.

Conclusion

The RWT gives a wide range of users quick and easy access to valuable bed-level measurements. This insight into the bed-level dynamics and the physical processes can improve decision making and intervention design in the operation and management (from morphological point of view) of the rivers.

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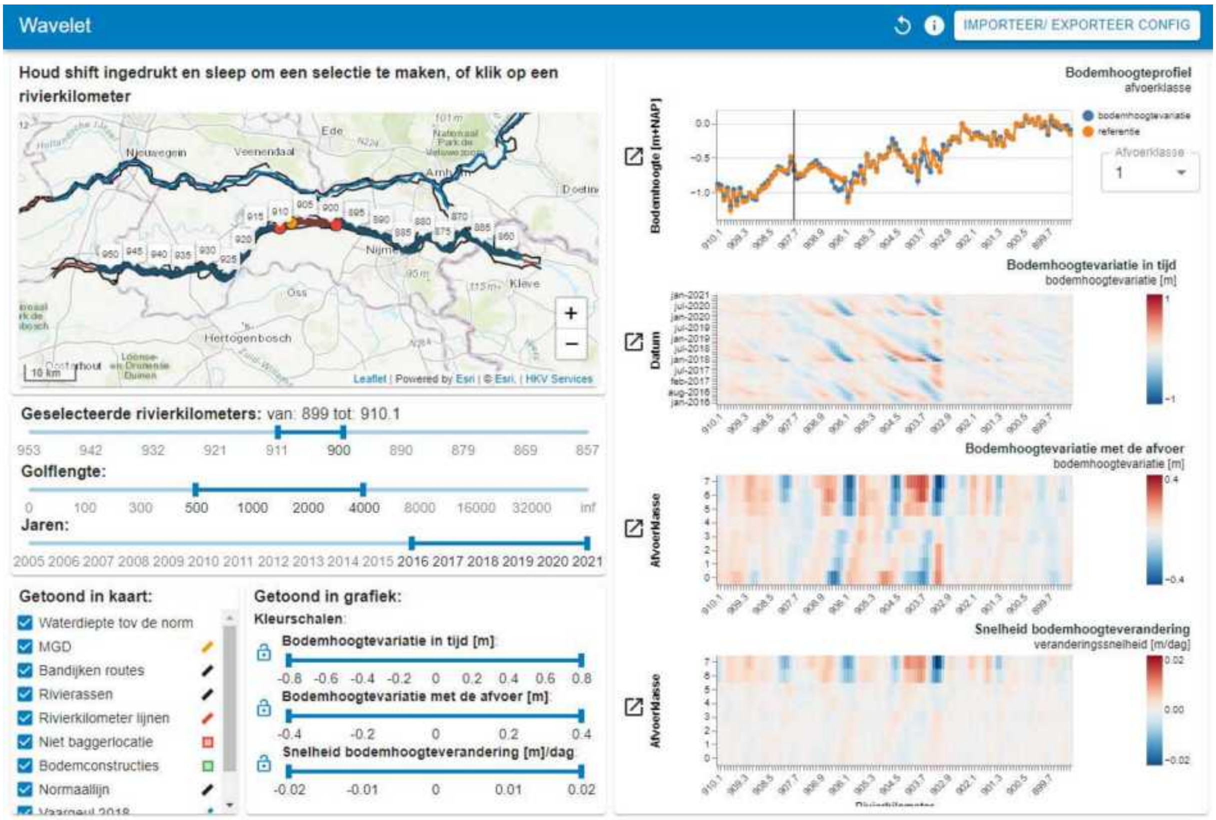

Houd shift ingedrukt en sleep om een selectie te maken, of klik op een rivierkilometer

Geselecteerde rivierkilometers: van: 899 tot: 910.1

953 942 932 921 911 900 890 879 869 857

Golflengte:

0 100 300 500 1000 2000 4000 8000 16000 32000 inf

Jaren:

2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021

Getoond in kaart:

- ☑ Waterdiepte tov de norm
- ☑ MGD
- ☑ Bandijken routes
- ☑ Rivierassen
- ☑ Rivierkilometer lijnen
- ☑ Niet baggerlocatie
- ☑ Bodemconstructies
- ☑ Normaallijn
- ☑ Vaargeul 2018

Getoond in grafiek:

Kleurschalen:

Bodemhoogtevariatie in tijd [m]:
-0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8

Bodemhoogtevariatie met de afvoer [m]:
-0.4 -0.2 0 0.2 0.4

Snelheid bodemhoogteverandering [m]/dag
-0.02 -0.01 0 0.01 0.02

Figure 1. A screenshot of the RWS Wavelet Tool (RWS).

Sediment transport measurements in the Lower Rhine: preliminary findings

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Keywords — sediment transport, ADCP, dune tracking, bed load sampling

Introduction

The Rhine river is one of the most heavily engineered rivers in the world. Since centuries, there have been interventions in its catchment that made the river smaller, shorter and fixed its planform by levees and dikes. Besides, many barrages have been constructed, with the one near Iffezheim in south-western Germany being located the furthest downstream. All these interventions resulted in a transformation from a multi-thread river with many channels to a mostly single-thread river. Advantage for agriculture and navigation are obvious, but the adverse consequence was that the Rhine river started to evolve towards a new equilibrium state, resulting in considerable bed erosion (Arbos et al. 2021). Floodplains started to become disconnected from the river, and the transport of gravel and sand throughout the river became distorted, making it harder to predict the future state of the system. In order to be able to make appropriate predictions for the systems future state, it is vital to have a clear understanding of the current mechanisms of sediment transport in the Rhine, which allow for estimates of future sediment fluxes at various locations. This data (together with multi-beam echo-soundings and measurements of water levels and discharges) can be used to calibrate and validate numerical models. These models, when provided with the correct initial and boundary conditions, then generate predictions of the river bed over 10, 50 or even 100 years. The various data themselves (provided that there exist long temporal data series) give information about trends on large scale erosion and sedimentation patterns.

Measurements of sediment transport are rare in the Dutch part of the Rhine, and even in the German part, sediment measurements fall short compared to measurements of water levels and discharges, even though they are continuously and regularly conducted since several decades. German and Dutch Water Authorities and institutes (Bundesanstalt für Gewässerkunde (BfG), Bundesanstalt für Wasserbau (BAW), Wasserstraßen- und Schifffahrtsverwaltung des Bundes (WSV) and Rijkswaterstaat (RWS)) have taken the initiative to perform joint measurements on sediment transport in the Dutch-German border area to correlate the respective measurement techniques and revive and share the knowledge of sediment transport measurements. This is acknowledged as a first step towards more, more frequent and conveyable measurements in the future, leading to a better transboundary understanding of the sediment system.

Figure 1. Improved Arnhem Sampler, as used by the German authorities (top) and Delft Nile Sampler, as used by the Dutch authorities (bottom). Note the difference in mesh size and the sample container.

Method

On November 3-5, 2021, a survey took place in the Dutch-German border area (around river kilometre 859, see figure 2) in which German and Dutch vessels measured directly and indirectly suspended load and bed load with different techniques. Bed load refers to the sediment which is in almost continuous contact with the bed, carried forward by rolling, sliding or hopping. Note that all measurements have to be related to the specific discharge occurring at the time of the survey, which was approximately 1050 m³/s at Lobith, The Netherlands.

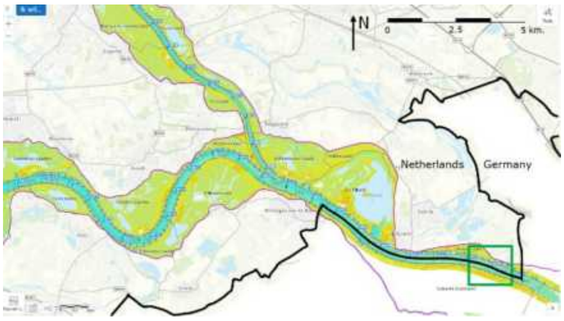

Figure 2: Location of the measuring site: The upper Rhine in the Dutch-German border area. The river kilometre 859 is located within the green square. The black line is the Dutch-German border.

Bed load was sampled with an improved Arnhem Sampler (Germany) and a Delft Nile Sampler (Netherlands). The setup of both devices is very similar: they consist of a small container with an opening facing upstream, that is mounted on a frame, which is lowered to the bed level. Bed material (gravel and sand) enters the container and its weight and composition is analysed afterwards in a laboratory. The exact procedures (samples per location, duration of the frame on the bed level, etc.) are put forward in protocols. The main differences between the German device and the Dutch device are the mesh size of the container and the size of the container itself. In Germany, a mesh size of either 1.4 mm is used (a mesh size of 0.5 mm was used for comparison with the Dutch samples), while in the Netherlands, a mesh size of 0.25 mm is used.

Apart from the direct measurements, also indirect dune tracking measurements were conducted. On several days, detailed multi-beam echo-soundings (MBES) of the bed level have been made with a focus on dunes. Analysing these measurements with respect to dune tracking gives information about the fluxes of bed sediment. In addition, indirect ADCP bottom track measurements were conducted as a comparative method for assessing sediment fluxes.

Suspended load was measured directly from samples and also indirectly with ADCPs, using backscatter information. In this way, information about velocity, the depth of particles and the concentration of suspended matter throughout the water column is obtained.

Results and Conclusion

The data is still being analysed and at this moment and no conclusive results are available, yet. It is however clear that the direct sediment transport measurements from Germany and the Netherlands are hard to compare, due to the different measuring protocols, and the different mesh sizes. The large mesh size used in the improved Arnhem Sampler probably underestimates the fine sand fraction, while the small mesh size in the Delft Nile Sampler was not able to catch coarser sediment. In addition, the net volume of the samples differs considerably due to the differences in mesh size.

The recording of the dune tracking data was successful, but the analysis raised some questions that need an answer before conclusions can be drawn. It is, for instance, not clear yet what an appropriate estimation of temporal intervals between successive MBES measurements is, to get a reliable magnitude of bed load transport.

A first result based on the German bed load data indicate a total daily bed load flux of 332 T/day.

Analysis of the ADCP data on suspended load transport was done with existing software. First results indicate an average suspended load of 1500 T/day during 2-4 November 2021, although the error margin in this number is still large, and there is some ambiguity between the Dutch and German results.

Acknowledgement

The measuring campaign was part of the 'Living-Lab Rhine' (LiLaR) project, supported by INTERREG regional funding of the Euregio Rhine-Waal.

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Quantification of accuracy in morphodynamic modelling

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Keywords — Numerical scheme, upwind, central, bars

Introduction

The importance of numerical modelling of morphodynamic changes has increased in the last decades up to the point that it is becoming a compulsory step in the design phase of interventions. The evident question arising is: how representative is the numerical solution of the actual physical process? The differences between reality and the numerical solution are due to approximations undertaken in several steps, the two main steps being the conceptualization of the physical process into a set of equations and the numerical solution of the set of equations. We here focus on the second source of differences.

Due to the general lack of analytical solutions, the quality of numerical models is often judged based on expertise, previous experience, and the Principle of Least Astonishment (Mosselman, 1995; Merrill, 1995): it is accepted if expected features with reasonable magnitudes are observed. This approach is logical but it also limits our confidence and reduces the power of numerical solutions as a tool for resolving disputes between experts. Our objective is to also quantify the ability of a solver to reproduce specific morphodynamic processes.

Numerical modelling entails deciding how to discretize the equations (i.e., the numerical scheme) and the domain (i.e., the grid and time resolution). We intend to provide guidance on choosing a scheme and a grid for modelling 2D morphodynamic processes.

Methodology

Quantitatively judging the quality of a numerical solution requires a known solution to which compare. Here we focus on a straight alluvial channel for which the flat bed is unstable when the width-to-depth ratio is above a critical value (Engelund and Skovgaard, 1973). Analytical expressions exist for the growth rate and propagation celerity as function of transverse and longitudinal wavenumbers starting from infinitesimal perturbations. We verify whether we are able to numerically reproduce these expressions using Delft3D 4.

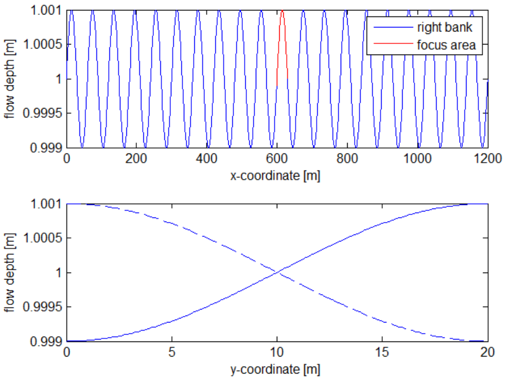

Figure 1: Flow depth before morphodynamic changes start.

The equilibrium bed profile of a straight channel with a flow depth of 1 m is slightly perturbed by adding to the bed the product of half a cosine in transverse direction and a sine in streamwise direction with amplitude equal to 1 mm. Figure 1 shows an example of the initial flow depth. The grid resolution (i.e., the number of parts in which the wavelength of the bed perturbation is divided) and the longitudinal wavenumber are varied. Two numerical schemes for the morphodynamic update are compared. The first (default) option is first order "upwind" where the sediment transport at a cell edge is equal to the one of the upstream cell, and the second is central where the average of the upstream and downstream evaluated transports is used.

Results

Figure 2 shows the relative bed level variation over time for the case in which the width is equal to 20 m and the longitudinal wavelength is equal to 600 m. We focus on the evolution of the bed disturbance highlighted in Figure 1. Under these conditions the perturbations are expected to decay. Both the upwind and the central scheme correctly predict the trend. However, while the celerity is correctly captured using both schemes, the negative growth rate is larger using the upwind scheme than when using the central scheme (the latter one matches the theoretical one). Increasing the resolution by a factor 2 decreases the artificial dampening of the upwind scheme

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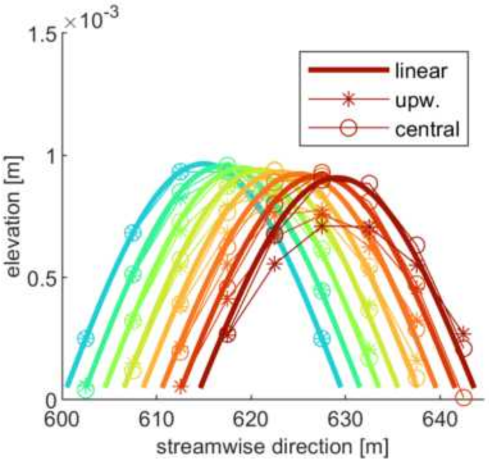

Figure 2: : Longitudinal profile along the side of the domain of the bed elevation with respect to the reference bed elevation for the focus area highlighted in Figure 1. Colour represents time (blue to red). The markers indicate the scheme: central (circle) and upwind (asterisks). Wavelength is discretized in 12 parts.

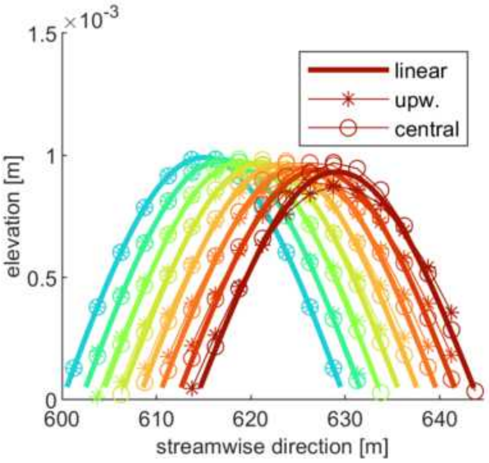

Figure 3: : Longitudinal profile along the side of the domain of the bed elevation with respect to the reference bed elevation for the focus area highlighted in Figure 1. Colour represents time (blue to red). The markers indicate the scheme: central (circle) and upwind (asterisks). Wavelength is discretized in 24 parts.

(Figure 3). This trend applies to all simulated cases. Upon first glance one could say that this is the expected result given that a central scheme is second order accurate while the upwind scheme is first order, and that the central scheme is preferred. However, a forward (i.e., explicit) Euler is applied for the time integration of the mass balance equation for updating the bed. This equation is hyperbolic when linearized. Hence, the combination of forward Euler and a central discretization of the spatial derivatives yields an unconditionally unstable numerical scheme for the mass balance equation. The intrinsically unstable scheme is regularized for the conditions reported here by numerical diffusion, bed-slope effects, and some upwinding applied in the flow equations. An implicit flow solver that allows timesteps closer to the limit timestep based on the bed update as well as using large morphodynamic acceleration factors (i.e., MorFac) would highlight the limitations of the scheme and show instabilities.

Conclusion and Further Research

Under specific conditions, the numerical solution converges to the analytical solution regardless of the scheme employed.

Dividing the wavelength into 6 cells is enough for obtaining “accurate” results for this case when using the central scheme. The grid resolution needs to double in case the upwind scheme is employed for obtaining similar accuracy. However, the superiority of the central scheme must be handled with attention as it is regularized by properties of the flow solver among other things. This analysis will be extended by comparing the numerical growth rate and celerity for comparison with the analytical values for a wider range of conditions. The focus will then be on studying accuracy depending on the grid properties (i.e., orthogonality and smoothness). A similar study will be conducted using Delft3D FM which applies a different hydrodynamic numerical scheme. In this case, the effect of the grid shape (e.g., triangles vs. quadrilaterals) will be studied as well as the effect of transitions between grid resolutions.

Finally, we aim at developing an improved numerical scheme that combines the stability of the upwind approach with the accuracy of the central approach.

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How effective are multiple side channels in the River Waal in mitigating bed degradation?

