Towards 2048:
the next 25 years of river studies

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Towards 2048: The next 25 years of river studies

Wilco Verberk, Frank Collas, Gertjan Geerling & Marie-Charlott Petersdorf (eds.)

Organising partner:

Radboud University

Conference venue

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Preface

Welcome to the 25th edition of the NCR Days, an annual gathering of river experts, researchers, and practitioners focused on river ecosystems. The theme of this year's edition is "Towards 2048, the next 25 years of river studies", for which we will also look into the past for lessons to be learnt there. This year's meeting will take place in Nijmegen, one of the oldest cities in the Netherlands. Its strategic location in between the rivers Waal and Maas, which are connected via the Maas Waal kanaal, has made it a significant hub for river trade and commerce since Roman times. There is also a long tradition in riverine studies from the Radboud Institute for Biological and Environmental Sciences ranging from riverine ecology and toxicology to water governance.

This year we decided to organize keynote lectures as pairs of speakers, each providing complementary perspectives on a given topic. Ad Ragas and Gerard Stroomberg will both offer a perspective on water quality and changes therein, both from a more toxicological standpoint and from a societal standpoint focusing on the purification needed for riverine water to become drinkable. Astrid Blom and Rick Delbressine will talk about causes and consequences of channel bed erosion and how such knowledge is relevant for the replacement of weirs and other structures in rivers. Esther Stouthamer and Rob Lenders will take a long-term paleogeographic and paleoecological perspective on how rivers have changed through the millennia. Finally, Bregje van Wesenbeeck and Ralph Schielen will both reflect on Nature Based Solutions and how to apply them in river management.

We very much hope you will enjoy this 2023 edition of the NCR Days and share your knowledge and experience on how to contribute to solutions for river conservation and integrated river management. 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.
Happy reading, the LOC

Wilco Verberk, Frank Collas and Gertjan Geerling

Nijmegen, April 2022

Conference details

Organising partner

Organising partner of the 2023 edition of the NCR Days is the Radboud University in Nijmegen.

Venues

The Lindenberg Cultuurhuis is a cultural center located in Nijmegen, Netherlands. Designed by Dutch architect H.P. Berlage in the early 20th century, the building was originally a school for girls before being converted into a cultural center in the 1960s. Today, it offers a wide range of cultural activities such as music, theater, dance, and visual arts, and serves as a popular venue for concerts, festivals, and other cultural events.

The Lindenberg Cultuurhuis offers stunning views of the Waal River and the surrounding landscape from its location on the northern bank. The building has undergone several renovations in recent years to modernize it and enhance its cultural offerings. Despite these changes, it remains an important historic landmark in Nijmegen and a vital part of the cultural scene in the region.

Local organising committee (LOC)

The LOC consists of the following members: Wilco Verberk, Frank Collas and Gertjan Geerling.

Program

Netherlands Centre for River studies NCR

2023 NCR Day 1 - Wednesday 12 April 2023

	09:00 - 09:30	Registration, welcome & coffee
	09:30 - 09:45	**Opening of the 25th edition of the NCR days**
Session 1	**River water quality**	*Session chair: Wilco Verberk*
	09:45 - 10:30	**Ad Ragas | Radboud University Nijmegen** *Keynote: The past, present and future of river water quality* **Gerard Stroomberg | RIWA** *Keynote: River water quality and drinking water production*
	10:30 - 10:50	**Poster pitches**
	10:50 - 11:30	Poster session 1 & coffee
	11:30 - 12:30	**Frederik Huthoff | HKV** *A mass balance model for transported waste in rivers* **Kaisa Västilä | Aalto Universy, Finnish Environment Institute** *Two-stage channels for nature-based agricultural water management: Northern European experiences* **Hermjan Barneveld | Wageningen University and Research** *Summer flood 2021 impacts overwhelm the long-term sediment balance of the River Meuse* **Jill Slinger, Gerald Jan Ellen | Delft University of Technology, Deltares** *NCR and societal impact*
	12:30 - 14:15	River expedition (incl. lunch)
Session 2	**Bed erosion and structures**	*Session chair: Gertjan Geerling*
	14:30 - 15:15	**Rick Delbressine | Rijkswaterstaat** *Keynote: Replacement and renovation of the weirs in the Meuse: the long start of a challenging project* **Astrid Blom | Delft University of Technology** *Keynote: Channel bed erosion in rivers and mitigation measures*
	15:15 - 15:45	**Anne Kosters | Deltares** *Weirs in the Waal? – an exploratory study* **Francesco Bossini | Politecnico di Torino** *Assessment of 2D hydro-morphological processes to support river restoration at Isola Serafini in the Po River (Italy)*
	15:45 - 16:15	Poster session 1 & coffee
	16:15 - 16:45	**Lieke Lokin | University of Twente, HKV** *How sediment transport processes control the shape of simulated river dunes* **Cesar Adolfo Alvardo Ancieta | Cesar Alvarado Ancieta Expert Consulting** *Fluvial-geomorphological and anthropogenic changes of Piura River - La Niña anthropogenic basin - El Niño, Peru*
	17:00	Drinks & Bites*
	18:15 - 21:00	Conference Dinner & Pubquiz

16:45-18:15	**NCR Board Meeting**

Poster session 1

Ceasar Alvardo Ancieta et al.	*Bed topography and scour in sharp river bends - Curved flume models and river Ucayali evolution 1969-2023, Peru*
Ceasar Alvardo Ancieta et al.	*Characterizing bed forms downstream Los Ejidos Diversion Dam Spillway, Bajo Piura, El Niño impact, Peru*
Maha Sheikh	*Numerical study on the effects of river bank stabilization*
Leon Besseling	*Application of machine learning for real-time prediction of dike breach inundation*
Loreta Cornacchia	*How to build vegetation patches in hydraulic studies: a hydrodynamic-ecological perspective on a biological object*
Evelien van Eijsberg	*Long-term development of lowland rivers ; Rivers2Morrow - a research program;*
Jan Fliervoet	*Mediated participation for integrated river management with Visual Problem Appraisal (VPA)*
Bas Gradussen	*Exploring changes in discharge distribution in the Rhine branches induced by extreme scour*
Robert Groenewege	*Multi-model simulation of wadi flash floods using global data*
Joël. R. Haase	*Analysing the spatio-temporal variability or river dune induced bed roughness for the Midden-Waal*
Sebastian Hartgring	*Flood forecasting for the Rur: preliminary results for the 2021 flood event (MSc thesis)*
Steven Huls	*Future dikes: species rich and sustainable river dike grass covers*
Parisa Khorsandi Kuhanestani	*Improving mesh set-up to increase discharge capacity accuracy for water level prediction*
Jiaqi Liu	*Assessment of vegetation modelling approaches in simulating suspended sediment transport in Delft3D*
Xenia Martinez	*Sedimentary characteristics of channel bars and banks along the Roer River, Netherlands: linkages with meander dynamics of a 'rewilded' river*
Irfan Nazar	*Investigating the effectiveness of Nature-Based Solutions (NBS) for climate change adaptation using coupled MIKE SHE-MIKE11 model*
Paul Vriend	*Macroplastic concentrations in the water column of the river Rhine increase with higher discharge*
Paul Hudson	*Repeat sedimentation measurements for large floods along the lower Mississippi River and comparison with older events*