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Keywords — River morphodynamics, side channels, 1D modelling

Introduction

Over the last 60 years the bed in the Dutch section of the Rhine and its major distributaries has been degrading. Along the Waal this degradation has been more than 1.5 meter, with some locations exhibiting degradation rates between 2 cm/year (Blom, 2016) and 4 cm/year (Havinga, 2020). Degradation is observed also in parts of the IJssel, Nederrijn and Lek (Ylla Arbós, 2019). Spatially varying bed degradation has negative consequences for a multitude of river functions, such as navigation (Blom, 2016; Havinga, 2020), ecology, infrastructure and water safety (Zuijderwijk et al., 2020), and water management practices resulting from the discharge partitioning at bifurcation points (Gensen et al., 2020). One way to counter bed degradation is to apply sediment nourishments, which have proven to stabilize the bed, but have to be conducted periodically to have a sustained effect (Frings, 2019). Another way to counter bed degradation is to make use of river interventions, such as side channels. Zuijderwijk et al. (2020) suggested that it is possible to implement side channels along large parts of the Dutch Rhine branches. However, a quantification of the large-scale effects of side channel implementation on the system as a whole has currently not been done. The objective of this research is to quantify the morphological impact of large-scale implementation of side channels in the Waal on the long-term bed degradation of the Dutch Rhine branches.

Methodology

We apply a 1D-model developed by Deltares for the 'Integral River Management'-programme (Chavarrias et al., 2020), which is suited for long-term and large-scale morphological analysis of the main channel river bed. The model uses Delft3D FM and includes the main Rhine branches in the Netherlands as well as a part of the German Rhine (Fig. 1). Boundary conditions are represented by four cycles of observed discharge and water level time series from 1994 - 2020, which have been used by Chavarrias et al. (2020) to calibrate and validate the model. In total we simulate 100 years. We consider a reference case without side channels and seven cases with side channels. The side channels are implemented in the same locations for all seven cases (Fig. 1), however, they all start flowing at a different discharge for each of the six cases (see Fig. 2). The discharge at Lobith (Fig. 1) is used as design discharge. The width of the side channels has been set at 25% of the width of the adjacent main channel. After 100 years, the bed level is evaluated compared to the reference case.

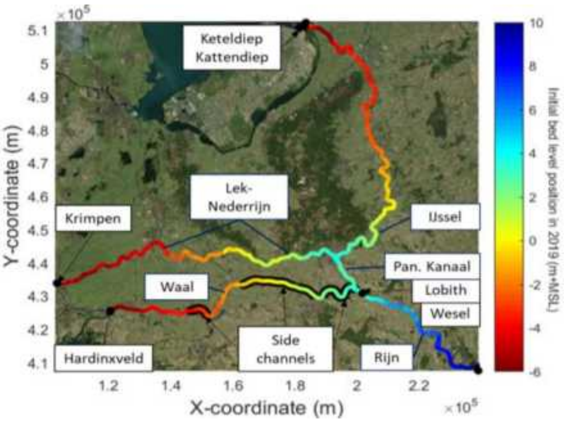

Figure 1. Model domain of the 1D-model including initial topography, boundaries and location of side channels.

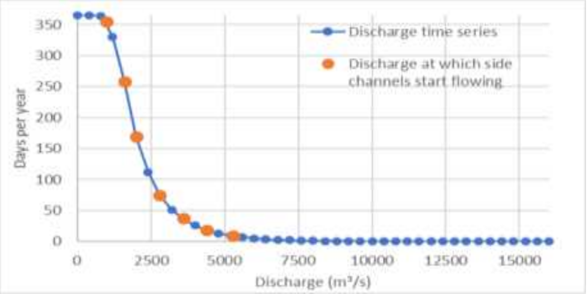

Figure 2. Exceedance frequency of discharge at Lobith and the discharges at which the side channels start flowing for the seven cases.

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Results

Reference case

The results show that compared to the initial bed level (Fig. 1), bed degradation will be quite severe if no interventions are implemented (Fig. 3). At some locations in the upper Waal, between 3.5 and 4 m of degradation is to be expected over the next 100 years, which is on the higher end of what might be expected based on the current erosion rates. On the other hand, near the mouths of the IJssel and Waal, sedimentation rates are in the order of 2 m, pressing the need for (additional) dredging. Furthermore, at the bifurcation of the Bovenrijn into the Waal and the Pannerdensch Kanaal, it is visible that degradation in the Waal is much more severe than in the Pannerdensch Kanaal. This is also the case for the IJssel compared to the Nederrijn at the bifurcation of the Pannerdensch Kanaal. It is therefore necessary to update the rating curves and discharge partitioning.

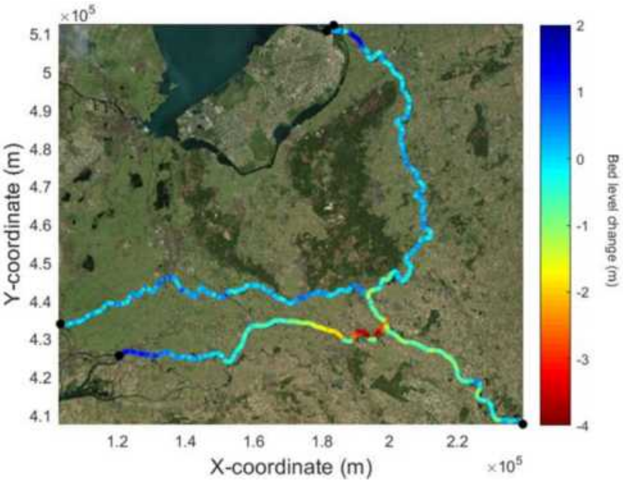

Figure 3. Bed level change for the reference case, with no interventions, after 100 years compared to the initial bed level.

Effect of side channels

The side channels are able to reduce the bed degradation over 100 years by a maximum of 0.45 - 0.50 m (Fig. 4), which is in the order of 10 - 15% of the total bed degradation. As expected, the highest reduction in bed degradation is obtained for the side channels that start to flow at low discharges. Up- and downstream of the side channels erosion is observed, which enhances local bed degradation rates. Besides a reduction of bed degradation in the Waal, a reduction in bed degradation in the Pannerdensch Kanaal is observed as well, which is almost as large as the reduction of bed degradation in the Waal itself. It should be noted that the effects of side channels have a strong variability in time and are highly influenced by upstream discharge.

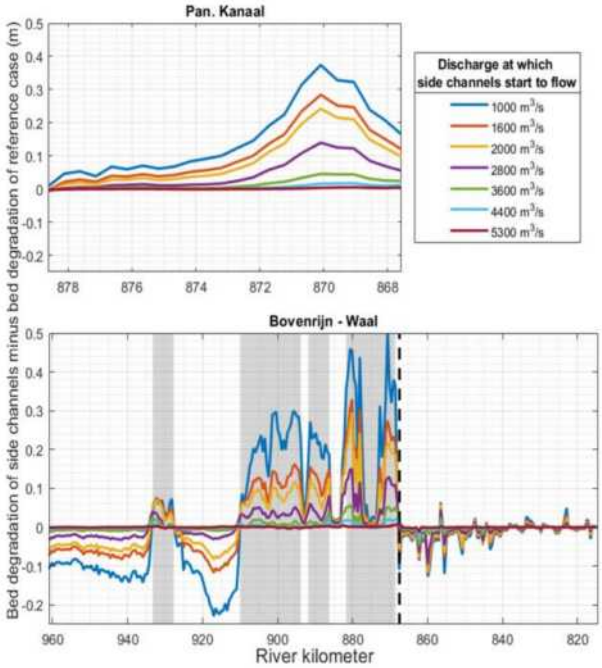

Figure 4. Reduction of average main channel bed degradation along the Rhine branches after 100 years for multiple side channels (locations indicated by grey bands and bifurcation to Pannerdensch Kanaal indicated by black dashed line).

Conclusion

Multiple side channels in the Waal are able to reduce bed degradation in the Waal and Pannerdensch Kanaal, but only to a limited extent (10 - 15%) and with high spatial and temporal variability. Additional measures are necessary to stop bed degradation.

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Evaluating Sediment Diversion Channels on Sediment-Heavy Rivers

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Keywords — Diversion, Sediment

Introduction

The natural transfer of sediment from channel to floodplain has been disrupted on many rivers by levees and dams. One unfortunate consequence of this disruption is the accumulation of sediment on riverbeds. In extreme cases, this accumulation can lead to rivers flowing above their floodplain. Super-elevated riverbeds increase the chance of levee breaches, cause waterlogging outside levees, and heighten the potential danger of a breach and flood risk. This is a concern along China's Yellow River, India's Kosi, the Indus in Pakistan, and the Missouri River in the United States among others. In lieu of continual dredging or other costly sediment management, we investigated diversion channels to reduce sediment accumulation on the riverbed of the Kosi River in Bihar, India where flooding claims an average of 238 lives each year (Prasad, 2021). Sediment diversion channels use the power of the river to redirect sediment to the floodplain or storage areas outside river levees. This technology is currently being implemented on the lower Mississippi river to replenish the Louisiana delta (Gaweesh, 2016). To investigate the efficacy of sediment diversion channels for removal of riverbed sediment, we used Delft3D Flow to create a 2D schematic model of flow and sediment in a reach of the Kosi.

Model Development

Our schematic model is based on a strand of the middle Kosi's braided channel running along the eastern levee. This reach is highly super-elevated and aggrading, with the deep channel encroaching on the levee. It was also the site of a major breach in 1984. To calibrate our schematic model, we began with a hydrodynamic model whose domain encompassed two gauges (Figure 1). The model surface was based on survey transects and satellite data and roughness was adjusted to achieve relative agreement between the modelled and observed water levels at the Basua gauge site. A model with sediment was then created with a smaller domain (D2) to test bed level change and morphology relative to literature data and satellite imagery. Soil borings from 40 KM upstream of D2 were used to determine sediment and morphological characteristics. Average accumulation of the modelled reach after one year was 3.5 cm, within the range from 2.2 to 5.33 cm reported in literature (Hooning, 2011; Kaur, 2018). Channels and islands were also found to evolve similarly to satellite data observations. The schematic model was finally created, using boundary conditions and parameters from the previous larger models.

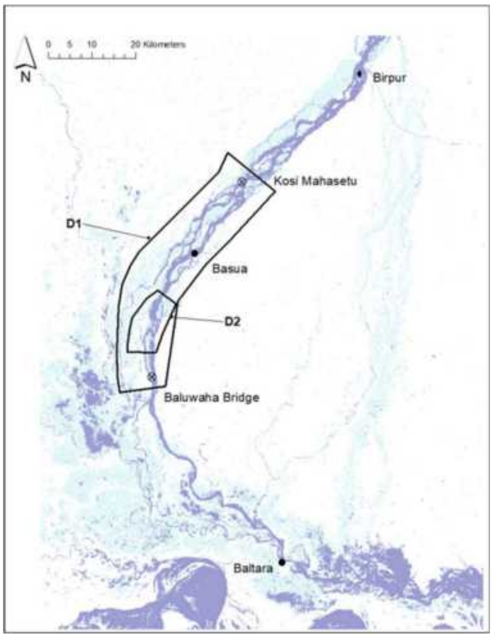

Figure 1. Model domains and gauges for the initial hydrodynamic and sediment models of the middle Kosi river.

Scenario simulations and analysis

With our schematic model we compared six diversion scenarios, varying threshold elevation and offtake angle, as well as a no-diversion scenario. After one year of unsteady flow simulation, morphological variation between scenarios could be easily observed. These changes impacted diversion efficiency, primarily through channel clogging (Table 1). Channels set at a 45-degree angle from the main channel

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captured two to three times as much flow and sediment as the other scenarios, with captured portions ranging from 2.5-percent to 17-percent of the upstream sediment load. The diversions affected river levels to varying degrees. Initially causing water level drawdown in proportion to the diverted flow, but this effect decreased over time. This decrease may be related to the reduced sediment transport observed in the main channel downstream of diversions.

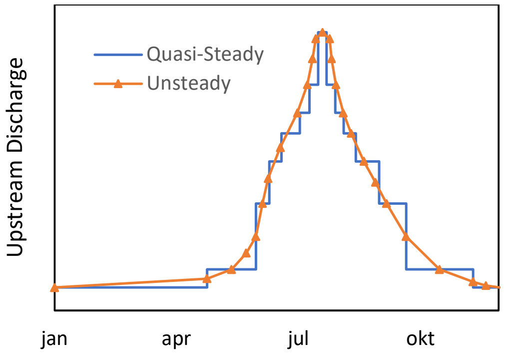

Figure 2. Unsteady and quasi-steady upstream boundary conditions for an average year on the Kosi river.

Application of Simulation Management Tool

In our examination of the long-term benefits, challenges, and maintenance needs of our diversion and no-diversion scenarios, we first conducted a comparison of quasi-steady and unsteady simulations (Figure 2). Deltares has developed a simulation management tool (SMT) that manages quasi-steady analyses where morphology factors are varied at each step. This tool has been used on many long-term studies on rivers in The Netherlands (Yossef, 2008, 2012), however, it has not been tested on other large and dynamic rivers. By comparing both unsteady and quasi-steady boundary conditions, we evaluated the effect that “squeezing” the hydrograph using varying morphological factors has on morphology. Furthermore, we used SMT for simulating longer-term (10 years) morphological impact of diversion scenarios. The work is in progress.

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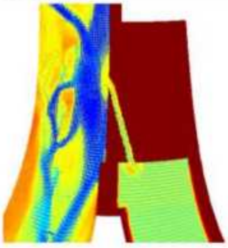
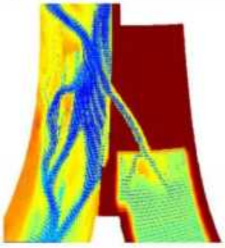
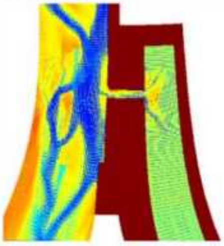
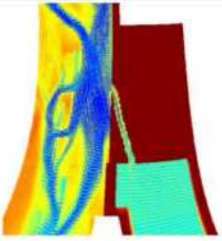
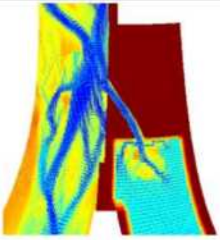
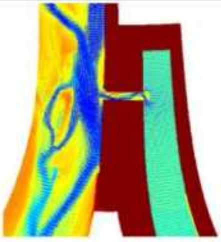
Flood-Only			
Year-Round			

Table 1. Bed level and depth-averaged flow vectors on final day of year-long simulation. In-channel accumulation reduced sediment transport by 40 to 50-percent for both 25-degree scenarios and the year-round 90-degree scenario. For the other scenarios, in-channel clogging had a much smaller effect and more sediment can be observed in the storage areas of these scenarios.

Competition and interaction between two bedform scales in the Dutch river Waal

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Keywords — River dunes, Dune tracking

Introduction

In fluvial systems worldwide, multiple scales of bedforms coexist. Where most research has focused on the larger, primary dunes, recent studies have indicated the importance of the small, secondary bedforms that are superimposed on the primary ones (*Galeazzi et al.*, 2018; *Zomer et al.*, 2021). The secondary bedforms migrate fast and the bedload sediment transport associated with secondary bedform migration equals that associated with the much larger primary dunes. Depending on the primary lee side slope, secondary bedforms disintegrate or persist at the primary dune lee. Secondary bedforms might have large implications for hydraulic roughness, for local flow dynamics and may interact with the development of primary dunes. Current work focusses on understanding the competition and interaction between primary and secondary bedforms in a lowland river, based on a large, multi-year dataset of bed elevation scans as well as a dedicated field campaign that maps the dynamics of both primary and secondary dunes.

Methods

A large dataset of fortnightly repeated bed elevation scans has been acquired for monitoring purposes and is provided by Rijkswaterstaat. This dataset is used to study primary and secondary bedform characteristics throughout the Dutch river Waal and over a range of discharge levels. The bed elevation scans are analyzed following the approach of *Zomer et al.* (In review). During the dedicated field campaign, the river bed has been scanned at an exceptionally high temporal resolution (5-20 mins between scans) to be able to track the rapidly migrating secondary bedforms. The high-resolution bed scans are used to quantify bedload transport associated with secondary bedform migration based on dune tracking. This is done for individual secondary bedforms to assess the variability in sediment transport over the length of a primary dune.

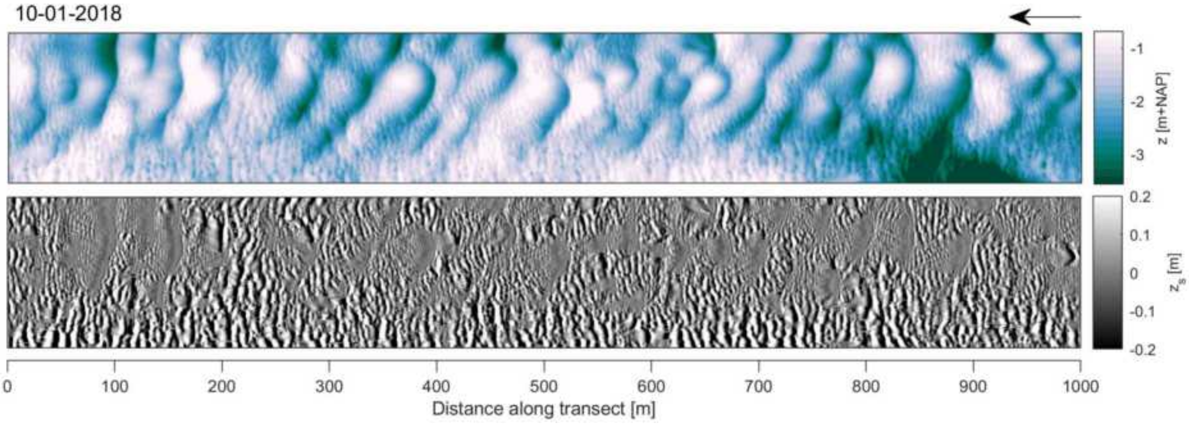

Figure 1: A bathymetric map before and after decomposition. The first panel shows the initial bathymetry. The second panel shows the secondary bedforms.