2023 NCR Day 1 - Thursday 13 April 2023

	09:00 - 09:30	Registration, welcome & coffee
Session 3	**Long term changes in rivers**	*Session chair: Wilco Verberk*
	09:30 - 10:15	**Esther Stouthamer | Utrecht University** *Keynote: Holocene palaeogeographic development of the Rhine-Meuse delta: a historical perspective* **Rob Lenders | Radboud University Nijmegen** *Keynote: Historical-ecological lessons for future river management*
	10:15 - 10:30	**Willem Toonen | Vrije Universiteit Amsterdam** *The rhythm of the river: variability in Meuse deposition identified from the meta-analysis of radiometric data*
	10:30 - 10:50	**Poster pitches**
	10:50 - 11:30	Poster session 2 & coffee
	11:30 - 12:30	**Marijn Nijssen | Bargerveen Foundation, Radboud University Nijmegen** *Filling the food web: restoration of ecological functioning temporary water bodies in river floodplains* **Yasir Munir | IHE Delft Institute for Water Education, Punjab Irrigation Department** *Effects of vegetation on gravel-bed river channel formation* **Bas van Leeuwen | Svašek Hydraulics** *3D modelling of Saltwater Intrusion into the Haringvliet to support Evidence-based Policy Development*
	12:15 - 13:15	Lunch
Session 4	**Nature Based Solutions**	*Session chair: Frank Collas*
	13:15 - 14:00	**Bregje van Wesenbeeck | Deltares, Delft University of Technology** *Keynote: Nature based solutions 2.0* **Ralph Schielen | Delft University of Technology, Rijkswaterstaat** *Keynote: NBS in practice: upscaling and mainstreaming*
	14:00 - 14:30	**Maria Barciela Rial | HAN University of Applied Sciences** *RiverWorks: from river DNA to sustainable soil winning* **Kifayath Chowdhury | Delft University of Technology** *Response of the Upper Dutch Rhine Bifurcation Region to Peak flows*
	14:30 - 15:10	Poster session 2 & coffee
	15:10 - 15:40	**Sien Kok |Deltares, Wageningen University and Research** *Towards a holistic economic assessment of integrated river management strategies* **Kshitiz Gautam | Delft University of Technology** *To what extent is morphodynamics of Terai Arc Landscape rivers altered by human actions?*
	15:40 - 16:00	Awards, and closing

Poster session 2	
Ceasar Alvardo Ancieta et al.	*Discovering the ancient outlet to the sea of river Piura due to anthropogenic changes - La Niña basin - El Niño, Peru*
Ceasar Alvardo Ancieta et al.	*Piura River, origin of the sedimentation of the estuary of Virrilá due to anthropogenic changes - El Niño impact, Peru*
Pratik Chakraborty	*On the relationship between flow-field and bank erosion in rivers: insights from large-eddy simulations*
Victor Chavarrias	*Implementation of an implicit 1D scheme in Delft3D FM*
Joshua Climo	*Assessing the ecological state of the Common Meuse and its restoration potential*
Jelle Dercksen	*Genetic-based biomonitoring in an annular flume*
Matthijs Gensen	*Calibrating hydraulic models of bifurcating rivers: avoiding uncertain discharge measurements*
Tors Kouwenhoven	*The effect of modifications to a groyne area in the Nieuwe Waterweg*
Simon van Laarhoven	*Investigating and modelling nourishments strategies for the Midden-Waal River*
Birgit de Lange	*Sediment nourishments in the River Waal to mitigate bed degradation*
Bram Langeveld	*Investigating the effect of streamlining groynes with experimental research*
Anna Loboda	*Is riverbank vegetation important for the estimation of flood water levels?*
Iris Niesten	*Effect of increasing channel depth by sea level rise and active deepening on water levels peak in deep estuarine channels*
Faisal Sardar	*The influence of precipitation spatial variability on mesoscale catchment hydrology: A study on the impact of rainfall distribution patterns*
Melanie Schippers	*Large-scale bank restoration in the Overijsselse Vecht River*
Jeroen Vos	*Invited versus claimed spaces for citizen participation in river governance*
Wiebe de Jong	*The Meandering Maas Project, an example project for integrated River Management*
Heleen Vreugdenhil	*Learning Spaces in river management: Innovating in the quadruple helix*
Jeroen Warner	*River governance out of bounds – untaming the transboundary, transformative, transgressive river Meuse?*

Session 1

River water quality

Netherlands Centre for River studies NCR

Keynote Presentation Session 1

Ad Ragas – The past, present and future of river water quality

We are delighted to announce the upcoming keynote speech by Professor Ad M.J. Ragas on "The Past, Present, and Future of River Water Quality". Professor Ragas is a highly respected expert in the field of environmental risk assessment of chemicals, and this keynote promises to be a fascinating and informative exploration into the chemical and biological status of our rivers. Professor Ragas will provide a historical overview of the factors that have contributed to water pollution, examine the current challenges facing our rivers, and provide a future perspective on the management of chemical risks.

Ad Ragas (1964) studied biology and obtained his PhD at the Radboud University in Nijmegen, the Netherlands. He currently holds a position as a full professor in Human and Ecological Risk Assessment at this university. His main expertise is the modelling of human and ecological risks of chemicals, covering emissions of chemicals, their fate in the environment, toxicokinetic processes and their adverse effects in humans, farm animals and species of ecological interest. Within this field, his focus is on quantifying and assessing uncertainty of model predictions. He actively participates in several large research projects on pharmaceuticals and contaminants of emerging concern, i.e. PREMIER, LABPLAS, TransPharm and SUSPECt.

Gerard Stroomberg – River water quality and drinking water production

The European Water Framework Directive (WFD) Article 7.3 states:

‘Member States shall ensure the necessary protection for the bodies of water identified with the aim of avoiding deterioration in their quality in order to reduce the level of purification treatment required in the production of drinking water.’

Hence, for water managers it is of key importance to evaluate and report on the quality of water and the level of purification treatment that is required. For this purpose a novel framework of indices is defined, and their definition allows the inclusion of new, emerging substances. The indices can be calculated based on micropollutant characteristics alone and do not require any knowledge of specific purification treatment installations. Applying this framework of indices to water bodies provides an objective and reproducible way of evaluating the required purification treatment level. The indices were calculated for water quality data for up to 600 micropollutants from five sampling locations along the river Rhine in the Netherlands. This revealed differences between the sampling sites (index values ranged from 145 to 273) and showed that for the river Rhine the required purification treatment level, as well as the underlying removal requirement and purification treatment effort, have not improved over the years, despite the introduction of the WFD in 2000.

Dr. Gerard Stroomberg is director of RIWA (https://www.riwa-rijn.org) which monitors, analyses and advocates river water quality improvement on behalf of the drinking water companies that use river water. RIWA’s mission is “RIWA strives for a quality of the surface water that requires natural purification to prepare impeccable drinking water.”

A mass balance model for transported waste in rivers

Authors:
Fredrik Huthoff[a,b], Carolien Wegman[a], Joana Vieira da Silva[a]

Highlights

- A mass balance model for transported waste in rivers was developed
- Results match with observations in the field and allow deeper understanding of waste accumulation sites
- The model is useful for strategic planning of monitoring campaigns, for estimating yearly waste emissions to the sea and to indicate suitable solutions.

Overview

We are proposing a new methodology to grasp the mass balance of transported waste in rivers. The approach is based on a simplified representation of flow distributions in compound channel sections, and relates transported and deposited waste to proportions of flow that go through the main channel and the floodplains. A key assumption in the model is that in floodplains the retention rate for transported waste is much higher than in the main channel, which leads to a net "sink effect" of waste as it is transported down the river. We show that the simplified model matches with field observations of waste depositions after a recent flood event, and demonstrate how it adds more insightful interpretation of waste accumulation sites. The model also allows a more strategic planning of waste monitoring in a real river setting, by highlighting which inputs are needed to get a complete overview of the quantities and timings of transported waste throughout the river system. Finally, the model can be used to estimate the yearly waste loads that a river transports to the sea and the proportion that remains stored in the river itself.

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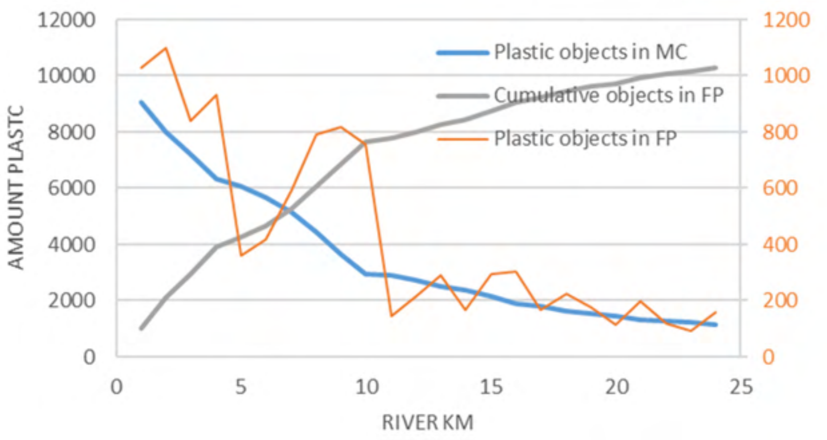

Figure 1. Results from the new waste balance model for an idealized river section of 25 km length, showing downstream filtering of waste in the main channel (MC) and accumulation in the floodplains (FP).

Two-stage channels for nature-based agricultural water management: Northern European experiences

Authors:
Kaisa Västilä[a,b], Tom Jilbert[c], Krister Karttunen[b], Kaisa-Leena Huttunen[b], Jari Koskiaho[b], Jani Wikström[c], Pasi Valkama[b], Jukka Aroviita[b]

Highlights

- We report preliminary results on two-stage channels compared to conventional dredging
- Floodplains improved riparian diversity and moderately trapped particulate substances
- Partial mowing improves the conveyance and likely the water quality benefits

Overview

Conventional dredging of agricultural streams and small rivers to support drainage and flood management substantially degrades the ecosystem and the natural channel processes (e.g. Västilä et al., 2021). The objective of this contribution is to investigate an alternative, nature-based two-stage (compound) channel design (Figure 1) aiming to improve the flow conveyance, water quality and biodiversity in small agricultural catchments. The analyzed two-stage channels (TSCs) located in Finland were constructed by excavating a 1-5 m wide floodplain on one or both sides of the low-flow channel.

The TSCs have provided well-functioning drainage since their establishment ~5-15 years ago. To mitigate the increase in flow resistance generated by natural vegetation succession, partial mowing of the floodplain is recommended instead of maintenance dredging. For instance, mowing in 40% of the two-stage reach length improved the conveyance capacity at autumn flood flows by ~25%. Regarding water quality, TSC construction increased suspended sediment (SS) and phosphorus (P) loads when the newly excavated floodplain was unvegetated, but the loads returned to the pre-excavation values in ~1 year. Deposition on the floodplains significantly increased with increasing floodplain inundation frequency, i.e., decreasing elevation of floodplain above channel bed (H_{FP}), from ~10 kg SS/m^2 and 7.3 g P/m^2 for H_{FP}=0.6 m to 0.6 kg SS/m^2 and 0.6 g P/m^2 for H_{FP}=0.92 m. The water quality performance of TSCs can likely be improved by selective vegetation maintenance (Figure 1; see also Västilä et al., 2016).

The TSC design could benefit riparian biodiversity, as indicated by results on beetles. In addition, the five examined TSCs had 10-50% higher number of plant species on the riparian areas (floodplain and channel banks) and low-flow channel compared to conventionally dredged reference reaches. The TSC design seemed not to provide much improvement to physical habitat quality in the main channel, in contrast to DeZiel et al. (2019) who found improved fish diversity.

There are currently few tens of kilometers of two-stage channels in Finland, but since 2023 TSCs are integrated into the new European Union agri-environmental subsidy scheme (CAP-AES), which is expected to aid in mainstreaming them (see also Västilä et al., 2021). The two-stage channel design is considered widely applicable under Boreal and Continental climates, with cost-efficiency gained by applying it instead of conventional re-dredging when flow conveyance needs improvement.

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Introduction

Two-stage channels are applied for agricultural drainage particularly in Midwest US while pilot sites and field investigations in Europe are sparse (Västilä et al., 2016; EA International, 2020). According to the limited evidence available, agricultural two-stage channels likely improve water quality by retaining suspended sediments and nutrients on the floodplain and potentially enhance plant and fish biodiversity (e.g. Trentman et al., 2020; Västilä et al., 2021). This study addresses some of the remaining knowledge gaps, including the optimal design and maintenance of TSCs to maximize their benefits.

Method

We conducted field investigations in six agricultural channels where a two-stage channel design was applied 3-15 years ago, and in conventionally dredged reference reaches. The influence of the elevation of the floodplain above the main channel bed and of the partial mowing of the floodplain vegetation (Figure 1) on the retention of suspended sediment (SS) and sedimentary phosphorus (P) was measured at two sites by grass mats 0.09 m^2 in area, water levels by pressure sensors, transported SS and P loads by in-situ calibrated sensors (as in Västilä et al., 2016), and biodiversity based on abundance and richness of diatoms, invertebrates, riparian beetles and plants. Sedimentary phosphorus was analyzed using ICP-OES and sequential extraction.

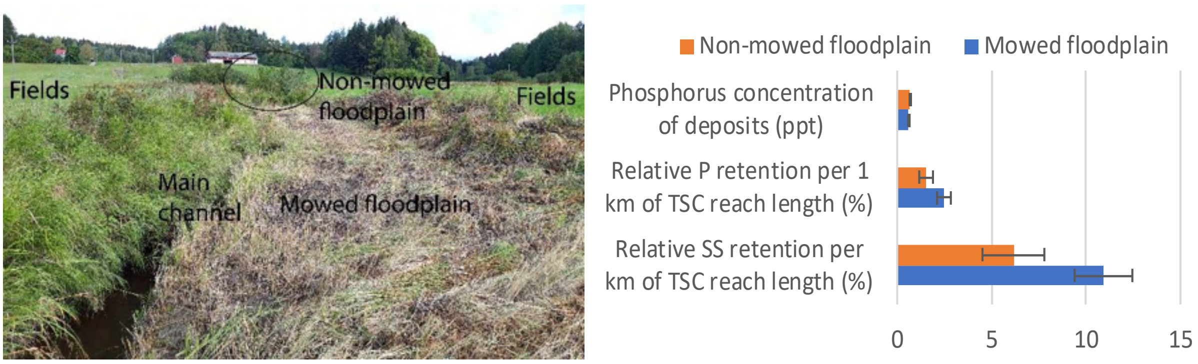

Figure 1. A studied agricultural two-stage channel (Ritobäcken Brook, Finland) consisting of a narrow main (low-flow) channel and a vegetated floodplain (left). The influence of the mowing of the floodplain vegetation on the suspended sediment and phosphorus deposition was compared to a non-mowed control reach (right).

Results and discussion

At the longest monitored site, SS deposition on the floodplains was around two-fold in the first few years after the two-stage channel construction compared to a decade later when the very dense vegetation likely limited the supply of SS from the main channel to the floodplain (see also Västilä et al., 2016). The trapping increased by 77% for SS and 60% for P when the > 1 m high floodplain vegetation was mowed to the height of ~10 cm (Figure 1). The total P retention is larger through additional uptake in plant biomass (e.g. Trentman et al., 2020). At the two investigated sites, over half of the total P was formed of iron-bound fraction, which can become bioavailable under reducing conditions.

Regarding biodiversity, the TSCs had, in general, slightly lower diatom richness and no difference in invertebrate diversity compared to the conventional dredging, although there was high variation in responses among the study systems. TSCs had higher riparian beetle diversity and more unique beetle species compared to the conventionally dredged or natural-like reference sections. As TSCs exhibited unique species, also for pollinators (Västilä et al., 2021), the modification of part of the conventionally dredged channel network to two-stage channels could enhance the catchment-scale biodiversity.

Climate change increases the need for efficient drainage, flow conveyance and such new methods for decreasing the transport of fine sediment and nutrients to downstream water bodies. Further investigations at TSC study sites of varying drainage designs and maintenance practices are needed to understand the variables controlling the SS and nutrient retention under Boreal conditions, while the mass balance for suspended sediment and nutrients in two-stage channels and conventionally dredged reaches should be compared taking into account the processes in the low-flow channel.