Results and discussion

Fig. 1 shows an example of a bed elevation scan during high discharge (km 35, near Tiel at Q = 7486 m^3/s). The bottom panel shows the secondary bedform morphology after separation of the bed elevation scan into secondary bedforms and the larger scale morphology. The separation of scales, as well as bedform identification based on zero-crossing has been applied to a reach of about 50 km of

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URL: `www.wur.nl` (Judith Zomer)

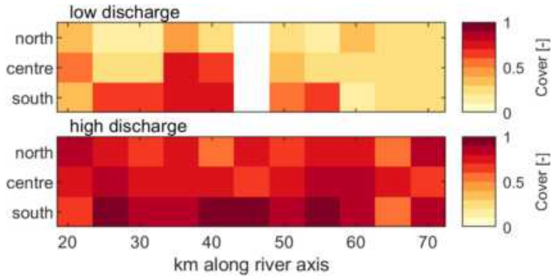

Figure 2: The fraction of the river bed covered with secondary bedforms. The x-axis indicates the distance along the river axis, increasing in upstream direction and starting at 129711N, 425761E in RD New coordinates (EPSG: 28992), near Vuren. The river width is divided in three sections of equal width.

the river Waal for high ($Q = 5649 - 5880\,m^3/s$) and low ($Q = 1080 - 1352\,m^3/s$) discharge. Fig. 2 shows the fraction of the river bed that was covered with secondary bedforms for approximately every fifth kilometer. This indicates that both for low and high discharge, secondary bedforms are present throughout the Waal. Especially during high discharge, secondary bedforms are ubiquitous, indicating their importance. Fig. 1 indicates that over well-developed primary dunes, secondary bedforms disappear and start to develop further downstream.

Fig. 3 shows the median secondary bedform properties over a river reach of 1 kilometer (km 35, near Tiel) for different timesteps and corresponding to a range of discharge levels. This shows a positive correlation between discharge on the one hand, and cover, height, length and lee side slope on the other hand. This is unlike primary dunes in the river Waal, where primary dune length decreases with increasing discharge.

An important objective of the field campaign was to shed light on the interaction between migrating secondary and primary dunes. Where secondary bedforms disintegrate at the primary lee, the secondary bedform migration contributes to primary dune migration. Secondary bedforms are also observed to persist over the primary dune lee however. Both scales are then actively migrating. Preliminary results suggest that sediment transport associated with secondary dune migration varies depending on the position of the small dunes on the primary dune. Sediment transported by secondary dunes seems to increase over the primary stoss and decrease on the primary lee. The variability in sediment transport indicates net erosion of the primary dune stoss and net deposition on the primary dune lee, resulting in a downstream migration of the primary dune.

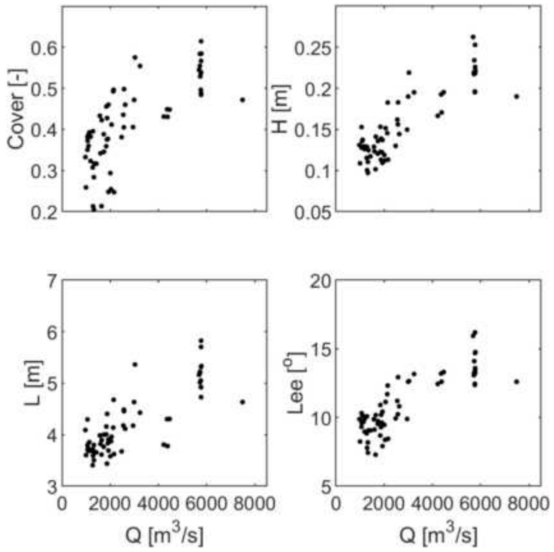

Figure 3: The fraction of the river bed covered with secondary bedforms and secondary bedform properties (height, H, length, L, and the max. lee side slope) for different discharge levels. The presented data is based on analysis of bed elevation scans at km 35 in the river Waal, near Tiel.

Acknowledgements

This study is part of the research program Rivers2Morrow, which is funded by the Dutch Ministry of Infrastructure and Water Management and its executive organization Rijkswaterstaat. We thank Rijkswaterstaat-CIV for providing the data used in this study and enabling the dedicated field campaign.

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Session 4

Challenges in River Governance

Floods and Human Health

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Keywords — floods, health impacts, flood management

Introduction

World-wide flood disasters account for about a third of natural disasters, by number and economic losses (CRED, 2018). With increased variability in weather and climate changes, extreme weather is more common, and floods may occur more frequently all over the world. For example, in Europe floods and associated damages may double by 2050 (Jongman et al., 2014).

Flood events have direct and indirect effects on human lives (Messner and Meyer, 2006). Direct effects are such as damages to properties, appliances, vehicles, infrastructure, and immediate deaths and injuries to humans. Indirect impacts include negative effects on human health, such as spread of waterborne diseases or deteriorating mental health (Alderman et al., 2012). Often the effects during and shortly after the floods get the most attention. Flood effects can have an impact long after the flood event, for instance destroyed water distribution infrastructure, a decline in sanitation services, compromised waste processing infrastructure, the mobilization of dormant pathogens, increased spread of disease vectors, and high exposure of vulnerable people (Messner and Meyer, 2006; Alderman et al., 2012).

While the economic impact of floods has been studied massively, the impact of health effects or post flood disease, while being studied, often is being neglected in flood management planning in the water sector. Probably due to difficulties in quantification of these effects. We aim to synthesize the knowledge on direct and indirect health effects of floods, improve quantification and predictability of the impacts, to foster inclusion in flood management planning.

Health effects & vulnerability

The ultimate health impacts depend on the health hazards, the exposure to these hazards and vulnerability of the exposed people. Table 1 shows results from a literature review on (global) flood related health hazards (Geerling et al., in prep). The occurrence of the health hazards is dependent on local environmental conditions, such as existing chemical of biological pollution of water or what diseases are endemic (i.e. vector borne diseases).

Table 1: Overview of possible health effects of flooding (source: Geerling et al., in prep)

Health hazard	Examples
Accidental death and injuries	Drowning, physical trauma, electrocution, wounded by falling/moving object
Mental health and well-being	Anxiety, depression, PTSD, behavioural issues
Water-related infections	*Vibrio cholerae, Escherichia coli* O157:H7, *Shigella,* Norovirus, rotavirus, *Cryptosporidium* spp, Acanthamoebic keratitis, Leptospirosis
Vector-borne diseases	Dengue, zika, chikungunga malaria, yellow fever, St Louis encephalitis, lymphatic filariasis, chagas
Chemical pollution and salinization > Heavy metals Oil and grease Hydrocarbons Road salts agrochemicals salt	Skin diseases, earache, nausea, cancer, liver and kidney diseases, gastrointestinal diseases, cardiovascular diseases, neurological diseases, carbon monoxide poisoning, reduced food and water security
Secondary effects	
Moulding	asthma, allergy symptoms, respiratory disorders
Food insecurity	undernutrition, micronutrient-related malnutrition
Birth outcomes	preterm birth, low birth weight, increased spontaneous abortion
Failing infrastructure	Hospitals, Access roads, Drinking water
Crowding	Infectious diseases

Vulnerability of the population depends on many aspects, ranging from individual health status; social and economic capacities of individuals and/or the local community; local availability and state of housing and health related infrastructure. These aspects determine how deep an impact flood related hazards can create. In space, i.e. a basin or city, the vulnerability varies. Mapping vulnerability is used in various disaster related studies and highly multi-disciplinary (de Sherbinin, 2014).

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Towards health inclusive flood management planning

The EU Floods Directive names ‘human health in its main aim: “to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community” (EC. DIRECTIVE 2007/60/EC). However, in many (quantitative) flood management assessment and planning efforts the emphasis is on minimizing damage to quantifiable entities such as damage to properties and physical infrastructure, often expressed in monetary value. On the other hand, flood related health hazards and impacts, especially on the longer-term, are poorly understood and therefore rarely considered in the prevention and management of flood risks (Tong, 2017). Direct health related impacts are combatted with relief aid after floods, and longer-term impacts, after the immediate humanitarian aid period, are mostly not planned for.

The vision is that flood management actors and public health actors (including humanitarian aid) co-manage floods and prepare integrated flood management plans and collaborative actions. A first step could be to set up a common assessment and set of indicators of impact. Leading to new trade-offs/synergies, such as less hospitalisations or quicker resumption of health services versus investments in flood protection and early warning.

To achieve the vision, a better understanding of the various health impacts is needed (in time and in space) to be able to bridge flood and public health management. As first steps we:

- are collaboratively developing a scoping method for potential health hazards and vulnerabilities. To be used as first step (preliminary flood management plan).
- Aim to map and predict health impacts arising from exposure to hazards, (cascading effects from) failing health related infrastructure to better assess flood management alternatives.
- Use the same integrated information for collaboration with aid relief organisation working in disaster areas.

By using these ‘tools’ flood managers get more insight in the flood related health impacts, can analyse cause and effect chains, and address the health impact with measures of social, governance, or infrastructural nature into flood management plans. This will not only improve post-flood aid efforts, but also strengthen the prevention of impact. However, this requires a broadening of the stakeholders involved in flood management planning.

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Living labs for improved collaboration in river management

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Keywords — Living labs, river management

Introduction

Living labs are increasingly recognized as a way of promoting innovation and strengthening collaborative planning (Lupp, Zingraff-Hamed et al. 2021). As of recent years, the concept of the living lab has gained strong attention in European Union research and innovation agendas (Lupp, Zingraff-Hamed et al. 2021). With the shift in paradigm from closed to open innovation, living labs are referred to as a suitable example of open innovation environment that combine the changes in the socio-economic environment along with technical opportunities for the given context (Leminen 2015). Hence, living labs are increasingly applied across many disciplines including water and river management (Westerlund and Leminen 2011). In this paper, we aim to characterize living labs and understand their relevance to river management, their envisioned and realized impact, and how living labs improve collaboration, if any, for river management. The results are based on a literature study and empirical data on living labs for river management.

Living labs characteristics and their relevance to river water management:

The concept of living labs is still very vague and remains open for different interpretations. This diverse definition of living labs has led it to be used as an umbrella term under which a large diversity of projects and activities are included (Capdevila 2014). However, the core of a living lab is mainly driven by two ideas; (i) involving stakeholders and users as co-creators, and (ii) experimentation/ innovation in a real-world setting (Almirall, Lee et al. 2012).

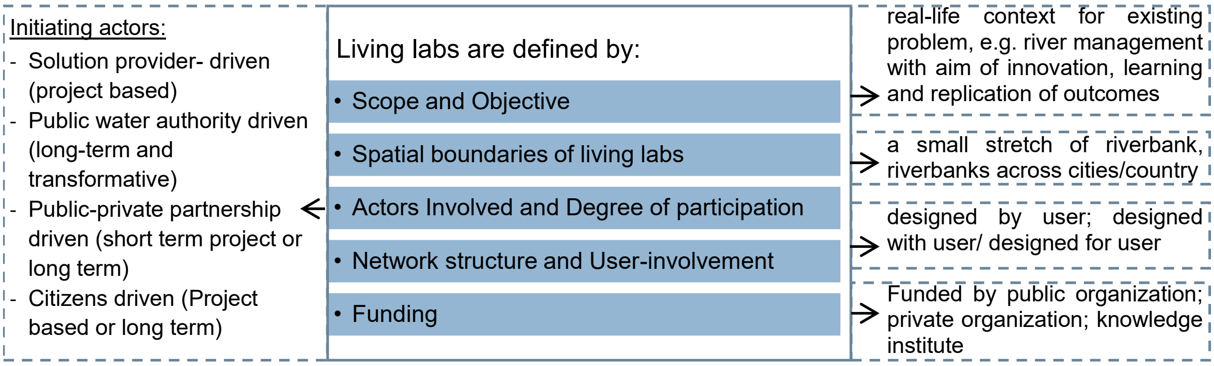

Fig: Living labs characteristic and typologies

The living labs are highly relevant for river management problems where multi-functional solutions are required with broad collaboration between multiple stakeholders such as citizens, companies and knowledge institutes. The challenges faced by river-managers requiring multi-functional solutions such as (i) integrated approach of flood risk management, (ii) cohesive task of dike improvement, nature conservation and recreation, (iii) integrated flood risk management with a focus on nature and tourism, (iv) connecting and balancing floods and droughts, etc. can be addressed successfully using living lab approach through close collaboration with residents, entrepreneurs, research institutes and governmental organizations. An example of such living lab in the Netherlands developed under the Delta programme is Overijssel living lab in IJssel-Vecht delta which was centred on climate resilience (Kennisportal Klimaat adaptatie 2020). Other living labs with a focus on river management are the Grensmaas Project (Living Lab Grensmaas) and Hedwige-Prosper polder (Antoine, Fauchard et al. 2021) that are currently being developed (researched).

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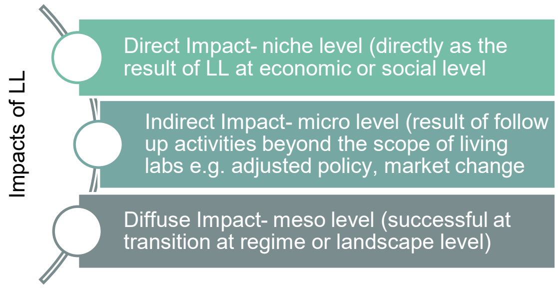
(Envisioned) Impact of living labs on river management:

Living labs are intended to enhance the creation of research and innovation synergies through the integration of knowledge, experience and expertise under the inclusion of different views and perspectives to create a useful and innovative product or service e.g. river management (Papadopoulou, Sophronides et al. 2018). The impacts of living lab can be seen as direct, indirect and diffuse impact. (fig. below)



One of the direct expected impacts of implementing living labs on river management is that the involvement of multiple stakeholders leads to the socio-economic feasibility of the innovation. For example, projects such as living lab Grensmaas created a platform for a dynamic trans-disciplinary community where professionals, businesses and locals worked together to make the project a long-lasting success. Since the Grensmaas project followed the living lab approach, residents' knowledge about nature and ecology could be used to improve integrated flood models as it was evident that many residents were experts by experience. As a result, the project successfully combines flood risk management, nature development and commercial gravel excavation (Consortium Grensmaas , Living Lab Grensmaas). Similarly, the Hedwige-Prosper polder project under Living Labs for Dutch Delta (LLDD) aims to re-design dikes under nature restoration context and reconnect people with the changing landscape (TUDelft 2019).The indirect impact of living lab takes longer time than direct impact while diffuse impact takes a long time and is difficult to measure as it usually lies beyond the scope of the project.

Collaboration as a result of living labs:

Existing examples of living labs in various disciplines show improved understanding of system elements, capacity building, and trust & relationship building among participants (stakeholders) which allows for the creation of a mutual understanding between science, policy and society (Veeckman and Temmerman 2021). The equivalent role of end-users in living labs makes them feel heard by scientists and policymakers, thus improving collaboration leading to the social and economic success of the projects. Even though the living labs appear to be a perfect way of testing, demonstrating and initiating the spread of knowledge, practices and socio-technical solutions, they might not always necessarily provide the resources for diffusion beyond a certain boundary (von Wirth, Fuenfschilling et al. 2019). In the context of living labs for river management, which usually has a bigger spatial scope and objective of safety and risk minimization, a greater attention for interrelations with more formal structures, institutions and governance is required so that innovations in the living labs are effective and can be translated into policy development.

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Long-term development of lowland rivers *Rivers2Morrow* - a research program

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Keywords — Long-term trends, river morphology, river policy

Introduction

The National Knowledge and Innovation Program for Water and Climate (NKWK) comprises a number of research lines that focus on the various water systems in the Netherlands. One of those research lines has been given the name Rivers2Morrow, and deals with rivers. Within this research program, work is being done to increase the system knowledge of lowland rivers with respect to hydraulics and morphology, as well as ecology and governance. The program focuses on developments that take place on a long temporal time scale until 2100, and sometime beyond). The results of this research can add to substantiate policy decisions and make the management and maintenance of rivers more effective and efficient. The research focuses on the effects of climate change, such as increased discharge, a changing discharge regime, sea level rise, and large-scale human interventions.

Policy themes

Rivers2Morrow focusses on policy questions concerning flood protection, pavigability, freshwater supply and nature and water quality. R2M is in the centre of this complex interplay.

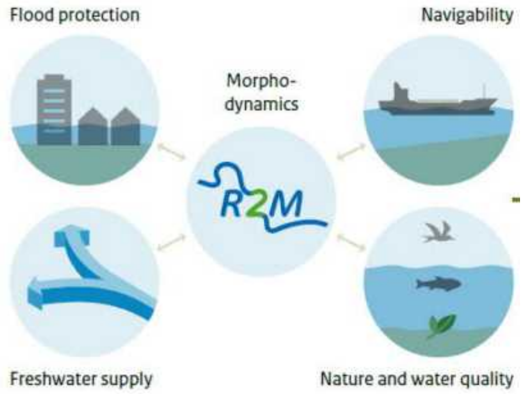

Figure 1. Policy themes of Rivers2Morrow.

Research themes

The eight PhD research topics within this program focus on: the supply of fine sediment from the Rhine basin, the stability of river bifurcations in the Rhine, the effects of climate change and sea level rise on bed level elevation of the Rhine Branches and the morphology of the Rhine-Meuse estuary, improved quantification of sediment transport, the dynamics of bed forms, sediment dynamics in the Rhine-Meuse estuary, and the sediment budget of the Meuse.

The research program also aims to improve morphological models to support various policy and maintenance decisions.

A synthesis report (Ten Brinke, 2020) present the research focus and questions from policy and management for all eight research themes in more detail, and illustrates this with informative infographics

Organisation

The program is funded by the Ministry of Public Works and Watermanagement and Rijkswaterstaat. The universities of Twente, Wageningen, Utrecht and Delft conduct the studies. The research will also make frequent use of the knowledge available at Deltares and specialized engineering firms.

Each researcher has his/her own supervision team consisting of expert users, varying from the government, engineering firm or regional stakeholder.

Results

Rivers2Morrow has started in 2018 and will run until 2024. The first researches are finalised in 2022.