Acknowledgements

We acknowledge funding from Ministries of the Environment and Agriculture and Forestry, Academy of Finland, Maa- ja vesitekniikan tuki ry, and Salaojituksen tukisäätiö sr. We thank laboratory technician Antti Louhio at Aalto University for help in constructing equipment for the field investigations.

Summer flood 2021 impacts overwhelm the long-term sediment balance of the River Meuse

H.J. (Hermjan) Barneveld[a,b], R.M. Frings[c], , D.G. Meijer[e], W.H.J. Toonen[d], R.P. van Denderen[b], B. Vermeulen[a], J.G.W. Beemster[a] and A.J.F. Hoitink[a]

Highlights

- Highlight 1 Assessment of dynamics in sediment sources and sinks for the River Meuse
- Highlight 2 Main components sediment balance and its extent assessed from field measurements
- Highlight 3 Impacts of the summer flood of 2021 greatly exceed decadal changes under normal conditions

Overview

Establishing the dynamics of sediment budgets in rivers (see Fig. 1) is crucial in assessing the morphological impact of interventions and changes (Frings and Ten Brinke, 2018; Habersack et al., 2013). This study aims to assess such a sediment balance for sand and gravel for the Meuse River in the Netherlands over the last 25 years, to identify the impacts of human interference during this period, and to compare annual estimates of sediment balance components to erosion and sedimentation volumes observed during the extreme flood of July 2021.

Assuming that negligible volumes of sand and gravel pass the weir of Lixhe at the border with Belgium, bed level changes (erosion and deposition), dredging, riverbank erosion, deposition on floodplains and in lakes, tributaries and outflow to the delta are key components of the sediment balance. Available and collected data provide preliminary orders of magnitude of sediment balance components, and the impact of engineering works such as the river widening program Meuse Works (Looy van and Kurstjens, 2022).

Analysis of the morphological changes during the July 2021 flood (Flierman and Frings, 2023) show that the erosion and deposition volumes in a week overwhelmed the average annual values. The ongoing bed erosion in the Meuse River, caused by supply-limited conditions, geological composition of the Meuse valley and human interference (dredging, river engineering, Meuse Works) impacted the sediment balance, and increased the risk of massive morphological changes as experienced in July 2021. These observations highlight the need to terminate extraction of sand and gravel from the riverbed, to design sediment management strategies and to evaluate the morphological impacts of plans for the future.

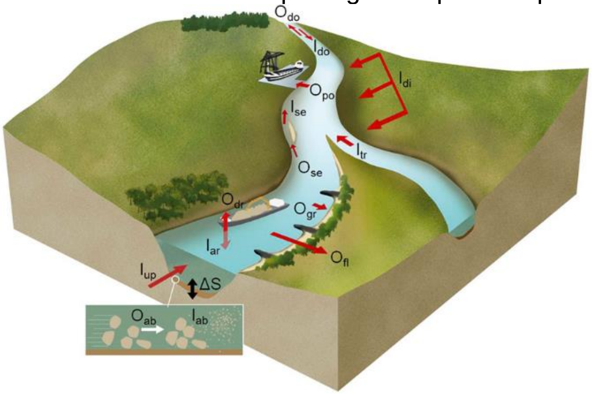

Figure 1. Representation of a channel sediment budget in a human-controlled river system, showing different sediment inputs (I),outputs (O) and the storage term (ΔS). Source: Frings et al. (2019).

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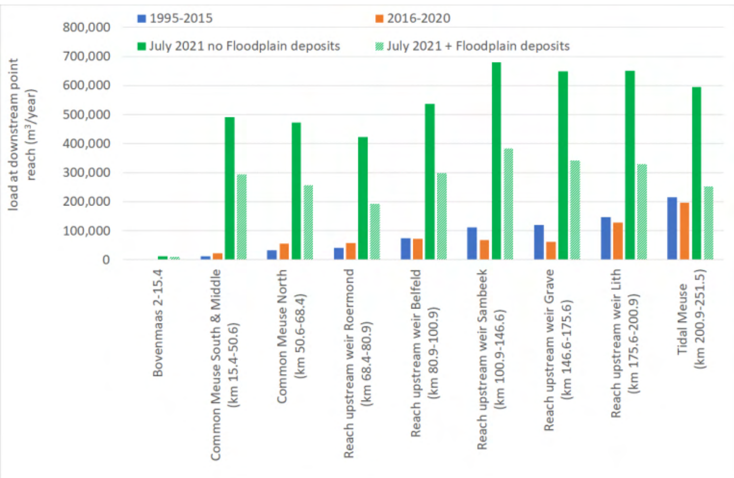
Method and Data

For the long-term development of the riverbed (main channel and floodplains) annual single-beam and multi-beam measurements in the main river, the Dutch Actual Altitude Database for different periods (AHN-1 to -4) and periodic soundings in lakes and harbours are available. For the bed changes in the main channel during the flood of July 2021, additional multi-beam measurements were taken during the falling limb of the flood wave. In addition, fieldwork on the floodplains by the Wageningen University & Research (WUR) and Vrije University Amsterdam (VU) was carried out, and laser altimetry surveys for the floodplains and echo soundings in several lakes became available. In addition to the data quantifying geometrical changes, a database has been constructed with all sediment management measures since 1995, such as dredging and implementation of engineering works.

The base data reveals the trends in (1) riverbed profiles and corresponding sediment volumes, (2) the annual volumes of eroded bank material, (3) the volumes of deposition on floodplains, in lakes and in harbours and (4) dredging and dumping volumes. The data from field work of the WUR in the proximal floodplain zone along the complete Meuse River in August 2021 was enriched by the data from the VU in the distal zone to estimate the background sand deposition and by the laser altimetry data for areas missed or not accessible during the fieldwork. The laser altimetry data had to be treated with care, as the images were collected during the growing season. The algorithms for identifying vegetation filtered out large areas from the elevation model, but also proved to be insufficiently accurate. The first sediment balance equations were constructed using the hypothesis of nil inflow from upstream, data on riverbed changes, dredging, dumping and bank erosion volumes.

Results and Discussion

The average annual sediment loads per river reach for the periods 1995-2015 (period of Meuse Works implementation) and 2016-2020 (Meuse Works largely completed) are limited compared to volumes during the 5 day flood period in 2021 (Fig. 2). The massive riverbed and riverbank erosion, especially in the Common Meuse during a few days of extreme discharges, produced sediment loads equivalent to those of multiple average hydrological years. The contribution of floodplain deposits to the sediment balance during such high floods shows to be significant. Differences between the multi-annual periods reveal the impacts of summer bed deepening of the Meuse Works between the weirs of Belfeld and Lith.



Component	Volume (10^3 m^3)
Riverbed level change	-575
Bank erosion	-210
Floodplain deposition	340
Dredging delta	-90

Figure 2. Left: sediment loads (sand and gravel) based on bed level changes, sediment management (dredging) in the main riverbed and bank erosion estimates (van Houten, 2022; assuming 10% sand in eroded banks) for 2 long-term periods and for July 2021 (load in 5 days!). Floodplain deposits are not indicated in long-term periods and presumably small. For July 2021 floodplain deposits are included in the light green bar. Right: Average volume components in the sediment balance for July 2021 (rounded values) based on measured data (Flierman and Frings, 2023), and dredged volumes. Negative values show erosion or dredging. Floodplain deposits relate to proximal zones (river banks, WUR) and distal zones (>80 m from river, VU).

The long-term sediment balance and resulting sediment load diagram will be extended with data on floodplain and lake deposits and tributary loads, for which analyses are ongoing.

Conclusions and Recommendations

The sediment balance clearly shows the supply-limited character of the river. The resulting eroding trends have increased the risk of massive morphological changes. Improved sediment management is recommended as well as morphological impact assessment of future plans. Data collection and analyses should continue and be extended, for example in tributaries and on sediment transports.

The Productive Interaction Facility (PROD) – A National Research Infrastructure Facility

Jill Slinger[a]
Gerald Jan Ellen[b]
Heleen Vreugdenhil[a,b]

Highlights

- The Δ-ENIGMA National Research Infrastructure Facility grant has been awarded
- A networked, accessible Productive Knowledge Interaction Facility (PROD) is part of Δ--ENIGMA
- Labs from Deltares, TUD, WUR and UT form complementary and specialized building blocks
- Setting up, protocols and testing of the PROD facility in use will be undertaken in the coming years

Overview

As a Large-scale Research Infrastructure facility, the overall aim of Δ-Enigma is to strengthen the international position of bio-geomorphological research in the Netherlands, by providing advanced observation instruments, distributed over key areas in the river-estuary-coast continuum, and capable of observing normal conditions and extreme events. It will support interdisciplinary research by promoting developments in process knowledge at the interface between geology, physics, ecology, and the social sciences. In particular, the Productive Knowledge Interaction Facility (PROD) will enable social science action research on productive knowledge interactions between bio-geomorphological scientists and engineers (science-science), policymakers and managers of the delta (science-practice).This will deliver insights on the role of visualisation, simulation modelling, interpersonal interactions and activity design in the efficacy of knowledge interventions related to river-estuary-coast systems. Through the provision of high quality facilities for ongoing, structured research in this field, different knowledge interactions can be compared and patterns can be identified over a longer time horizon. The insights obtained can lead to the improved design of diverse knowledge interaction methods and management decision making that is based on a sound understanding of bio-geophysical dynamics in a delta. The involvement of a wide range of scientists, public officials and stakeholders in these knowledge interventions also serves to actively communicate results to management authorities in the Dutch Delta.

The four facilities that form complementary and specialized building blocks for the national network or Productive Knowledge Interaction Facility (PROD) when it comes to river-sea systems and geoscience include:

- TUD: Simulation and Game Lab: Focusses on simulation and gaming to support complex decision making at the Faculty of Technology, Policy and Management and at mobile locations.
- WUR: Wanderlab provides state of the art visualisation of monitoring data and predictive modelling outputs of geomorphic systems.
- Deltares: The Deltares iD-Lab brings together models, data, visualisation techniques and expert knowledge for geoscience applications.
- UT Design Lab is the experimental collaborative ecosystem at UT for innovative changemakers aiming to connect society, technology, science and design.

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Acknowledgements

Text from the Δ-Enigma grant application (Middelkoop, 2022) has been used in this abstract. All contributors are acknowledged, specifically those from the UT, WUr, TUD and Deltares staff involved in drafting the PROD text.

Background

Decision making regarding river-estuary-coast management involves dealing with inherent uncertainties and variability as well as with the complexity of various stakeholders and their interests. Insight into the consequences of proposed interventions, based on state-of-the-art bio-geomorphological and engineering knowledge, as well as the effects on all stakeholders is needed. Involvement of non-academic stakeholders provides access to experiential knowledge and promotes the real-world relevancy of research outcomes (Lang, 2012). However, knowledge uptake and understanding of the societal impact of science are still often framed as a linear model that eventually leads to an effect or 'impact' outside of research. Exemplary of this is the 'end of pipe' approach where dissemination often forms a separate work package at the end of a complex research project, although empirical studies show that the production and use of knowledge can better be understood as a process of interaction and co-creation. A seminal article by Spaapen and van Drooge (2011) termed these 'productive interactions', which they described as exchanges between researchers and stakeholders in which knowledge is produced and valued that is both scientifically robust and socially relevant. Such productive interactions can contribute to the societal impact of research. Productiveness is considered to be fulfilled 'when it leads to efforts by stakeholders to apply research results to social goals, i.e. when it induces behavioural change' (Spaapen et al. 2012, p. 2).

Current practice in the field of river, estuarine and coastal science in the Netherlands reveals that important networks where science and practitioners connect are already in place e.g. NCR and NCK. Within these networks stakeholders participate in the science process and its interpretation. However, how *productive knowledge interactions* function, how they can be studied over longer periods of time, and how this understanding can be used to enhance the interchange and use of knowledge does not receive attention. We lack a national infrastructure of facilities supporting the ongoing study of productive knowledge interactions and their effects in designing and decision making on river-estuary-coast systems. Within Δ-Enigma, we aim to create a joint national facility or network for the study of productive knowledge interactions - the Productive Knowledge Interaction Facility (PROD) (Middelkoop, 2022).

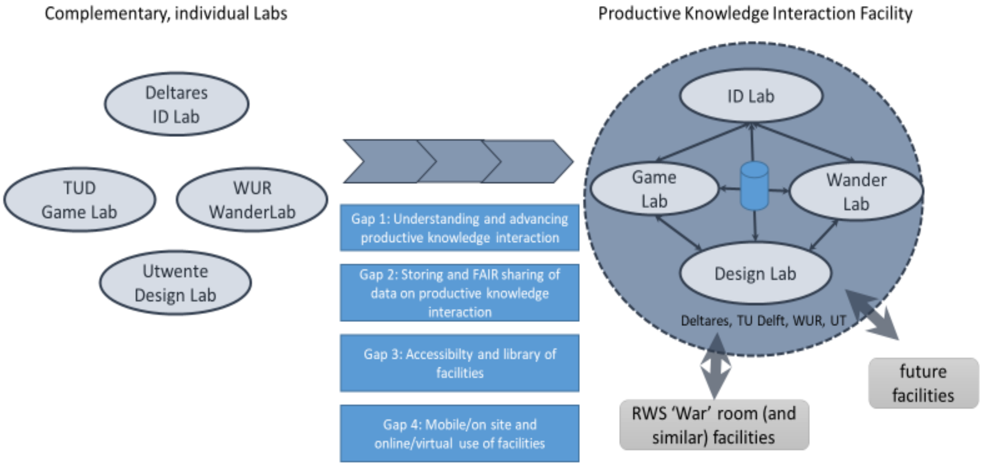

Figure 1. From 4 islands to a complementary, networked, accessible Productive Knowledge Interaction Facility (PROD)

PROD Components and Design

As depicted in Fig.1, each of the four labs at TUD, WUR, UT and Deltares has different, specific and complementary expertise, but (1) there is no coherence between the labs when it comes to undertaking research on productive knowledge interactions; (2) there are no shared protocols nor exchange of information on technology and methodologies, nor are ethically responsible and FAIR data capturing and data storage procedures routinely applied; (3) access to the facilities is limited to staff or projects from the own organisation; and (4) a lack of mobile or online facilities is hampering the study of productive knowledge interactions on site rather than in the labs themselves.

By connecting the four specialised facilities from Deltares, TUD, WUR and UT in an accessible national network and adding specific technology, protocols and shared data storage, a joint platform is created that will facilitate scientific research on productive knowledge interactions in river-estuary-coast systems. It is envisaged that the PROD national facility to advance the science of productive knowledge interactions can in turn contribute to achieving societal impact and the uptake of Δ-Enigma research.

Session 2

Bed erosions and structures

Netherlands
Centre for
River studies
NCR

Keynote Presentation Session 2

Rick Delbressine **Astrid Blom**

Channel bed erosion and man-made structures

Rick Delbressine

Rick Delbressine works at the Department of Waterways and Public Works (in Dutch: Rijkswaterstaat Programma's, Projecten en Onderhoud). He works as a senior advisor with a specialisation on the Meuse. Amongst others he is involved in the Multi-Year Programme for Infrastructure, Spatial Planning and Transport (MIRT) regarding the 'Zuidelijk Maasdal' and the project replacement and renovation of the weirs in the Meuse.

Rick studied civil engineering at the TU Delft and has worked at the Department of Waterways and Public Works since 2013 in various functions.

In his keynote, Rick will address the start-up phase of the project regarding the replacement and renovation of the weirs in the Meuse. The reason for this project is that the weirs are nearing the end of their longevity. A potential replacement provides the opportunity to also take into account other functions of the river system.