The studies contributes to the following programmes:

- Integrated River Management
- Knowledge Program Sea Level Rise
- Programmatic Approach to Large Water Systems

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Modelling both local and national effects of construction and operation of the Pwalugu Multipurpose Dam

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Keywords — Dam Operation, Flood-Recession Agriculture, Riparian Communities, System Dynamics

Introduction

Dam construction and operation tend to put more focus on the national benefits while disregarding the effects the dam can have on local communities Darko et al. (2019). The construction of the Pwalugu Multipurpose Dam (PMD) in Northern Ghana would be no exception to this. The dam, mainly used for flood mitigation, irrigation and electricity generation, could affect the flow of the White Volta river in such a way that the Ecosystem-based Activities (EBA) effectively of the riparian communities could not be performed anymore Mul et al. (2017). These EBAs include farming, riparian pond fishing and livestock watering Mul et al. (2017). However, the riparian communities will also benefit from the construction of the PMD as they will become less prone to floods caused by high spillage at the upstream Bagre Dam Gonzalez et al. (2021).

Many of studies have been done on dam operations and the accompanying effects on the flow of the river. However, these studies have a propensity to underestimate the effects the dam will have on the local communities or simply suggest displacing the local communities Darko et al. (2019). This thesis research will not only build a System Dynamics (SD) model that aims to give insight into how the construction and operation of the PMD will affect the riparian communities, but it will also try to quantify these effects. The modeling of the EBAs of the riparian communities, like flood-recession farming, is a complex task which has not been done often in studies on previously constructed dams. Therefore the aim is to model the effects the construction and operation of the PMD has on the EBAs of the riparian communities, in such a way that the model and approach can be applied to other future dam constructions.

System Dynamics approach

This research applies a System Dynamics approach to model the effects of the construction and operation of the PMD. System Dynamics does not only help quantifying the effects of the PMD but also makes it possible to add seasonality, which has not yet been possible in ordinary Environmental Impact Assessments eg: Volta River Authority (2014). This seasonality is an important part of the system as the EBAs of the riparian communities are heavily dependent on the seasonality of the river. Moreover the White Volta River system and all the dams operating on it are suitable for SD as there are multiple stock and flows within the system as well as feedback loops and delays Nabavi et al. (2017) as can be seen in figure 1 underneath.

Direction of Results

As this thesis research is still in the early stages and the SD model is still under construction, there are no final results just yet. However, from available literature and the current behaviour of the model preliminary results are available. The construction of the PMD will probably cause the base flow of the White Volta river to increase, which is what the Bagre Dam further upstream did too. Moreover, it will reduce the number of floods experienced by the riparian communities as the dam adds another buffer to the system. The presence of the PMD will also affect the filling of the riparian flood plains and ponds, which are used for farming and fishing, less water here could lead to less arable farmland and less fish, however how significant this effect will be can't be stated yet.

Nevertheless, it is already clear that policy makers will have to make trade-offs between electricity generation at the PMD and operating strategies that support the local communities more. This research hopes to find a dam operating strategy that would not only be a national but also a local success.

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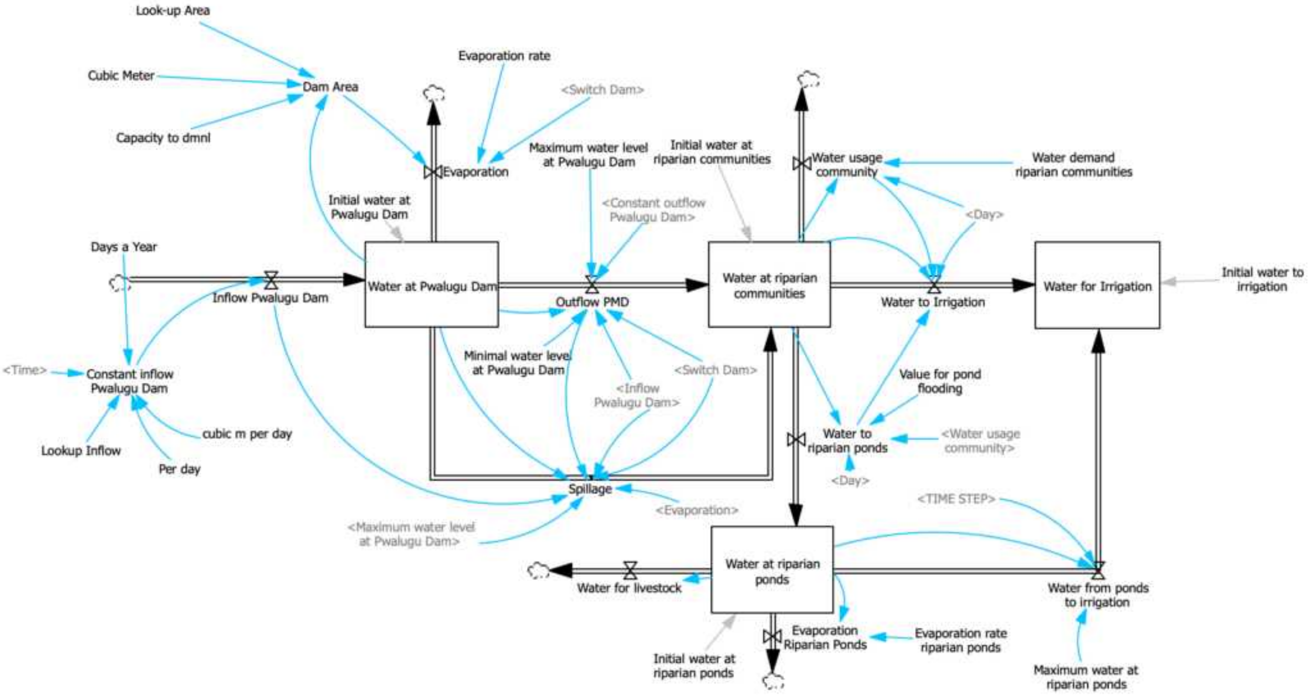

Figure 1: A simplified version of the System Dynamics model that will be constructed for this thesis research. It can be seen that water at the different locations can be considered stocks while the stocks are connected with flows which in this case is the White Volta River.

Water governance and management transition: An actor network analysis of stakeholders in the Irish Water sector.

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Keywords — Water governance, RBMP, Network analysis, Stakeholders, Republic of Ireland

Introduction

Water governance and management have undergone some changes in recent times to facilitate a more integrated national approach to protecting water resources in the Republic of Ireland (ROI). These changes are driven by a number of factors, such as the European Union (EU) Water Framework Directive (WFD, 2000/EC/60), which serves as the fundamental principle upon which European countries tailor their water governance strategies. An essential component of the WFD is River Basin Management Plan (RBMP), which details an integrated approach required to protect, improve and sustainably manage water resources in Europe. Climate change impact on water resources has also been a contributing factor. Although surface and underground waters in the Republic of Ireland (ROI) are among the best in Europe, shreds of **the** literature reveal that the ROI will feel the brunt of climate change across various sectors with water resource**s** at its core (Department of Culture Heritage and Gaeltacht, 2019; McElwain & Sweeney, 2003; MECLG, 2019; O'Driscoll et al., 2018).

Beyond the WFD directive and climate change, other factors that have also been contributing to changes in water governance and management in recent times are social demographic changes, population growth, and water conservation and consumption patterns coupled with water financing.

Seminal research has shown structural changes in governance and management of water resources in the ROI by implementing new programmes and institutions such as the Local Authority Waters Programme (LAWPRO), which engages with communities to initiate actions that promote water quality (LAWPRO, 2017). Other Institutions such as An Fórum Uisce|The Water Forum have also grown in stature, competence and capacity through continuous stakeholder engagement and contributions to the discussion on water policy at the national level (The Water Forum, 2018). There has also been significant catchment characterisation by the EPA catchment unit. The Agricultural Sustainability, Support and Advisory Programme (ASSAP) also supports the implementation of best practices at the farm level in 190 Priority Areas for Action aimed at addressing agricultural pressures on water (ASSAP, 2019). There also exist a broad spectrum of actors associated with water management and governance in the ROI through a three-tier governance structure that has been delivered (with amendment) through the RBMP. Despite these structural changes and progress made over time, ineffective communication among relevant stakeholders in the water sector and duplication of managerial roles and responsibilities have been hampering the water sector's effectiveness in governance and management (Antwi et al., 2021). This research aims to assess the level of influence among actors in water resource management in the ROI by taking into stock their interests, resources and means of engagement, and their trade-offs and conflicts. The research delves into how these elements contribute to the design, adoption and implementation of water legislation, especially under changing climate conditions.

Methodology

Stakeholder Interviews

The water sector in the ROI has many stakeholders from different domains. Through interviews and web-based questionnaires, identified stakeholders in the sector will also be engaged to discuss their alignments to water governance and management in the country. In total, 20 key stakeholder interviews will be conducted.

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Network Analysis
The research aims to assess the level of influence among actors in water resource management by taking into stock their interests, resources and means of engagement, and their trade-offs and conflicts. An actor-network analysis of stakeholders in the Irish Water sector will be used to achieve this. Network analysis has been deployed in various fields to facilitate and provide a deeper understanding of human actors in an essential sector like water (Vreudenhil et al.,2010). The actor-network analysis will be carried out from the results of the key stakeholder interviews and through a case study description in the Netherlands where water resources management has a high political and public profile.

As early-stage research, the crux of this abstract will be to solicit participants' lessons from diverse disciplines and their thought and perceptions on stakeholder engagement in water governance and management.

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Communicating water availability to improve awareness and implementation of water conservation: A study of the 2018 and 2020 drought events in the Republic of Ireland

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Keywords —Drought, water availability, water conservation, social media, newspaper, communication.

Introduction

The Republic of Ireland's climate is changing and this, combined with demographic change will affect the availability of water resources for critical use such as drinking water, both in terms of water quality and water availability. Improving public communication surrounding forecasting of groundwater and surface water variability at a regional scale has the potential to be used as a precursor for highlighting water conservation needs. Drought in the form of either socio-economic, meteorological, agricultural, or hydrological drought can concurrently grow to affect towns, regions, countries and even continents at different degree, time and spatial scale (King-Okumu, 2019; Murphy et al., 2020)

Historical reconstructions indicate that the Republic of Ireland (ROI) has experienced about 45 droughts since 1850. The summer of 2018, was recorded as the driest summer in the country for 56 years. On April 22nd 2020, Met Éireann declared drought in the ROI due to a combination of stress on available water resources and limited rainfall (Ryan & Grant, 2020).

The impact of the 2018 and 2020 droughts in the ROI and across many countries reveals the extent to which water availability and supply could be affected. It further highlighted the need to improve public communication surrounding forecasting of groundwater and surface water availability as a precursor in highlighting water conservation needs especially as water demand rises sometimes up to 30% during periods of drought in the ROI (Irish Water, 2020).

Improved public communication also carries the propensity to influence a positive public response to water conservation measures, increase trust between a water utility and the public, and help achieve sustainable drought policies (Tortajada & Nambiar, 2019).

Observations from data

The study used a mix method approach to explore the progress and challenges in communicating water availability in the Republic of Ireland (ROI) by reviewing the social media posts (i.e. Twitter and Facebook) of Irish Water and collating newspaper articles (Fig 1), comments from consumers and six key stakeholder interviews. The analysis of social media posts and news articles aimed to identify trends, frames, and communication styles, especially during periods of extreme weather conditions in the country (Culloty et al., 2019; Wagner & Payne, 2017).

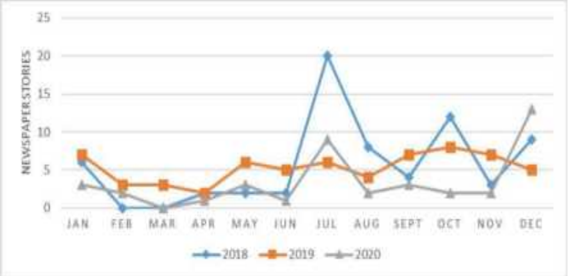

Fig 1: Newspapers coverage of research terms from 2018-2020 per month

We categorised all 172 newspapers articles under five frames (Fig 2). Uncertainty and risk emerged as the common frame under which droughts impact on water resources were covered by newspaper articles (41% of frames). Within this frame, drought impacts were presented as a threat to society with profound effects on citizens' wellbeing and health due to rising temperatures and risk associated with stormy conditions, heatwaves, and prolonged dryness. Although news publications under this frame also considered acute water supply and

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availability during periods of extreme conditions, the content avoided or rarely used words like water scarcity to discuss the long-term impact of drought on water resources

Sentiment analysis

The sentiments of 1,671 tweets by Irish Water were tested to gain insight into the nature, intensity and opinion of the public and how they act on communication received from the utility. The results of our sentiments score showed 63% (n=781) of Irish Water's tweets being generally positive, 16% (n=575) as negative, and 21% (n=375) neutral. The positive and neutral sentiments stemmed mainly from campaigns and initiatives that Irish Water was involved in to promote water quality and conservation measures, whiles the negative sentiments were detected to be mainly due to external factors like droughts and storms, which the utility has limited control over. Despite the positive sentiment, comments and reaction to conservation messages suggested disdain among Irish Water followers on Twitter (Table 3). The limited engagement between the utility and the public and the difficulties that exist in simplifying the highly technical and engineering nature of its work to the consumers, according to Irish Water accounts for the public's reaction towards its communication on social media (Irish Water, Pers. Comm).

The Irish Independent had the highest number (13) of stories on economic frame, whereas the Irish Times had fourteen under the eco-hydrological frame. The Irish Times reported under technical/policy frame with ten stories and the Irish Independent with six stories. Interestingly, the content of 23.13% (n=62) of all stories reported by Irish newspapers under the search terms were predominately outside the ROI. These stories focused on the impact of drought in countries like Kenya, Zimbabwe, the Sahel regions of Africa, flooding in Mozambique and bush fires in Australia and other environmental concerns in the USA. The RTE News carried the majority of these stories, but though such stories were filtered out (Appendix 1), the finding is consistent with a considerable body of literature that shows developed countries emphasise climate change impact in developing countries, rather than portraying the climate crises in their own locality (Tavares et al., 2020; Vu, Liu, & Tran, 2019).

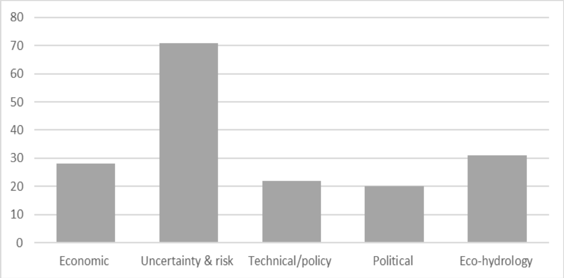

Fig 2: Coverage of drought under-identified frames

The study in brevity reveals that many of the foundations for real-time data and interactive river flow forecast systems are already in place in the ROI. Adding to effective drought preparedness through monitoring and early warning systems as found in parts of Central and Eastern European countries, the UK and the USA (Melvyn, 2019; Noel et al., 2020). It would be beneficial for the ROI to have a consolidated National Integrated Drought Information System (NIDIS) to coordinate, monitor, forecast and help plan and inform national, regional, and local levels of drought issues, while also serving the general public, stakeholders, policymakers and the media. This is increasingly important as climate projections indicates wetter winters and drier summers with a high probability of intense future drought events in the ROI (Murphy *et al.*, 2019; Cammalleri *et al.*, 2020). Such a NIDIS could be managed by the Environmental Protection Agency given their experience and vast data repository. It could also be accessible online, user-friendly and designed to provide actionable, shareable and easy to understand information and visuals/maps that highlight present and historical drought conditions across different parts of the country

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Session 5

River Restoration and Ecology

Migration of migratory fish species through shore channels along longitudinal training dams in the River Waal

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Keywords — downstream migration, NEDAP, stow net, upstream migration

Introduction

Several migratory fish species occur in the River Rhine. In spite of significant improvements of the river water quality and habitat rehabilitation, the recovery of their populations is lagging behind expectations. One of the causes is the closure of several river estuaries by storm surge dams, which has recently been partially reversed by 'opening' the Haringvliet sluice. However, numerous other limitations for fish migration remain. Moreover, migratory fish may be hit by the bow or propeller of inland navigation and stressed by ship induced changes in flow velocity during their up- or downstream migration (Collas et al. 2021). Particularly the river Waal and the river Rhine at Lobith experience a high navigation intensity and thereby are potential bottlenecks for the migration of migratory fish species.

Recently, three longitudinal training dams (LTDs) have been constructed in the river Waal, separating the river in a main channel for navigation (the fairway) and a shore channel that is largely void of the negative effects of navigation (e.g. wave action, underwater sound; Collas et al. 2020). These shore channels could provide a migration route free of navigation for both up- and downstream migrating fish. To assess the use of the shore channels as a migration route monitoring was performed using a stow net for the downstream migration and the NEDAP Trail System® for monitoring up- and downstream migration (Van de Ven & Vriese 2021).

Methods

Stow net fishing was performed in both the main channel and the shore channel at Dreumel of the river Waal (Collas et al., 2021). The technique is based on anchoring a boat in the flow after which a net is lowered into the water. Downstream migrating fish were collected. Stow net monitoring was performed in November 2018, May 2019, September 2019, October 2019, September 2020, October 2020 and April 2021. On average, every 2 hours and 15 minutes the net was retrieved and all fish in the net were collected, identified, measured and released. Subsequently, the CPUE (catch per unit effort; unit equals one haul) per migratory fish species was calculated and compared between the shore channel and the main channel.

NEDAP monitoring consisted of releasing fishes outfitted with a transponder. Subsequently, the fishes swam over detection cables placed in the river Rhine at various locations (REF) during their up- or downstream migration. Fish species tagged were Atlantic salmon (smolts and adults), eel, houting and sea trout. To assess the use of the shore channels as migratory route NEDAP data was used from four stations: Xanten, Wamel shore channel (left bank), Ophemert shore channel (right bank) and Brakel. Based on the ratio between the total amount of tagged fishes that passed upstream and downstream of the shore channels and through the shore channels, indices were developed for the use of the shore channels as migration routes.

Figure 1. Photo of eels caught in the LTD shore channel at Dreumel using stow net fishing.

Results and discussion

In total 10 downstream migrating fish species were detected in the shore channel during stow net monitoring (Table 1). Monitoring in the main channel yielded 6 migratory fish species. The CPUE was higher in the shore channel for 8 out of the 10 species detected during stow net fishing (Table 1). These results indicate that the shore channel is used by the majority of

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migratory fish species for downstream migration. Moreover, the higher CPUE combined with the fact that the shore channels have a discharge of around 10% of the river Waal imply that they might serve as a major downstream migratory refuge.