Astrid Blom

Astrid Blom is an associate professor in the Hydraulic Engineering department of the Faculty Civil Engineering & Geosciences of Delft University of Technology, Netherlands. In her research, she focuses on changes in engineered river systems. In particular, she asks how anthropogenic modification and natural change affect the river equilibrium state regarding channel slope and bed surface grain size, as well as how the river responds with time to such change. She loves to develop conceptual and analytical models as tools to increase insight into the physics governing modern and/or historic river problems. She combines these models with analyses of field and lab data, and numerical modeling to extend physical understanding to engineering applications. She is motivated to increase diversity in engineering and science, and loves to work with and educate young researchers.

Engineered rivers are often prone to channel bed incision. This decreases the channel-floodplain connection, hampers navigation where non-erodible reaches increasingly protrude from the bed, and can destabilize structures. Here we inventorize causes and characteristics of channel incision measures. We elaborate on how channel bed incision is a transient channel response toward a new equilibrium channel state. Causes of incision comprise base level fall, channel narrowing (e.g., due to river training), channel shortening (bend cut-offs), an increased channel-forming discharge (e.g. due to climate change), and a decrease (or fining or coarsening) of the sediment flux from the upstream part of the basin. Finally, we discuss two measures that may mitigate channel bed incision: sediment nourishments and longitudinal training walls.

Weirs in the Waal? – an exploratory study

Anna Kosters[a]
Aukje Spruyt[a]
Remi M. van der Wijk[a]

Highlights

- We explored the feasibility of regulating the Waal with weir-lock complexes as a starting point for discussion and further research.
- Weir-lock complexes are beneficial for navigation and freshwater supply, but detrimental for ecology.
- Attractiveness of regulating the Waal by means of weir-lock complexes depends on the development of transport demand and the way the Netherlands will adapt to sea level rise.

Overview

Ongoing river bed erosion in the Waal exposes non-erodible elements that form obstacles for navigation during low flows (e.g. De Jong, 2020). Due to climate change, the frequency and duration of periods with low discharges are expected to increase (Sperna Weiland et al., 2015). Due to this combination of developments, inland navigation is increasingly hampered by limited navigable depths. As the Waal is one of the most important transport corridors within Europe, extended periods of limited navigable depth lead to large economic damages (Vinke et al., 2022).

Measures to improve the reliability of inland transport on the Waal may be aimed at increasing the robustness of the logistics chain (e.g. by increasing storage capacity), adapting vessel design and fleet composition to small water depths, improving forecasts and real-time information on navigable depths and regulating the river itself to increase water depths at a given (low) discharge.

As regulating the Waal with weir-lock complexes has been suggested by stakeholders to improve conditions for navigation, we explored the feasibility of this measure from an inland shipping point of view, as well as the effects on flood safety, ecology and freshwater supply.

Ligtenberg (2022) shows that two weir-lock complexes, with four chambers each, lead to a reliable and efficient fairway according to Rijkswaterstaat standards. Implementation of this design into a 1D hydrodynamic model of the Rhine branches allowed us to investigate effects on water levels and discharge distribution. Combined with expert judgement, the effects on different river functions were assessed.

By decreasing streamwise connectivity, temporal variation in flow and sediment transport and habitat diversity, the weirs have detrimental effects on ecology. Allowing more control over the discharge distribution during low flows, weirs are favourable for freshwater supply, while, assuming the weirs do not affect the flow at high discharges, effects on flood safety are negligible.

Attractiveness of regulating the Waal by means of weir-lock complexes depends on the development of transport demand and the way the Netherlands will adapt to sea level rise. As effects of this measure are largely irreversible, construction of weirs and locks may lead to regret.

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Effects of weir-lock complexes on discharge distribution

We investigated the effect of the proposed measure on the river system and its main functions. In the remainder of this abstract we focus on consequences for the discharge distribution. Hydrodynamic effects of the preliminary design by Ligtenberg (2022) largely depend on the weir operation. Two important operation variables are the criterion for the weirs to become operational and the target water level during operation.

Closure criterion

Currently, nearly all vessels can sail fully loaded when the discharge at Lobith exceeds 2000 m^3/s (Ligtenberg, 2022). Under these conditions, the weirs should be open. To find the optimum water depth or discharge at which the weirs should become operational from an inland navigation point of view, a trade-off must be made between navigable depth and passage time: closure of the weirs leads to an increase in passage time as vessels have to wait to pass the adjacent locks, but the average loading capacity per vessel increases (for $Q_{Lobith} \leq 2000$ m^3/s) such that less vessels are needed to transport the same amount of cargo. However, in a broader perspective other factors need to be considered to determine an appropriate closure criterion. Ligtenberg (2022) assumes the weirs are operational for $Q_{Lobith} \leq 1600$ m^3/s.

Target water levels

Subsequently, the target water level during operation must be determined. A simple approach, as taken on by Ligtenberg (2022), is to increase water levels such that all vessels can pass fully loaded when the weirs are operational. This can be considered an upper limit for the target water level.

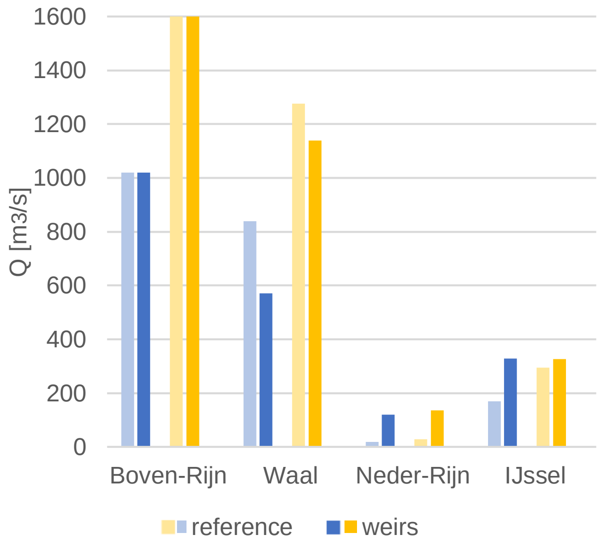

Fig. 1. Discharge distribution in the reference case and the case with weirs for two discharges at Lobith: 1020 m^3/s (blue bars) and 1600 m^3/s (yellow bars).

Modelled discharge distribution

Fig. 1 shows the discharge distribution for two different discharges at Lobith (1020 and 1600 m^3/s, the latter being the assumed closure criterion), for the situation with and without weirs. In the situation with weirs, the target water levels as described above are used.

For $Q_{Lobith} = 1020$ m^3/s, the discharge to the Waal reduces significantly when weirs are implemented, while the discharge to Neder-Rijn and IJssel increases with 100 and 160 m^3/s, respectively. For $Q_{Lobith} = 1600$ m^3/s, the reduction on the Waal is smaller and the surplus is mostly directed to the Neder-Rijn. Note that in these simulations, the currently valid operational rules for the weirs on the Neder-Rijn/Lek are implemented.

Discussion and recommendations for further research

This exploratory study gives a first overview of effects of weir-lock complexes in the Waal on the river system and its functions. It is meant as a starting point for further discussion and research into this topic. Recommendations for further research include:

- Investigate the effects of weirs on the morphology of the lower Rhine (can this measure reduce river bed erosion?);
- Investigate the effects of different weir operation schemes (on both the Waal and the Neder-Rijn) on the discharge distribution;
- Determine the optimum closure criterion, taking different river functions into account.
- Analyse costs and benefits of this measure;
- Consider the available navigable depth (with and without measures) along the entire transport corridor (i.e. including the German part);
- Further investigate effects on salt intrusion in the Nieuwe Waterweg;
- Investigate feasibility within different adaptation strategies for sea level rise.