Only a few species were outfitted with a NEDAP transponder. Of the two species released with a transponder upstream of the shore channels, both the European eel and the Atlantic salmon smolts were found to migrate downstream through the shore channels. Species released downstream of the shore channels were found to migrate upstream through the shore channels (sea trout and houting). Interestingly, the houtings were found to aggregate in the shore channel of Ophemert (Hop & Van de Ven 2021), indicating spawning behaviour in that shore channel. Indeed, during seine net fishing in 2021 several juvenile houtings were caught in the shore channel supporting this hypothesis (Flores et al. 2021).

In addition to the 10 migratory fish species caught in the shore channel using the stow net and NEDAP monitoring an adult thicklip grey mullet (> 60 cm) was also caught in 2016. Overall, we can conclude that: 1) the shore channels are used for both down- and upstream migration of migratory fishes, and 2) some species appear to favour migration through the shore channels. Since the shore channels are void of commercial navigation, this offers the opportunity to set up a (semi) permanent monitoring program of migratory fish to improve our understanding of fish migration in multifunctional river systems.

Acknowledgements

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Table 1. Overview of migratory fish species caught or recorded in the shore channel during stow net fishing in comparison with records of the NEDAP monitoring system during 2018 - 2021.

	Stow net (CPUE)		NEDAP	
	Shore channel	Main channel	Shore channel	
Common name	Downstream	Downstream	Upstream	Downstream
European eel	0.58	0.22	n.t.	x
Sea trout	0.03	0.04	x	n.t.
European brook lamprey	n.d.	n.d.	n.t.	n.t.
thicklip grey mullet	n.d.	n.d.	n.t.	n.t.
Three-spined stickleback	1.33	0.47	n.t.	n.t.
Allis shad	0.07	n.d.	n.t.	n.t.
European sturgeon	n.d.	n.d.	n.t.	n.t.
Twaite shad	n.d.	n.d.	n.t.	n.t.
European/common Whitefish	n.d.	n.d.	n.t.	n.t.
Houting	0.08	n.d.	x	n.t.
River lamprey	0.65	0.21	n.t.	n.t.
European smelt	0.02	n.d.	n.t.	n.t.
Atlantic salmon	0.12	0.21	n.d.	x
Sea lamprey	0.05	0.01	n.t.	n.t.
Flounder	0.17	n.d.	n.t.	n.t.

X: fish species recorded; n.d.: not detected; n.t.: not tagged; CPUE: catch per unit effort (one haul)

Optimization of side channel reconnection measures at the Austrian Danube

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Keywords — River restoration, Hydrodynamics, Morphodynamics

Introduction

For a length of around 40 km, the Austrian part of the Danube River passes through a National Park located east of Vienna, with an alluvial forest that serves both as habitat for fauna and flora as well as an important recreation zone for humans. Originally an anabranching system (Hohensinner et al., 2004), river regulation dating back to the 1870s has cut off former side channels from the main river branch, which are nowadays often only connected for less than half a representative hydrological year. A major target of the long-term river management is therefore to reconnect the side channels at lower discharges to improve the overall ecological functioning of the river system. In the approximately 7 km long side channel system between the municipalities Haslau and Regelsbrunn, restoration measures conducted in the 1990s aimed at improving the flow conditions in the oxbows and increased the connection to over 200 days per year. However, sedimentation and morphodynamics processes caused the connection duration to drop again to 140 days today (via donau, 2021). The aim of the present study as part of a larger restoration project is to (i) optimize the reconnection measures to restore connectivity during most of the year, and (ii) identify design criteria that contribute to the long-term sustainability of such a side channel reconnection. This study is conducted based on numerical simulations.

Methods

Hydrodynamics and morphodynamics constitute the key parameters for assessing the general functionality and the sustainability of a reconnection measure. In this study, these were investigated using a modelling approach involving 3D hydrodynamics coupled with a sediment transport and morphodynamics model. Hydrodynamics were calculated using the three-dimensional numerical model RSim-3D (Tritthart, 2005) which solves the Reynolds-averaged Navier-Stokes equations on a mesh composed of arbitrary polyhedrons by means of the Finite Volume method. Details of the model are given in Tritthart and Gutknecht (2007). Sediment transport and morphodynamics were simulated using the integrated sediment transport model iSed (Tritthart et al., 2011) with both bedload and suspended load transport enabled. Bedload was calculated using a modified version of the equation by Meyer-Peter and Müller, accounting for non-uniform transport through a hiding-exposure correction.

Study site and measures

The side channel system Haslau-Regelsbrunn is located at the orographic right-hand side of the Austrian Danube between river-km 1902 and 1895. The inlet into the system is currently realized via two culverts that allow conveyance at elevated mean flow conditions (Figure 1, top). The planned restoration measures include removal of the two culvert structures, lowering of the inlet elevations and widening of the inlet areas (Figure 1, bottom). Moreover, the entrance to the side channel system is planned to be protected by an artificial gravel island structure towards the navigation fairway. While the main river branch is characterized by a gravel bed with mean diameters between 20 and 30 mm, sediments in the side channel system are mostly dominated by sand fractions, owing to the prevailing smaller flow velocities.

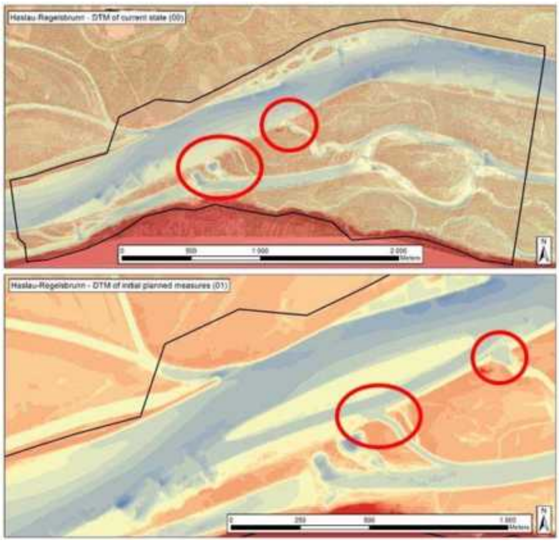

Figure 1. Digital terrain elevation model of the current status (top) and planned measures (bottom); circles indicate locations of inlet structures; flow direction is from left to right.

Following experience from side channel reconnection projects at other locations along the Austrian Danube River, during an optimization step smaller angles of the branch junction of less than 40° were tested as well as a variation of width and depth, resulting in a homogenized geometry of the entrance areas.

Results

Parameters investigated during the study were the discharge into the side channel system, flow velocities, bed shear stresses as well as volumes of sedimentation and erosion. All parameters were evaluated for three characteristic Danube discharges: (i) regulated low flow (94% probability of exceedance), (ii) mean flow, and (iii) highest navigable flow (1% probability of exceedance). Figure 2 exemplarily shows patterns of bed shear stresses for mean flow conditions. It is clearly visible that the projected variant features areas with very low bed shear stress conditions in both inlets, while the optimized variant shows a much smoother transition from the river into the side channel. This effect of the optimization is well discernible for the upstream inlet, however there is no visible change for the downstream inlet due to the low discharges present there. Optimization should therefore focus on the upstream inlet.

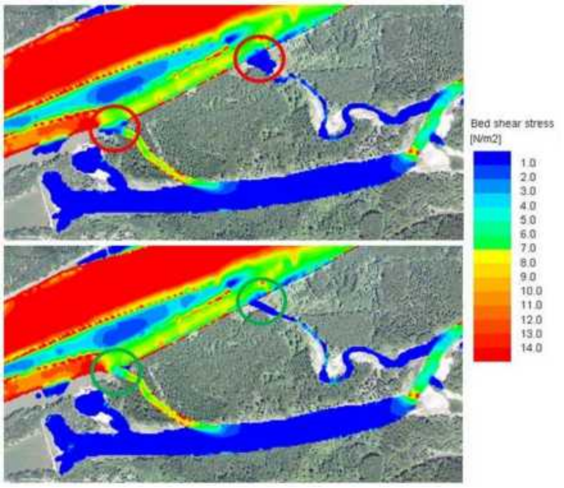

Figure 2. Comparison of simulated bed shear stress for mean flow; projected variant (top) and optimized variant (bottom); circles show locations of inlet structures.

A consequence of areas with low shear stresses is increased settling of suspended sediments, giving rise to clogging of the inlet over time. In contrast, the optimized variant shows a homogeneous distribution of velocity and shear stress at the inlet and also conveys slightly more water into the side channel. Thus, sediments are prevented from settling even under low flow conditions. This is evident from Figure 3, which shows the differences in sedimentation patterns between the two variants. Both directly at the inlet as well as further downstream in the side channel system, the difference map indicates up to 20 cm fewer sedimentation heights after a low flow period lasting through a month. While the sedimentation pattern directly at the entrance is influenced by the homogeneity (i.e., depth/width variation) of the cross-section, the processes further downstream are a function of the discharge through the system, which is higher upon implementing a smaller angle of the branch junction.

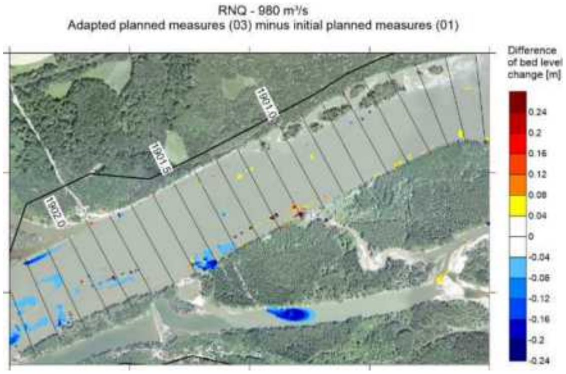

Figure 3. Differences in sedimentation patterns between projected variant and optimized variant after 30 days of regulated low flow.

Conclusions

It was found that a connection angle between main river branch and side channel entrance of less than 40° positively affects the inflowing discharge. Moreover, sedimentation in the side channel right downstream the junction was found to be smaller when the channel geometry was homogeneous, avoiding larger variations of width and depth. A side channel reconnection considering these constraints is therefore expected to exhibit improved long-term sustainability.

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Detection of macroplastics in riverine ecosystems using imaging sonars

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Keywords — ARIS sonar, plastic pollution, mesoplastic, side-scan sonar, rivers

Introduction

Globally, plastic pollution is a major problem with adverse effects for freshwater and marine ecosystems. Once plastic is produced and used on land, the majority of the discarded plastics end up in marine ecosystems via riverine transport (Schmidt et al., 2017). In rivers, plastics have been observed accumulating in sediments and vegetation of banks and floodplains, transported in the riverbed and floating or suspended in the water column (Schwarz et al., 2019). Currently, plastic monitoring in the water column of rivers is time consuming as it is done by collecting the plastics with nets, then sorting and counting it manually (Schmidt et al., 2017). Consequently, there is an increasing need for less labour intensive plastic monitoring in riverine ecosystems. Sonar technology offers an opportunity for off-site monitoring of plastics through the recording of data or remote monitoring via internet connection.

ARIS sonars are imaging multibeam sonars that emit a horizontal fan of high frequency (Megahertz) beams into the water column. The high frequencies allow continuous reflections to be received by the transducer and imaged in high resolution, capturing the shape, size, orientation and direction of travel of passing targets in turbid or low light settings.

A second promising imaging sonar technology for macroplastic detection is side-scan sonar (SSS). This technique consists of an oblique (>50º) transducer that emits and receives sound at an angle allowing for the imaging of the bottom in 2D along the horizontal plane. The technique has been previously used to map riverbeds. Compared to the ARIS sonar, some SSS are very low-cost (€2000-3000) as they are designed for sports fishing often combining SSS with CHIRP technology.

The aim of this pilot study is to determine whether 1) an ARIS sonar and a Lowrance SSS with CHIRP could detect macroplastics in the water column, and 2) the target reflections differ between various macroplastics. Macroplastics are defined as relatively large particles of plastic, typically > 0.5 cm.

Methods

ARIS Test in Standing Water

A semi-controlled test in standing water (flow velocity ~ 0 m/s) was completed as a first assessment of the reflections obtained by placing plastics within the beam fan of the ARIS sonar. On 16 April 2021, data were collected by submerging the ARIS sonar next to a dock in a floodplain lake in the Rosandepolder facility of Rijkswaterstaat (RWS; The Directorate-General for Public Works and Water Management) near Arnhem, the Netherlands (N51.978322, E5.867505). The sonar was mounted on a square metal frame that maintained the sonar off of the bottom while allowing to change the angle of the sensor as needed. For the test, 16 plastic pieces of different sizes were cut from recycled polyethylene terephthalate (rPET) clear-plastic cups (H = 10.5 cm and dia. = 6 cm) and polypropylene (PP) square white-plastic food containers (L = 17 cm, W = 12 cm and H = 8 cm). Detection of individual macroplastics using the ARIS sonar was completed while attached to a fishing line weighted with a stainless steel pin or a bow shackle. The area (pixels^2) and mean intensity (mean gray value) of the target reflections were measured using open-source ImageJ2 software (Rueden et al., 2017).

ARIS Test in Flowing Water

On 19 April 2021, flowing water data (flow velocities ~0.8 m/s) were collected using the ARIS sonar mounted in the square metal frame deployed in the littoral zone of a sheltered shore channel behind the longitudinal training dam in the river Waal near Dreumel, the Netherlands (N51.879571, E5.440354). This location was selected since it is void of the influence of passing inland navigation resulting in a more laminar flow pattern. A total of 27 macroplastics were released a few meters upstream from the sonar and allowed to be carried by the current to the sonar beam fan. The macroplastics used were retrieved from the river Waal during previous plastic monitoring (Collas et al., 2021).

ARIS Test in Standing Water

A semi-controlled test in standing water was completed on 19 November 2020 in the dock (water depth ~3.9 m) of the Rosandepolder RWS facility using a Lowrance unit. The

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transducer was pole mounted to a dock 20 cm below the water surface. Four macroplastics were used consisting of a polyethylene terephthalate (PET) 0.5 L water bottle, a polypropylene (PP) 150 g lunch meat packet, a low density polyethylene (LDPE) sanitary napkin wrapper and a small polypropylene (PP) cup. Each macroplastic object was prepared by attaching each to 1.2 m of weighted fishing line then leaving 1 m of fishing line between the object and a float (piece of wood) connected to a rope for towing. The objects were then introduced into the water and towed from a 5 m mark in front of the transducer to the starboard side at ranges equal to 0.2-1.2 m. The area (pixels^2) and mean intensity (mean gray value) of the target reflections were measured using open-source ImageJ2 software (Rueden et al., 2017).

Results and discussion

The ARIS sonar (Fig. 1) as well as a SSS (Fig. 2) 1) were able to detect macroplastics in the water column while tested in standing water, and 2) the resulting mean target reflections differed between the macroplastics tested. The ARIS sonar was also able to detect macroplastics in the water column of a river channel under flowing conditions.

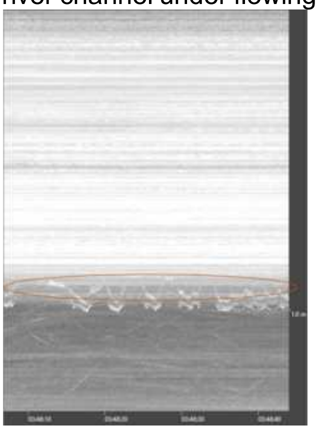

Figure 1. An ARIS echogram showing the return signal of a 1 cm^2 plastic object seen at ~1 m distance from the sonar unit. The return signal of the weight used is visible below

The ARIS sonar and the SSS were able to detect 100% of the objects tested in standing water. Under flowing field conditions up to ~0.8 m/s, the ARIS sonar was able to detect 67% of the objects tested, which consisted of actual plastic litter collected during plastic monitoring campaigns. The ARIS sonar was more effective at detecting objects in standing water as it was able to detect clear and opaque plastics, with targets as small as 1 cm^2. This sonar is promising for the detection, identification and counting of macroplastics including their shape, size, orientation, direction of travel and 2D horizontal location in the water column. The use of a second ARIS sonar could help to provide 3D images of macroplastics simultaneously providing their depth in the water column (Jing et al., 2018). The SSS with CHIRP sonar is a low-cost option for plastic detection and monitoring which may be mounted on a boat or used from a static position. This sonar provided the 3D location of targets, but it provided less detailed lower resolution images than the ARIS sonar.

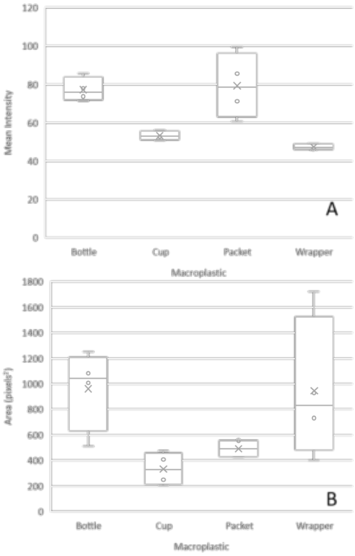

Figure 2. Box plots of (A) the mean intensity and (B) the area of the macroplastic (n = 4) reflections from the SSS images as detected in standing water. The center lines represent the median values, the edges of the boxes the first and third quartiles, the whiskers the minimum and maximum, and the points the underlying data

Acknowledgements

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The role of habitat heterogeneity as driver for diversity and abundances of young-of-the-year riverine fishes

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Keywords — Biodiversity, lateral connectivity, nursery habitat, river restoration

Introduction

To improve recruitment success and biodiversity of riverine fish in the lower river Rhine, authorities in the Netherlands have reconstructed numerous floodplains since the 1990s.This resulted in local habitat of increased quality, but not in the expected increase in diversity and abundance of riverine fishes. The lack of substantial improvement of the riverine fish community may be caused by a mismatch in the spatial configuration of nursery habitats in the reconstructed floodplains, as compared to the historical, natural floodplains (Stoffers et al., 2021). Nursery habitat conditions are directly influenced by hydromorphological (e.g.: water flow, substratum type) and biotic variables (e.g.: food availability, chlorophyll), as well as by water quality parameters (e.g.: conductivity, turbidity). The proper scale and spatial organisation (habitat heterogeneity) of essential habitats at these early life stages contributes greatly to the their survival (Van Looy et al., 2019; Ward et al., 1999). The objectives of this study were to (1) evaluate the functioning of different types of floodplain restoration projects as nursery area for the riverine fish community, and (2) identify the most important nursery habitat components, including the role of habitat heterogeneity.