Assessment of 2D hydro-morphological processes to support river restoration at Isola Serafini in the Po River (Italy)

Francesco Bossini[a]
Erik Mosselman[b,c]
Ellis Penning[b]
Carlo Camporeale[a]
Melissa Latella[a]

Highlights

- We developed a 2D hydro-morphological model of a segment of the Po River.
- Relevant 2D hydro-morphological effects were reproduced by the model.
- The 2D model provided insights to support restoration initiatives.

Overview

Restoration measures will be taken along the Po River (Italy) with the goal of protecting biodiversity and recovering its ecosystem (ADBPO, 2022). To that end comprehension of hydro-morphological features is crucial since these influence habitat distribution by distributing flow velocity and shear stress and shape bed topography patterns (Camporeale et al., 2013). Therefore, the aim of this study was to assess 2D hydro-morphological processes relevant for river restoration, with special reference to the Isola Serafini meander of the Po River. This segment of the river is experiencing functional inactivity of floodplains and biodiversity loss due to several factors (Filippi et al., 2013), including the construction of a hydropower plant in the upstream section. ADBPO (2022) is currently planning to reduce the height of existing training walls and mobilise sediments within the incised channel as an effort to rehabilitate river dynamics. These measures, however, have not yet been studied in detail with modelling support, for which a 2D approach is required.

The development of a 2D hydro-morphological model of the meander permitted to gain knowledge on the characteristic spatial distribution of bed topography by simulating the influence of helical flow and gravity pull along transverse bed slopes on sediment transport (Struiksma et al., 1985). Using Delft3D-4, it was possible to:

1. conduct sound engineering checks on the morphological evolution of an initial transversely flat topography of the meander following a constant water discharge (return period 1-2 years).
2. assess the influence that alternative operation rules of the hydropower plant's barrage could have in the morphological development of the meander and that could be implemented to accomplish river restoration goals.

2D hydro-morphological approaches were introduced from the Room-for-the-River programme in the Netherlands to study the Po Renaturation Plan in Italy as part of an emerging twinning activity between these restoration initiatives. Managers of the Po could benefit from Dutch experiences with stakeholder involvement, interdisciplinary teams and monitoring programmes. Managers of the Rhine could benefit from Italian experiences with freshwater supply in periods of draught that are expected to become more prominent according to scenarios of climate change. All these factors are relevant for reaching restoration targets and the provision of ecosystem services. We recommend developing a more elaborate programme of river surveys and monitoring of the Po River, continuing 2D hydro-morphological modelling of the Po River, and carrying out twinning activities between managers of the Rhine and the Po Rivers for mutual benefit.

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Sound engineering checks on a transversely flat topography.

Values for morphological parameters associated to critical 2D hydro-morphological processes were adjusted to reproduce key topographic features of the incised channel (bar extent and height, spatial position, etc.). The modelling outputs enabled identification of potential areas of bed erosion adjacent to defence works. Fig. 1 shows one of these areas resulting in a deeper channel at the outer bend in respect to the elevation detected by the topographic survey. The results suggest that sediment nourishments at the outer bend to stabilise the bank and increase lateral continuity within the incised channel may require supplementary measures, since released sediments may be removed in the medium-term.

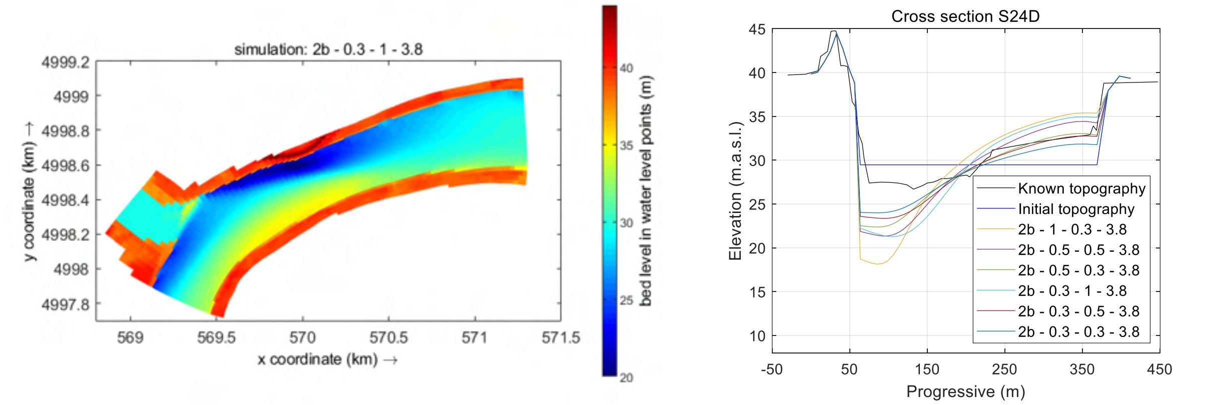

Figure 1. On the left: Final bed topography of the simulation that best fits the known topography overall, revealing the erosion area on the outer bend approximately 6 km downstream of the barrage. On the right: Results of simulations with varied morphological parameters. The outer bank (left side) is reinforced with bank defences and has been classified as potentially unstable by ADBPO (2005).

Morphological influence of alternative operation rules of the barrage

Asymmetrical distributions were imposed as inflow boundary conditions from the gates composing the barrage. The results showed that redistribution of flow (Crosato and Mosselman, 2009) occurred within about 2 km of the barrage. Nonetheless, in the medium term operation rules could influence the morphological development of the meander up to 6 km from the barrage, resulting in flatter or more heterogeneous topographies (Fig. 2), depending on the desired effect. Operation rules with higher flow rates on the left half of the barrage resulted in overall higher bedform heterogeneity, with shallow water areas shifting from the outer to the inner bends. The potential of alternative operation rules relies, however, on the possibility to regulate sediment rates through the gates rather than simply water inflow distribution.

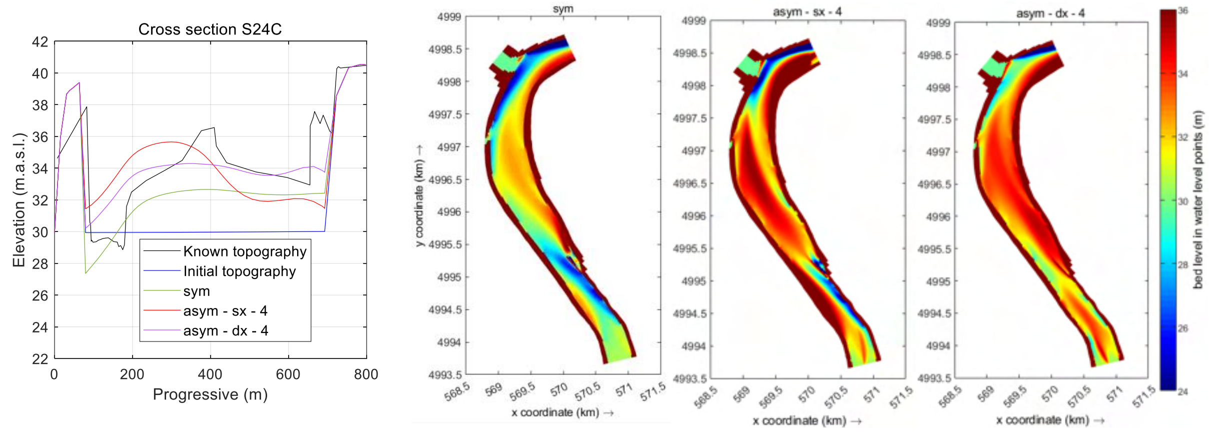

Figure 2. On the left: Comparison of bed topographies obtained by imposing symmetrical (uniform) and asymmetrical inflow distributions over the gates. Simulation "asym - sx - 4" consisted of water inflow on the left half of the barrage four times higher than the same value on the right half (analogously for "asym - dx - 4"). On the right: Corresponding bed topography maps of the upstream stretch of the meander influenced by the operation rules.