Methods

From 2017-2020, we collected a detailed data set on YOY riverine fish communities and their physical habitat preferences in 46 floodplain restoration projects in 3 branches of the lower river Rhine (the Netherlands), as well as in 26 control sites in the main channel (1253 sampling sites in total). We evaluated the nursery function of isolated waters, tidal channels, one-sided connected channels (1SC) and two-sided connected channels (2SC). Fish communities were assessed as a whole (including all species), and as rheophilic, eurytopic and limnophilic fish community. Communities were assessed by abundances (fish per 100m2), and species richness (diversity at restoration project level). We characterised habitat variables on three relevant spatial scales for YOY fish: sample level (~0.1 km), project level (~1.0 km) and river level (~10 km). Many of the 42 habitat variables were measured during field sampling, while floodplain channel metrics and data on habitat heterogeneity was retrieved from satellite images and aerial photographs taken annually. We used multivariate analysis (RDA: Redundancy Analysis) with a stepwise modelling approach to identify the most important nursery habitat components for rheophilic, eurytopic and limnophilic fish abundances (Figure 1).

Results and discussion

Highest abundances of YOY fish were found in 1SCs (293.3±99.9 fish per 100m2), followed by 2SC (133.6±37.4). For respectively the main channel and tidal channels we recorded mean abundances that were 11 to 18 times lower than for 1SC. Species richness was highest for 2SC (15.9±0.8 species per project) and 1SC (14.5±0.7), whereas diversity was significantly lower for tidal channels, isolated waters, and the main channel.

For common eurytopic species such as roach (*Rutilus rutilus*), perch (*Perca fluviatilis*) and bream (*Abramis brama*) we observed similar patterns in community

Table 1. Overview of fish community responses. Fish responses are shown as mean ± se fish per 100m^2. Means were tested for significance with a Kruskal–Wallis H-test. Dunn's test with Bonferroni correction was used for pairwise comparison between project types.

		Control	Restoration project type			
		Main channel (N=39)	**Isolated water** (N=11)	**Tidal channel** (N=18)	**1SC** (N=53)	**2SC** (N=61)
Ecological guild	**Fish response**					
Fish community	Abundances	24.5 ± 7.9^{b}	114.6 ± 42.3^{b}	16.4 ± 6.2^{b}	293.3 ± 99.9^{a}	133.6 ± 37.4^{a}
	Species richness	7.9 ± 0.8^{b}	7.4 ± 1.4^{b}	9.3 ± 1.0^{b}	14.5 ± 0.7^{a}	15.9 ± 0.8^{a}
Eurytopics	Abundances	21.2 ± 8.1^{c}	52.8 ± 15.9^{bc}	15.4 ± 6.1^{c}	277.6 ± 97.6^{a}	111.1 ± 32.4^{ab}
	Species richness	4.8 ± 0.6^{b}	5.4 ± 1.3^{b}	6.5 ± 0.4^{b}	9.1 ± 0.4^{a}	8.9 ± 0.4^{a}
Rheophilics	Abundances	3.2 ± 1.0^{b}	0.0 ± 0.0^{c}	1.0 ± 0.1^{bc}	7.8 ± 2.1^{ab}	12.8 ± 2.4^{a}
	Species richness	2.4 ± 0.2^{bc}	0.4 ± 0.4^{c}	2.3 ± 0.3^{bc}	2.4 ± 0.3^{b}	4.6 ± 0.4^{a}
Limnophilics	Abundances	0.0 ± 0.0^{b}	61.8 ± 44.7^{a}		8.0 ± 7.6^{a}	9.7 ± 9.5^{ab}
	Species richness	0.1 ± 0.1^{b}	1.4 ± 0.4^{a}		1.2 ± 0.3^{a}	0.67 ± 0.20^{ab}

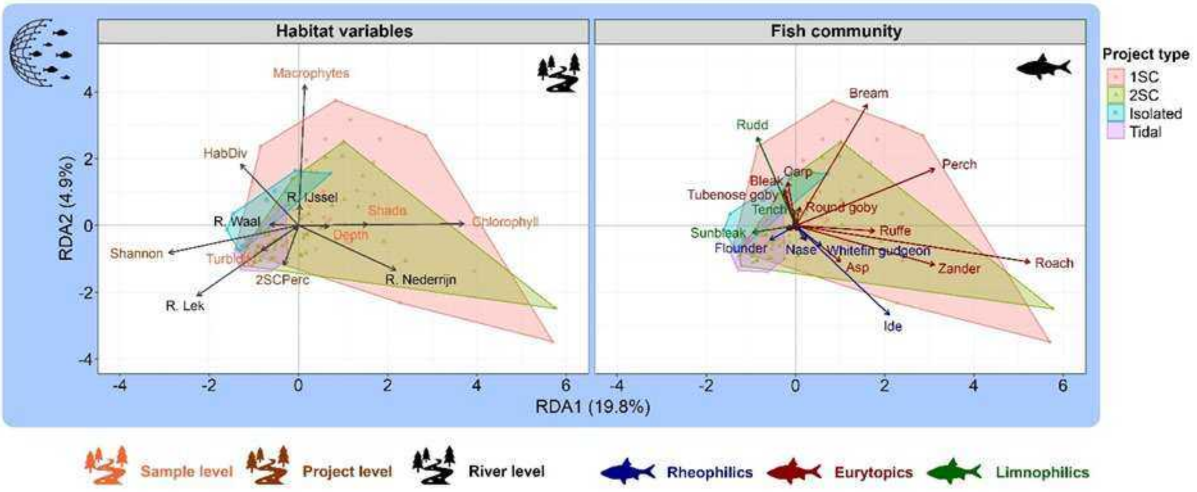

Figure 1. Redundancy Analysis (RDA) for YOY fish abundances (right panel) in 1SC and 2SC in relation to habitat variables (left panel) on different spatial scales in restoration projects of the lower river Rhine.

responses between the different restoration project types, as for the overall fish community. Both abundances and species richness of rheophilic species, such as ide (*Leuciscus idus*), nase (*Chondrostoma nasus*), and barbel (*Barbus barbus*), were significantly higher for 2SC than for other project types. In contrast to the other ecological guilds, rheophilic species richness for sites in the main channel was not significantly different from 1SC. Rheophilics were least observed (or even absent) in isolated waters, whereas both abundances and species richness of the YOY limnophilic fish community was highest for this restoration project type. Overall, with highest levels of YOY fish abundances and species richness, 1SC and 2SC provide best nursery conditions for YOY fish from all studied restoration project types. 1SC and 2SC primarily differ in flow conditions and therefore in the presence of habitats with permanent water flow and larger substrates, which may be the reason why more critical rheophilic (flow-loving) fish prefer 2SC over 1SC.

Abundances of YOY fish were most explained by 10 habitat variables (Figure 1; left panel). On sample level water depth, presence of macrophytes, chlorophyll and turbidity levels of the water, and shade were important. On project level the frequency of two-sided connectivity (2SCPerc), the Shannon habitat diversity index (Shannon), and shoreline habitat heterogeneity (HabDiv) were important. Eurytopics were more abundant in habitats with high levels of chlorophyll, shade and in the rivers Nederrijn and IJssel (Figure 1; right panel). The eurytopic species bream, common carp (*Cyprinus carpio)*, and bleak (*Alburnus alburnus*) and the limnophilic species rudd (*Scardinius erythrophthalmus*) were positively affected by the presence of macrophytes and high levels of habitat heterogeneity. On the other hand, abundances of rheophilic species nase, ide and whitefin gudgeon (*Romanogobio belingi*) were negatively affected by habitat heterogeneity. Rheophilic fishes mainly prefer habitats/projects with a high frequency of two-sided connectivity.

The role of spatial habitat heterogeneity in nursery habitat of riverine fishes is therefore ambiguous. Increased levels of shoreline habitat diversity and the Shannon index had a positive effect on abundances of many eurytopic and limnophilic species, whereas most rheophilic species were negatively affected by habitat diversity. For abundances of rheophilic to increase, first habitat conditions on a higher spatial scale (project level), such as permanent two-sided connectivity with the main channel, should be in order. If this criteria is not met, rheophilic fish abundances will be low or even non-existent. Eurytopic fishes show a high preference for a wide range of habitat variables on the smallest spatial scale (sample level), which probably explains their overall dominance in YOY fish communities in Dutch floodplain restoration projects. For the effective management and evaluation of floodplain restoration projects it is essential to take different spatial scales into account, as different components of the YOY riverine fish community may respond differently to habitat variables on different scales.

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The use of UV traps to monitor mayflies, stoneflies and caddisflies along the river Waal

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Keywords — Ephemeroptera, light trap, Plecoptera, Trichoptera, wave action

Introduction

Ephemeroptera (mayflies), Trichoptera (caddisflies and Plecoptera (stoneflies) (EPT species) are widely used as indicator species for the water quality of flowing water bodies. Many EPT species are susceptible to pollution and prefer specific habitats. Consequently these insect orders are often among the first groups impacted by human activity. Extensive pollution in the last century caused many EPT species to decline in the Dutch rivers and some species to go extinct. All three species groups are characterized by a free flying adult phase followed by an aquatic juvenile phase which can last several years depending on the species. To complete their life cycle the fully grown juveniles emerge from the water to become adults. During emergence the presence of human induced wave action (e.g. by recreational and commercial inland navigation) could negatively impact emergence success and thereby the long-term population viability of EPTs. Moreover, high hydrodynamics may render larval habitats unsuitable as many species prefer depositional habitats.

In a sheltered river channel behind recently constructed longitudinal training dams (LTDs) several juveniles of mayflies were found during macroinvertebrate monitoring (Collas et al. 2020; Flores and Collas 2021), whereas none were found in more hydrodynamic groyne fields. Here we ask whether this finding can be generalized such that sheltered habitats, such as LTDs, provide better abiotic conditions for juvniles and emergence conditions for adults of EPT species.

The patchy occurrence of EPT juveniles would require extensive, costly monitoring through macroinvertebrate sampling. Fortunately, there is an alternative monitoring for adult EPT species, which is based on the attraction of adults to ultraviolet light (UV) sources.

Recently, LED-based UV traps were developed and used to monitor EPTs (Price & Baker, 2016). Due to their low costs and low weight these traps could provide an important monitoring method for EPTs along the Dutch River Rhine and Meuse. Therefore, with the help of volunteers, a weekly monitoring campaign of adult EPTs was performed using the LED-based UV traps from June to august in 2020.

Methods

LED-based UV traps were constructed according to Price & Baker (2016; Fig. 1). The traps consist of a UV light placed upside down above a tray filled with water. Half an hour after dusk the UV light was activated automatically by a light sensor and adult insects were attracted to the light. When the insects landed on the water, they couldn’t escape as the water contained a cleaning detergent that reduced the surface tension.

Figure 1. Photo of one of the LED-based UV light traps along the LTD shore channel.

Weekly monitoring was performed from the 1st of June 2020 until the 31st of August in 2020, by volunteers that lived near the sampling location. Each trap was operated for approximately two hours after which any organisms present in the trays were collected by sieving the sample and storing it in 95% ethanol. Two locations were included in the monitoring: 1) the shore zone of the LTD at Dreumel (N51.861325, E5.422457) and 2) at a floodplain lake called the Vonkerplas (N51.860849, E5.424921).

After collection, the samples were sorted through under a microscope separating the organisms into mayflies, caddisflies and other insects. No stoneflies were collected. Hereafter, the caddisflies were sent to David Tempelman and Maria Sanabria (Stichting Semblis) for

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species identification. Mayflies were mainly identified to species level.

Results and discussion

The LED-based UV light traps were able to catch mayflies and caddisflies during the entire study period. In total 3560 adult EPTs were caught, of which 30% were caddisflies and 70% were mayflies. The mayfly *Ephoron virgo* was predominantly caught at the shore channel whereas the Caenidae were predominantly found in the floodplain lake. 96% of all caddisflies were found at the floodplain lake. A total of 16 caddisfly species were found of which 5 were unique to the floodplain lake and 2 to the shore channel. One rare species was found both at the floodplain lake and shore channel being *Hydropsyche bulgaromanorum*. Catches of mayflies and caddisflies in the shore channel were highest from half of July until half of August (Fig 2A). In the floodplain lake caddisflies were also caught early in June and Caenidae at the end of August (Fig 2B).

The successful collection of both adult mayflies and caddisflies shows that the LED-based UV light traps can be used as a cost effective alternative to monitoring EPT species in the river floodplain. The low costs of the light trap and easy set-up (less than €100) open up the possibility for elaborate and intensive monitoring of EPTs along the Rhine and Meuse. Having more information on the presence of EPTs could subsequently aid in improving the water framework directive (WFD) ecological water quality scores since the presence of EPTs species greatly affects the score assigned.

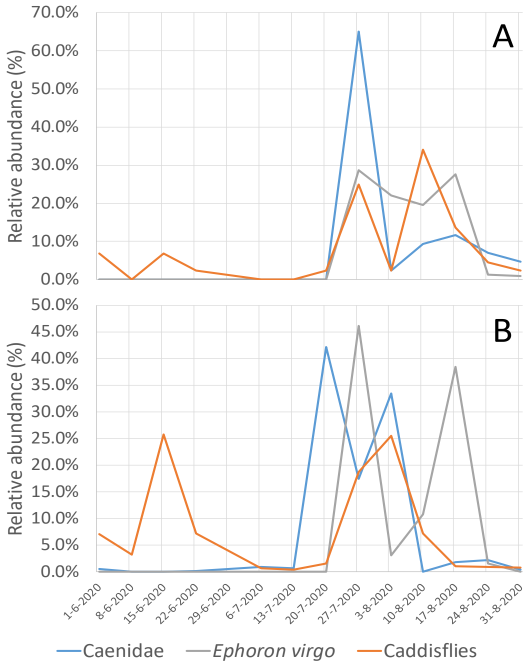

Figure 2. Relative abundance of mayflies and caddisflies along the shore channel (A) and near a floodplain lake (B).

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Exploring natural vegetation flow resistance for large-scale simulation of Dutch rivers

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Keywords — Vegetation roughness, Leaf Area Index, Remote sensing, Numerical simulation

Introduction

Riparian vegetation naturally grows on floodplains and areas surrounding fluvial channels. During floods, these plants interact with the flow of water and sediment. In many modern river systems this only occurs at relatively high discharge due to normalization works, which leads to a so-called disconnect between floodplains and a single main channel. Furthermore, in Dutch river systems the floodplains tend to be relatively narrow with high dikes. Therefore, vegetation in floodplains generally represents the most sensitive and uncertain parameter in flood modelling (Berends et al., 2019, among others).

Vegetation resistance

In the last decades, various formulations were developed to model the additional drag - and therefore overall flow resistance - exerted by vegetation on flow. Important physical phenomena modelled by these formulas are the influence of blockage (density of vegetation), the ratio between plant height and water depth (i.e., emergent or submerged plants) and the flexibility of the plants (i.e., flexible or rigid stems). It - and many other comparable formulas - were developed for vegetation that does not transform under flow, i.e. the so-call 'rigid stick approximation'. Among these, the well-known model of Baptist et al. (2007) is a two-stage equation that accounts for both emergent and submerged conditions. Conversely, the relationship proposed by Västilä & Järvelä (2014) considers flexibility of both stems and foliage, and vegetation is characterised by species-specific parameters and a density-specific parameter (namely, the Leaf Area Index, LAI). It is worth mentioning that Västilä & Järvelä's formula collapses to Baptist et al.'s for winter properties of vegetation (e.g., no foliage) and mature plants (i.e., negligible flexibility). Yet, while this formula was tested on lab experiments with good agreement for various species and submergence ratios and show an interesting perspective for seasonal variation in vegetation properties, it was never tested in real river and does not offer a two-stage flow out of the box, i.e. it is not a ready-made alternative to Baptist-like formulas.

Figure 1: A high-stage event of the Meuse River inundated floodplains and riparian areas.

Objective

In this work we implement the Västilä & Järvelä's formula in an experimental branch of D-Flow Flexible Mesh, using a modified Baptist two-stage formula to account for submerged flow conditions. We explore the potential application of the Västilä & Järvelä's formulation to the modeling of fluvial hydrodynamics at a large spatial-scale ($\sim$ 50-200 km), with particular focus on the Meuse floods of 2021, (figure 1). We also investigate whether LAI is overall smoother/rougher than the Baptist et al.'s roughness estimator listed in lookup tables (Van Velzen et al., 2003, e.g.,).

Approach

Species-specific parameters

The species-specific parameters are related to the reconfiguration of stem and leaves. They are determined using standardized lab experiments and reported in literature. In Dutch practice, land-cover maps (ecotope maps) are available in government databases (i.e. Baseline). These ecotopes are generally not single-species, but encode a certain heterogeneous type of vegetation (Van

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Velzen et al., 2003). Current automated classification using machine learning algorithmes (e.g., `https://vegetatiemonitor.netlify.app/#/veld`) also classifies heteregeneous types instead of single species. Therefore, for large scale application it seems necessary to develop a database for standardized ecotopes, either by mapping from available single-species parameters or by conducting new experiments. In any case, the sensitivity to uncertainty in these parameters on resulting flow resistance should be investigated.

Density-specific parameter

For the density-specific parameter good results were reported using the Leaf Area Index (LAI) as proxy for vegetation density. To this purpose, we explore the use of satellite-based maps (Sentinel) captured in the red and near-infrared frequency bands. These bands allow to characterize the presence of vegetation in terms of the Normalized Difference Vegetation Index (NDVI). This methodology has been commonly applied to the monitoring and management of forests and riparian areas (e.g., Nagler et al., 2004; Ricci et al., 2019) but seldom employed to define vegetation properties for hydraulic modeling (Lama et al., 2021). Different relationships are taken into account to calculate the LAI based on NDVI values (e.g., De Jong, 1994). As an example, we here report the equation proposed by Campbell & Norman (1998):

$$LAI = 1.2 \log \left(\frac{NDVI_{max} - NDVI_{min}}{NDVI_{max} - NDVI} \right) \tag{1}$$

where NDVI$_{max}$ and NDVI$_{min}$ are the 97th and the 3th percentile of the NDVI distribution, respectively. For the sake of validation, calculated values should be compared to available field measurements.

Application to practice

Species-specific parameters generally take the form of land-use polygons in GIS systems, both from human or machine classification. On the other hand, density-specific parameters, derived from satellite imagery, tend to be raster-based. A practical challenge exists in combining these two forms of data sources in a single robust framework for vegetation modelling.

Conclusions and future work

We explored the data requirements for the use of the novel implementation of the Västilä & Järvelä's formula in D-Flow Flexible Mesh. We identified three challenges: (1) mapping species-specific parameters to heterogeneous vegetation types, (2) validating satellite-based LAI maps and (3) combining raster-based information with vector-based land-use maps.

Future work will focus on these three challenges to develop a first procedure for large-scale application of vegetation formulas that take into account flexibility in numerical models. In this exploration, we focused on the practical application of a well-validated formula. However, it should be noted that, while direct validation is impossible due to the currently available data and techniques, validation of practical application would still be necessary. In this regards, validation-by-proxy (e.g., trough testing of seasonal stationarity of model error) looks an attractive alternative.

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Variability and dynamics of riverbank litter in groyne fields

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Keywords — Hydrology, Plastic, Monitoring, Groyne field

Introduction

As the use of plastics increases globally, concerns have been raised on the negative environmental impacts caused by accumulation of plastics in terrestrial and aquatic ecosystems. Entanglement and suffocation of wildlife are direct consequences of plastic debris in nature. Additionally, plastic litter can carry persistent organic pollutants, non-indigenous species and harmful algae (Barnes et al. 2009).

Rivers have been hypothesised as pathways for plastics from land to ocean. However, new studies suggest that the majority of riverine plastics never reach the ocean (Tramoy et al. 2020, Newbould et al. 2021). The concept of rivers as plastic reservoirs, as introduced by Van Emmerik et al. (2022), states that under regular hydrometeorological conditions, plastics are retained in various river compartments.

A better understanding of the factors that determine plastic accumulation along rivers is necessary to design efficient clean-up strategies. Monitoring and data acquisition is key in this process. This study is the first effort in monitoring individual riverbank plastics at a single location with high temporal and spatial frequency By counting, identifying and localising every single item in a groyne field at the Waal weekly for over three months, data on the transfer dynamics and the spatiotemporal variation of riverbank debris is collected.

Method

Monitoring is done in a single groyne field at the Waal near Winssen. The site was selected based on two characteristics:

1. The location was remote and rarely visited. minimising human interference
2. Plastic litter was present prior to monitoring

The site was visited 21 times (no measurements carried out when area was flooded) from November 2021 to January 2022. The groyne field area is approximately 200 meters long and 50 meters wide. The surrounding floodplain was not surveyed. Monitoring was done by measuring the location of every litter item using RTK GPS while also making photographs with a smartphone. The shoreline was also measured along the maximum wave reach. RTK GPS registers coordinates with centimetre accuracy. Items are categorised using the river OSPAR method.

Subsequently, an exploratory data analysis was performed focusing on the quantity and behaviour of plastic items with regards to hydrometeorological variables.

Results and Discussion

During the period of November 2021 to January 2022 the water level fluctuated between 3.7m NAP and 8.7m NAP. Two distinct hydrograph peaks could be identified. During the second peak, the groynes were submerged and the lower parts of the floodplain were inundated.

The amount of items found at the riverbank varied between 6 and 578. Figure 1 depicts *N* items interpolated over time. High water levels decreases the survey area but doesn't necessarily decrease the amount of items.

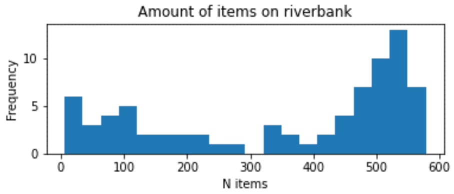

Figure 1: Histogram of number of items at riverbank

Notable is that 70% of the items found were wet wipes. The remaining 30% of the items were evenly distributed among various OSPAR categories.

During fieldwork it was observed that wind played a limiting factor in mobilisation of items on the riverbank. Only 3 mobilisation events were caused by wind (water caused 2,651 mobilisations). Wind mainly caused items to get covered in sand.

Movement of litter occurs primarily near the shoreline. A consistent spatial pattern could be identified in which items tend to accumulate in the floodmark zone (*see figure 2*).

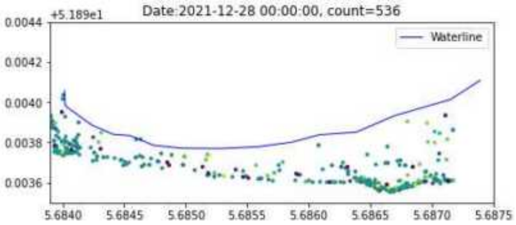

Figure 2: Top view of item location with respect to the shoreline. Colours depict OSPAR categories.

The vertical distance of items washing ashore with respect to the shoreline is normally distributed with a mode of 11.3 cm (STD: 7.7 cm) during rising water levels and a mode of 20.2 cm (STD: 15.1 cm) during dropping water levels.

Item fluxes (N_{in}, N_{out}) are estimated by counting the difference in item quantity per category. This method may slightly underestimate both fluxes, as exchange of items within one category is not taken into account.

The cumulative distribution of the item fluxes (figure 3) shows that the incoming flux is quite consistent. The magnitude of the outgoing flux is much more variable and seems to coincide with increasing water levels.

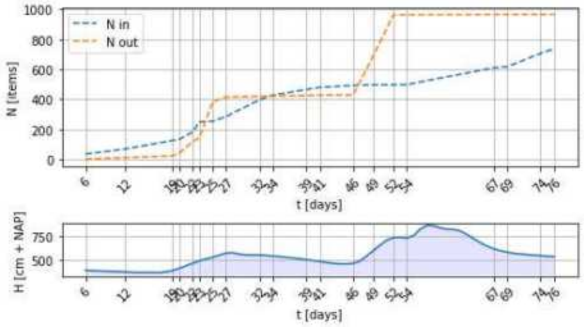

Figure 3: Cumulative representation of fluxes (top) and recorded water level (bottom)

The outgoing flux is strongly correlated with the rising limb steepness of the hydrograph. Figure 4 shows a positive linear relationship between N_{out} and dH. N_{in} seems to be less correlated with change in water level.

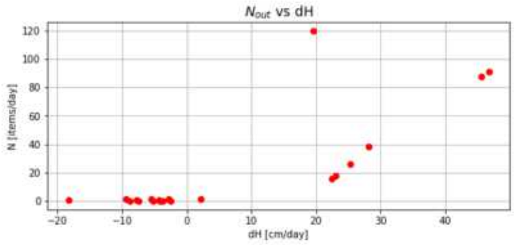

Figure 4: Outgoing flux (daily) vs. change in water level (daily)

A possible correlation with Northern wind (directed towards the riverbank) and incoming flux could not be found as Northern wind occurred rarely. Many items remained within the study area throughout the monitoring period. Items that washed away often reappeared at the riverbank one to two weeks later. This indicates that groyne fields may act as a trap for litter. It is hypothesized that suspended items remain within the groyne field for several days or weeks until discharge is high enough for the groynes to become submerged. Then, items flow downstream. This is supported by the amount of tagged items found during the monitoring period after hydrograph peaks (*see figure 5*).

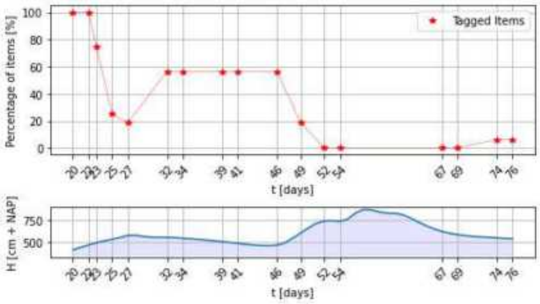

Figure 5: Number of tagged items (top) and water level (bottom)

Remarks

As the study is ongoing, definitive conclusions are not available yet. Preliminary results show that water level fluctuations play an important role in the amount of litter found at riverbanks. The data also suggest that groyne fields can act as a trap for (non-floating) litter as redeposition of particular items has been observed frequently. Items are more likely to leave the groyne field and travel further downstream during flood events.

The behaviour of litter fluxes is characteristic only for the particular groyne field included in this study. Further research should be conducted to whether similar behaviour litter with respect to water level changes is found in other areas. Combining such data with data on floating and submerged litter flows will drastically improve current understanding on riverine plastic pollution and helps coordinating clean up initiatives or finding possible pollution sources.

Data visualisations

Additionally, moving images of item distribution in the groyne field are available online. These visualisations are more descriptive than words. Please use the QR codes below:

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Exploring the relationship between eDNA and eRNA to advance biomonitoring techniques in rivers

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Keywords — eDNA, eRNA, river restoration, biomonitoring

Introduction

Freshwater ecosystems around the world are vulnerable to a number of increasingly present stressors: climate change, overexploitation, invasive species, and pollution. As such, restoration campaigns will be launched to meet targets proposed by the '2030 EU Biodiversity Strategy' in the near future (Cortina-Segarra et al., 2021). This emphasizes the need for new rapid biomonitoring techniques to register the impact of those campaigns. A particularly promising novel biomonitoring technique makes use of environmental DNA (eDNA): genetic material released by organisms in various forms (e.g. faeces, shed tissue, mucous) into their environment. Due to the persistence of DNA in aquatic environments, it can be captured by collecting water samples (in volumes of 250-1000 ml) and subsequently filtering them (through filter pores of sizes typically ranging between 0.2-1.0 µm). The application of eDNA surveys have proven to be more rapid and less dependent on taxonomic expertise than traditional monitoring methods (Ji et al., 2013), while also broadening the scope of biodiversity surveys (both taxonomically and spatio-temporally). More specifically by sampling eDNA, microscopic taxa that are indicative for the state of ecosystems, i.e. bacteria and phytoplankton, can now be assessed alongside influential macroscopic taxa, i.e. fish and invertebrates. However, a significant concern when utilizing eDNA is the detection of absent species (i.e. false-positive detection) caused by the detection of older (potentially resuspended) DNA. This study aims to reduce false-positive detection rates by quantifying both DNA and RNA.

DNA versus RNA

DNA and RNA are both polymers found in organismal cells. Their structural differences (e.g. DNA consists of two complementary genetic strands whereas RNA consists of one strand) and functional differences (e.g. the storage of information by DNA, and the control on gene expression by RNA), however, allow for the fulfilment of various key cellular functions. As of yet, most genetic biomonitoring studies have focussed on the analysis of DNA while neglecting the analysis of its derivative RNA. Comparatively, shed RNA in the environment is detectable for significantly shorter periods of time compared to DNA (Fig. 1). However, the isolated analysis of DNA introduces a number of challenges, for instance: the observed variable persistence of eDNA in aquatic ecosystems is ill-defined and the capture of legacy eDNA may lead to the false-positive detection of species (Laroche et al., 2017). To address this issue, Marshall et al. (2021) proposed the quantification of both DNA and RNA. They demonstrated that the ratio of RNA to DNA decreased significantly throughout the degradation process. This is important as the supplementary quantification of eRNA may provide estimates for the age of genetic material, thereby strengthening the application of eDNA methods. In their experiment, Marshall et al. (2021) used a static volume of water whereof only surface water was sampled. Although their results seem promising, questions remain on the relationship between RNA and DNA. For

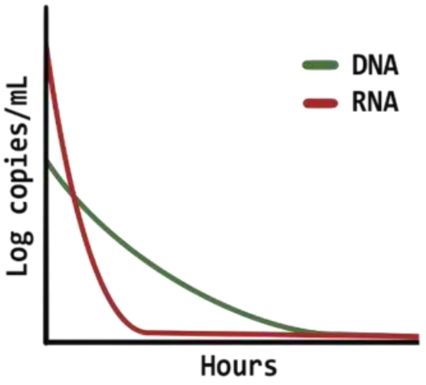

Figure 1. Schematic illustration of (e)DNA and (e)RNA concentrations (in log copies of DNA or RNA sequences per ml) degrading variably through time after release by its source organism.

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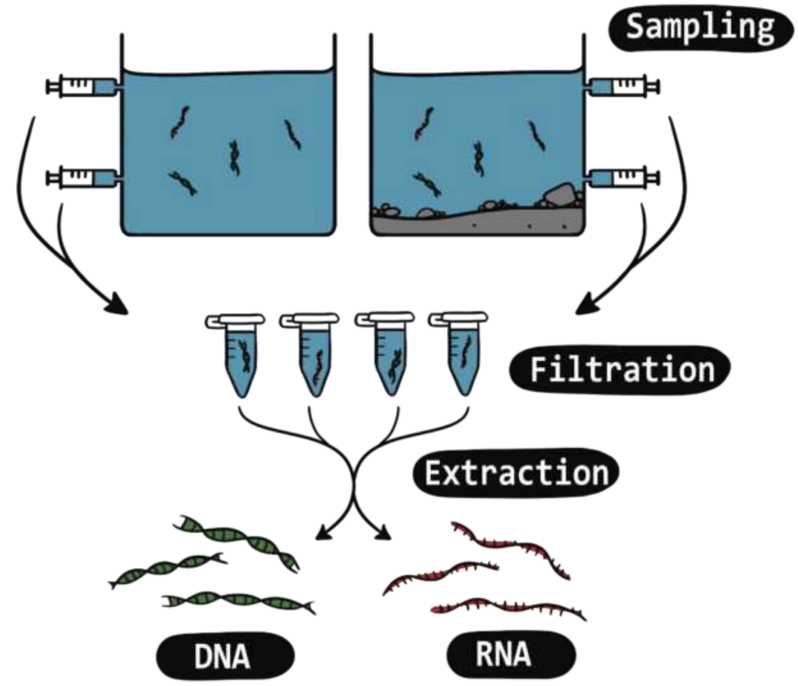

Figure 2. Schematic illustration of an experimental setup and workflow, wherein (1) water samples are taken at various depths in experimental water tanks, (2) samples are filtered and (3) extractions are performed to separately target DNA and RNA.

instance: is the ratio of RNA to DNA comparable at variable depths? How does the presence of sediment influence the ratio of RNA to DNA?

Advancing eDNA

We propose to quantitatively monitor the relationship between RNA and DNA at various depths and intervals in an experimental water volume (Fig. 2), to assess whether this relationship is reliably observable under variable circumstances. If so, false positive detection rates may be reduced, thereby advancing the application of eDNA-based methods. Since the presence of a sediment layer demonstrably changes the detectability of eDNA (Stoeckle et al., 2017), it will be accounted for in our proposed experimental setup. After sampling, filtration of genetic material is swiftly performed on-site to reduce degradation of eDNA and eRNA. Filtered samples are split in two, after which DNA is extracted from one half and RNA is extracted from the other half (Fig. 2). Depending on the targeted species (e.g., a species of fish), relevant genetic markers are selected. Subsequently, DNA and RNA concentrations are measured using quantitative polymerase chain reaction (i.e. qPCR) methods as described by Marshall et al. (2021). Challenges for this experiment arise in the design of an experimental facility that eliminates disturbances (e.g. during sampling) to the volume of water, while meeting microbiological requirements (sterility and reduced odds of contamination).

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Anthropogenic drivers of river levee heterogeneity: present and past interventions

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Keywords —river bank, morphology, antropogenic impacts

Introduction

River corridors are highly dynamic environments shaped by river flow variability and human-river interaction. The recent replacement of groynes by longitudinal dams (LD) in low-land rivers such as the Waal has been successful in restoring the ecological river functions while simultaneously achieving its navigation, recreation, and flood-protection functions. However, the impact of the LD on the riverbanks is still unknown despite recent investigations on the flow dynamics in the side channel behind it.

Bank response

We investigated initial bank responses and quantifying changes in sediment dynamics over five years since the completion of the LD in the Waal at Wamel. We rely on available annual high-resolution LiDAR-derived DTMs, orthophotos, and in situ measurements to estimate erosion and deposition rates and their changes over the study period. A two-stage initial response is revealed with the largest bank erosion (~140 x 10^3 m^3/yr) and deposition (~20 x 10^3 m^3/yr) confined in the first year after installation, as the banks adjust to a new hydrogeomorphic equilibrium. This is followed by successively lower rates of surface level changes (<70 x $10^3 m^3/yr eroded and <10 x 10^3 m^3/yr deposited) as a response to the hydro - geomorphic dynamics in the new system. The overbank deposits from recent floods have a similar distribution with those prior to LD construction based on the DTMs. However, higher volumes of sandy deposits are found post- compared to pre-LD construction for floods of similar magnitude and duration. This increase is caused by the additional contribution of the bank sediments that have been made available through the removal of groynes. Although eroding banks may be a threat for infrastructure and navigability, they have a positive effect on restoring ecological diversity and floodplain connectivity.

Historical land use

One of the factors influencing the stability of the river bank is the impact of historical land use on small scale heterogeneity of erosion resistance. Therefore, we aimed to relate the river bank morphology and shallow subsurface characteristics along a short reach of the river Waal in Wamel, the Netherlands with natural fluvial processes and anthropogenic impacts. The subsurface characteristics were mapped using a combination of in situ field sampling from boreholes and geophysical surveys including Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT). Two types of lithology characterizes the shallow subsurface in Wamel (up to 2m from the surface): interbeds of sandy-clayey layers and homogeneously clay layers. GPR and ERT profiles show that interbedded layers occur closer to the edge of the banks while the clay layers are found farther away. This is consistent with the typical levee and flood plain stratigraphy of a fining sequence away from the river bank. However, clay layers are also found closer to the river banks (~10 m) that contain traces of small brick fragments, based on both geophysical surveys and borehole data. These are considered atypical given its proximity to the river channel. Along the river banks, the clay layers manifest as sawtooth features which are distinct from the steep planar slopes underlain by the interbedded sandy-clay layers. Using historical maps since the middle of the 19th century, the said clay layers are associated with agricultural activities and clay extraction for brick manufacturing. The results highlight the influence of historical human activities impacts current river bank morphology that could be important in predicting their instability and erosional responses to extreme river discharge. Furthermore, historical land-use maps show that human activities extend beyond the study area. This indicates that atypical clay layers closer to the river channel may be widespread along the Waal.

Figures

Figure 1. Eroding steep edge of the bank levee at Wamel with clear layering of more clayey and more sandy sediments.

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Plastics on the move: Discharges to plastic transport in the Odaw river, Ghana

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Keywords — macroplastics, river, discharges

Introduction

Marine plastic pollution is an increasing environmental threat (van Emmerik et al.,2018) which is of growing concern due to its direct and indirect negative effects to the ecosystem (Duncan et al., 2020). Several sources have been identified as pathways for these plastics to reach the marine environment. Rivers have recently been identified as the dominant source to marine environment plastic pollution contributing to 80% of the plastics. Though riverine litter input is estimated to be a major contributor to marine litter, there is little comprehensive information (González et al., 2016) about its temporal transport mechanisms (Meijer et al., 2021). Transport of riverine plastic debris vary at very small spatial and temporal scales (Browne et al., 2010). Patterns in the concentration of plastics suggest natural events related to climatic and meteorological conditions (strong winds, rain, floods, etc.) play an important role in the transport of plastics in rivers (Schirinzi et al., 2020). Observational studies have collectively examined the relative importance of river discharges, storms, heavy rainfall events and tidal effects (Honingh et al., 2020) on the transport patterns of riverine plastics however due to the short term variability of these hydrological and meteorological conditions particularly in urban areas, less is well understood on the temporal dynamics of riverine plastic concentrations. Our study focuses on the Odaw river in Accra, Ghana. Due to no field data on the quantification of macroplastics in this river, temporal dynamics of plastic transport are unknown. We aim to quantify the macroplastic transport through the Odaw and investigate the relation between discharge and plastic transport.

Methods

To quantify the floating macroplastics in the river, we conducted visual observations at 4 bridges closest to the river mouth. These bridges were sectioned into 2-3. At each section, plastic counts were done for 2 mins and repeated 4 times at each section of each bridge. This field observations were done over a period of 3 months (March-May) on 8 different sampling days between 20 March and 18 May 2021 (i.e., 20 March, 7, 12, 14 April, 13, 14, 17, 18 May. With this, the total plastic flux P_c [items/h] for each bridge was calculated using

$$P_c = \sum_{i=n} \mathrm{Pi} \bullet 30 \qquad (1)$$

where i = section of the bridge and P_i [items/2 mins] being the average plastic flux at each bridge section per hour.

Since there were no measured discharges for the river, rainfall data collected from TAHMO (Trans-African Hydro-Meteorological Observatory) were used in a hydrodynamic model to simulate discharge. Field observed data were first plotted against the simulated discharges for each sampling day. Later, the field data was combined with the discharge simulations to extrapolate plastic flux along the river for the sampling period. The extrapolation was done using the means [(1)] and linear equation methods [(2)]

$$\bar{C}_p = \frac{\bar{P}}{\bar{Q}} \qquad (2)$$

Where $\bar{P}$ = mean plastic transport per second [items/s] and Q as mean discharge per second Q [m^3/s].

$$p = \bar{C}_p \bullet Q + b \qquad (3)$$

With p = mean plastic transport per second p [items/s] and Q mean discharge per second Q [m3/s] and b as the intercept of the regression line plotted for the plastic flux and discharges.

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However, for this study, “b” was set to zero with the assumption that no discharge equals no plastic transport.

The above equations were first applied separately to the measured fluxes at each bridge (Separate Dataset) and then to the combined measured fluxes from all the bridges (Combined Dataset). With the above methods, macroplastic transport and plastic flux extrapolation over a period of time for the Odaw river were explored.

Results

Floating plastic flux

The instantaneous average plastic flux varied between 320 and 2400 items/hr with the highest observed at bridge B and the least at A. Bidirectional flow of plastics was observed at Bridge C and D. During the sampling days, simulated discharges were relatively low due to the limited rainfall events during the sampling days. Relating the simulated discharges to the plastic flux, there wasn’t a consistent relation of plastic flux to the simulated discharges (Fig 1). For bridge B and C, plastic flux showed a clear follow pattern with the simulated discharges during sampling days in May. For bridge A on the other hand, though the simulated discharges were stable during the sampling days in May, the plastic flux showed a variation across the sampling days. Negative plastic fluxes related to negative discharges were observed at Bridge C and D. This indicates the influence of tides to the transport of plastics at these sections.

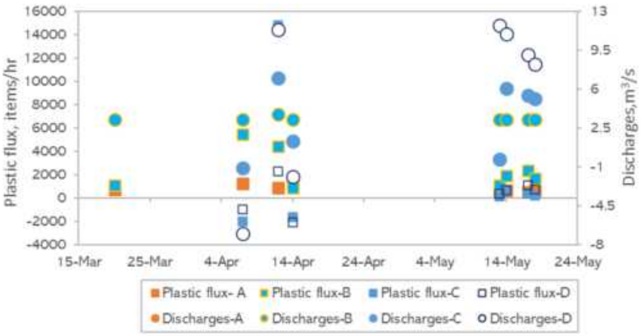

Figure 1. Measured plastics fluxes against simulated discharges at each bridge (A-D)

Extrapolated plastic fluxes

With the two equations (means and linear) applied on the two dataset approaches (separate and combined), the plastic flux extrapolation for the sampling period was estimated (Fig 2) A similar trend in extrapolated plastic fluxes across the sampling period was observed for each of the bridges except Bridge C and D that had fluctuations in their fluxes. Though the trend in temporal variation was similar, level of plastic fluxes for each of the extrapolation methods was different. Similar levels of extrapolated plastic fluxes were observed using the combined dataset approach as compared to the separate dataset. However, with relatively equal fluxes for the combined dataset, the means method resulted in higher peaks than the linear extrapolation method.

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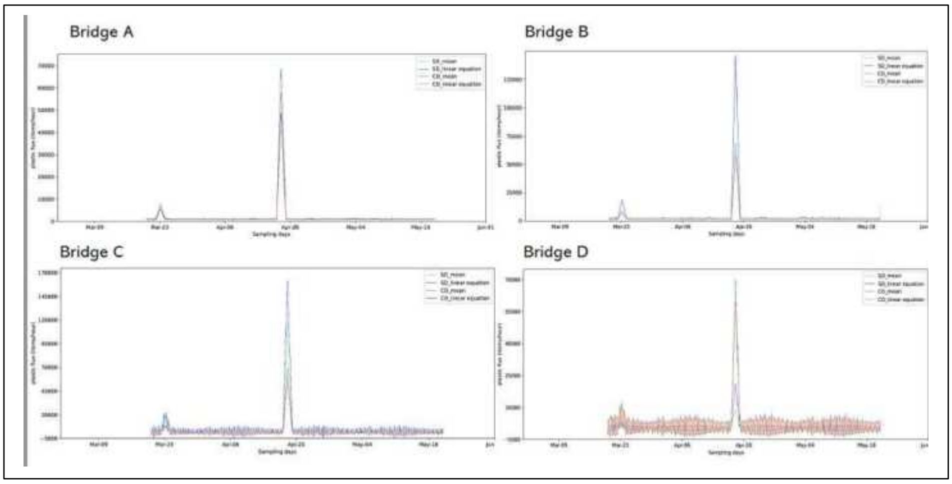

Figure 2. Extrapolated plastic fluxes during the sampling period at each bridge (A-D)

Adding up effects of warming and hypoxia and translating these to heat stress experienced by riverine animals

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Keywords — Amphipoda, mortality risk, climate change, water temperature, dissolved oxygen

Introduction

Rivers are warming up. The increase in water temperature is partly caused by the effects of climate change. In addition, discharge of cooling water has also contributed to increased water temperatures in the Waal (Reeze et al., 2017). An important question is whether this puts aquatic animals at risk from heat stress. In the literature, heat stress is often measured as the critical thermal maximum, i.e. the water temperature at which animals succumb to heat stress. The critical temperatures reported in the literature exceed riverine temperatures by a fair margin (e.g. Quin, 1994; Verberk & Bilton, 2013). Even for EPT taxa (species belonging to the insect orders of the Ephemeroptera or mayflies, Trichoptera or caddisflies and Plecoptera or stoneflies), the average critical temperatures are wel above 27.3 C which is a record water temperature for the river Waal measured at Lobith on August 7th in 2018 (Fig. 1A). *<u>But does this mean that riverine animals are not at risk from warmer water temperatures?</u>* To answer this question we need to consider three additional factors: water oxygenation, stress duration and thermal history.

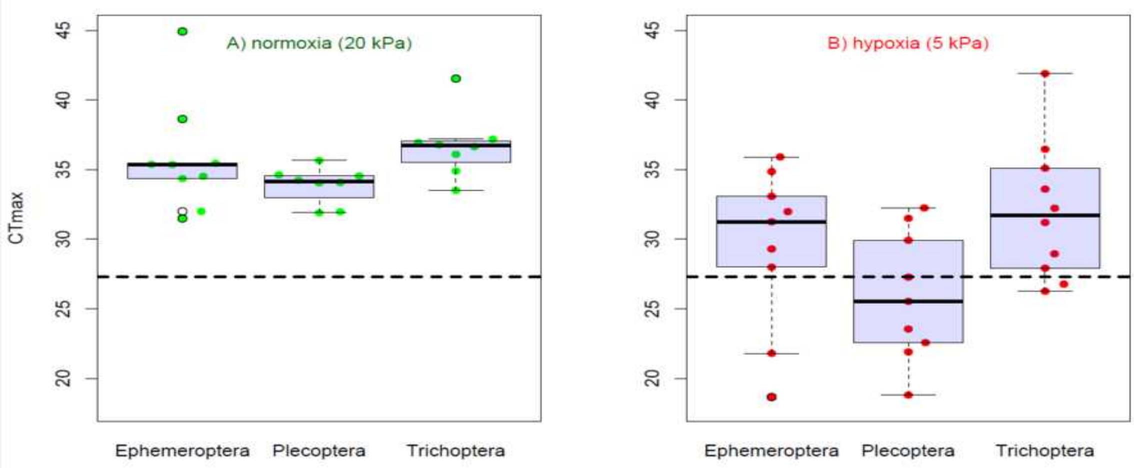

Fig. 1. Heat tolerance of mayflies, stoneflies and caddisflies, measured in normoxic (A) and hypoxic (B) water. The dashed line indicates the water temperature measured in the Waal on August 7th 2018.

Water oxygenation

Low levels of dissolved oxygen may exacerbate the stressful effects that warmer water has on aquatic animals (Verberk & Bilton, 2013). For example, critical thermal maxima of EPT taxa are strongly reduced under low levels of oxygen (Fig. 1B). There are several reasons for this. Foremost among these is that temperature drives the metabolic demand for oxygen in cold-blooded animals, or ectotherms. In addition, extracting oxygen from water is more challenging than breathing air because of the higher density of water and the lower diffusivity and solubility of oxygen in water. Thus, a combination of low levels of dissolved oxygen and warmer waters may decrease energy metabolism, with subsequent effects on growth, reproduction, limiting the occurrence of populations (e.g. Verberk *et al.*, 2016).

Stress duration

Stress is a function of both stress duration and stress intensity. Consequently, species can cope with intense heat provided it is of short duration (Rezende et al., 2014). Similarly, even mild heat can be stressfull when organisms are exposed to it for extended periods of time. The relationship between the duration of heat stress and the intensity of heat stress is linear when duration is log-transformed (Fig. 2).

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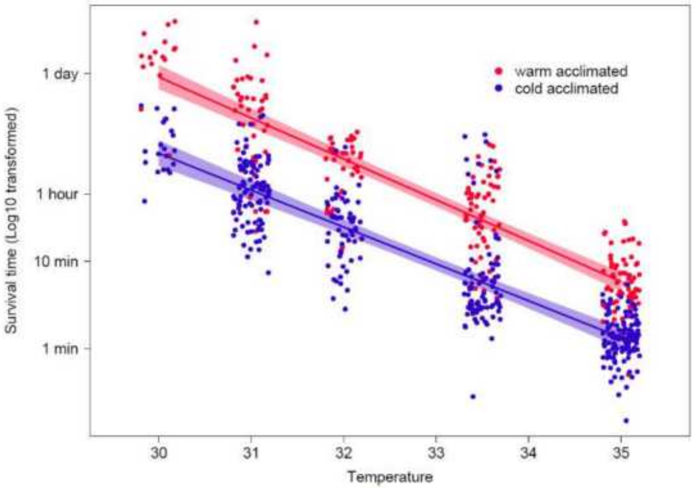

Fig. 2. Thermal death time curve, showing survival duration as a function of heat intensity for the amphipod Dikerogammarus villosus*. Amphipods were acclimated either to warm (20°C) or cold conditions (10°C).*

Thermal history

When exposed to warmer conditions, animals will acclimate by adjusting their physiology to the new conditions. Such physiological adjustment will increase the ability of an animal to withstand heat stress (Fig. 2). However, this plasticity in thermal tolerance has been deemed insufficient to buffer ectotherms from the effect of warming since critical thermal maxima do not increase sufficiently after warm acclimation (Gundersen & Stillman, 2015).

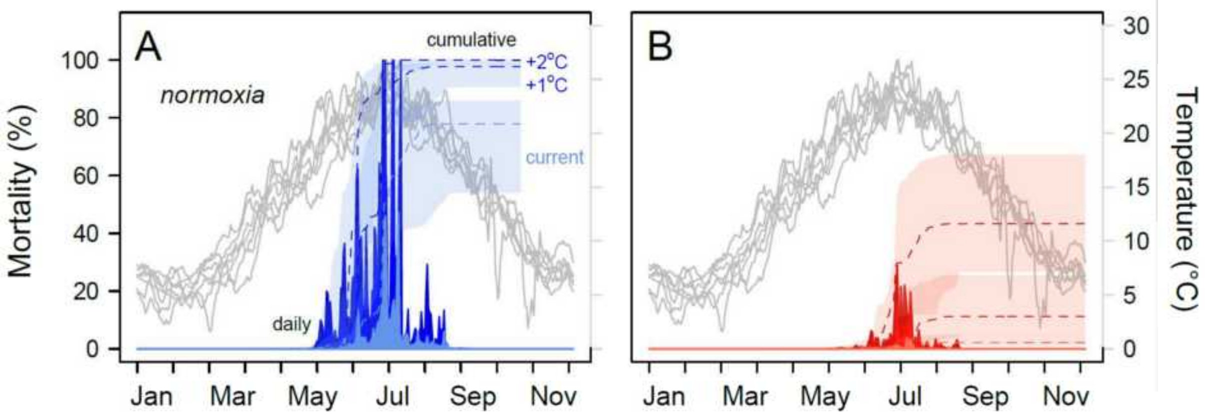

Fig. 3. Based on the thermal death time curve, river temperatures (shown in grey) are translated into daily mortalities. Cumulative mortality is shown for actual measured temperatures as well as future warming scenario's (+1, _2 C). Mortality is shown separately for amphipods acclimated to cold (A. 10°C) and warm (B. 20°C) conditions. Projections are for normoxic conditions.

Integrating stress using mortality risks

The temperature and oxygenation of rivers is not constant, but fluctuates diurnally and seasonally, complicating efforts to translate experimental data on heat tolerance into ecological risks. Recently, a new framework has been launched to do just that. The main idea is to first translate experimental data into mortality risk and second accumulate these mortality risks over time to estimate ecological risks. Here we apply this approach to data on water temperature measured in the Waal and thermal tolerance measured in the lab for amphipods (Fig. 3). Even though daily mortality risks are typically small, our model suggests that the cumulative effect results in high mortality for cold acclimated amphipods, while cumulative mortality for warm acclimated amphipods is much reduced. Nevertheless, warm acclimated amphipods do incur mortality, and this is exacerbated under hypoxia (not shown). Thus, amphipods and other riverine animals may already be suffering from heat stress during hot summers and their ability to physiologically acclimate is a vital part to cope with such heat stress.

By translating exposure to specific temperature and oxygen conditions for a given duration into mortality risks, their cumulative impact can be studied. This opens the way to link physiological experiments on stress tolerance to ecological reality of fluctuating conditions.

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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 combining the expertise of its partners, NCR forms a centre of excellence in river studies. Disciplines within NCR include hydrodynamics, morphodynamics, geomorphology, sedimentology, ecology, water quality, river governance, flood risk management, serious gaming and spatial planning.

NCR has four bodies: the program committee, Young NCR (YNCR), the supervisory board, and the program secretary. Except for YNCR, 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 its chair. Current chair is Matthijs Boersema (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.

Young NCR (YNCR)

Young NCR (YNCR) was created in December 2020 with the aim to strengthen the NCR for young/early career professionals within the field of river studies in the Netherlands. Current chair is Clàudia Ylla Arbós (Delft University of Technology). The main goals of YNCR are:

- to create a space where young river professionals can exchange knowledge and experiences;
- to promote the presence of young professionals in (multidisciplinary) cooperation and knowledge transfer between research, governance and practice;
- to promote the exchange of knowledge and experience between young and senior professionals;
- to make suggestions and give feedback to the NCR program committee from a young professional point of view, keeping in mind the interests and needs of young river professionals in different stages of their career.

To this end, YNCR organises social gatherings, career and professional workshops, lunch talks, and symposia. While YNCR activities target young/early career professionals, no age or professional experience limitation applies.

Supervisory board

The supervisory board consists of a senior member of each NCR partner. The members of the board choose its chair. Current chair is Jaap Kwadijk (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. Current program secretaries are Koen Berends and Anna Kosters of Deltares.

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