Acknowledgment

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How sediment transport processes control the shape of simulated river dunes

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Suzanne J.M.H. Hulscher[a]

Highlights

- Simulating dune development with different sediment transport processes result in different dune shapes
- Only near incipient motion transport capacity is dune height limiting in the simulations
- Suspended transport limits dune growth and initiates the offset to upper stages plane bed

Overview

Understanding the processes in river dune dynamics is important for efficient and durable river management. These river dunes result from the constant interaction between the stream flow and the alluvial bed of a river, grow and decay with changing discharges. After flood waves have passed and during low flows, the dunes can limit the navigable depth. Therefore, the crests of these bed forms are dredged. This paper assesses the influence of different sediment transport processes on dune shape with a numerical dune development model. The knowledge of these processes is a key point in the understanding of river dune dynamics and prediction of problematic dune crest locations in the future.

The dune development model is based on a 2DV flow module, of which the calculated bed shear stresses are used in a sediment transport and bed update modules (Paarlberg et al., 2009). Within the transport module the Meyer-Peter & Muller transport formula is implemented. To keep the computation time of this model at a minimum, some assumptions are made. First, the model has periodic boundary conditions, which creates a virtually infinite row of identical dunes, Second, the model uses a constant eddy viscosity, limiting the ability of flow separation at the lee slope of the dunes.

Three sets of transport related conditions are simulated, for conditions varying from extreme low to median discharges in the Waal River (Figure 1~~Fig. 1~~.). The first set of simulations was done with the standard Meyer-Peter & Müller sediment transport formula including a correction for gravitational bed slope effects (Sekine & Parker, 1992). Secondly, a set of simulations similar to the first, but with an increased critical shear stress was done. This increased critical shear stress corrects for the higher flow velocity due to the absence of flow separation (Lokin et al., submitted). In the third set, parameterized suspension through linear relaxation, after Tsujimoto et al. (1990), is implemented.

Accounting for the different sediment transport processes in dune dynamics, realistic dune shapes can be simulated, while different dune behaviour is observed Limiting the total transport capacity, possibly due to lower flow velocities, can limit the dune height. When the transport capacity increases the domain length of the model is probably the limiting factor for the dune height. Suspended sediment smoothens the dunes and initiates the transition towards upper stage plane bed at low flow velocity where this process is not seen in data. Adding this in a parameterized, Meyer-Peter and Müller only assume bed load, enables this smoothing. The implemented gravitational bed slope effect limits the growth of the lee slope angle towards the angle of repose, which may explain the occurrence or low angle dunes in rivers.

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Transport effects on dune height

Dune heights generally increase with increasing water depth and therefore river discharge (Lokin et al., 2022). The dune height related to the flow conditions in the simulations differ from what is expected based on literature and data. In the “normal” shear stress case, the simulated dune height is relatively constant over the different discharge regimes, while the water depth increases as the discharge increases. A possible explanation for this might be that the dune length, which is determined by the domain length between the periodic boundary conditions, may be a limiting factor for dunes to grow further when the water depth increases. Only when the sediment transport capacity iis lowered, simulated by the increase of the critical shear stress, the dune height shows the expected behaviour.

The decrease in dune height at higher discharges in the simulations with the parameterized suspension is opposite to what is expected from data representative for the simulated discharge regimes. However, the link between suspended sediment and the flattening of dunes is an accepted theory for the transition towards upper stage plane bed. For extreme low flows flattening of dunes has been found for extreme low flows in the Waal River (Lokin et al., 2022).

Additionally, shipping on the Waal River is expected to increase the amount of sediment brought in suspension, especially during low flows when the thruster jets are closer to the river bed. Adding suspension trough a parameterized suspension that is inversely related to the bed shear stress may be able to simulate the effects of shipping on river dunes. This study has shown that increased suspension leads to flattening of river dunes. However, the effects of shipping on sediment transport still need to be quantified, which is an important issue for future research.

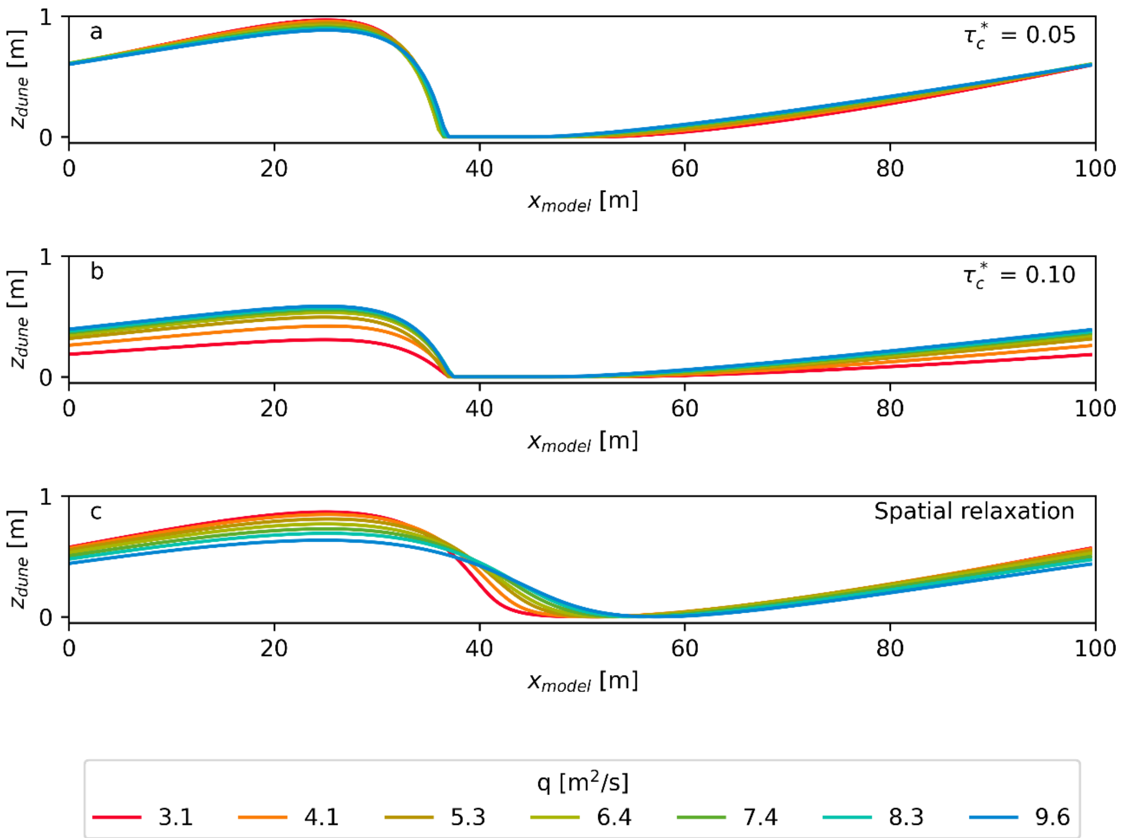

Figure 1. Equilibrium dune shapes resulting from the different sediment transport settings and increasing specific discharges representing discharges from extreme low up to mean discharges in the Waal River. a) Dune shapes resulting from the Meyer-Peter & Müller simulations with the critical shear stress according to the Shields diagram. b) Dune shapes resulting from the simulations with the increased critical shear stress. c) Dune shapes resulting from the simulations with parameterized suspension through linear relaxation.

Fluvial-geomorphological and anthropogenic changes of Piura River - La Niña anthropogenic basin - El Niño, Peru

Cesar Adolfo Alvarado Ancieta[a,b,c,d]

Highlights

- A research performed during the last 25 years, investing self-resources for river engineering passion
- Analysing available dataset since 1920 and performing a 1D- and 2D- numerical hydraulic modelling
- Fluvial-geomorphological changes in response to high sediment regimes. Anthropogenic changes together with El Niño Phenomena creates La Niña anthropogenic basin

Overview

150 years of human interventions have transformed the Piura River, Peru's main irrigation area, into a semi-channelled river with sediment floodplains in the lower river basin, Bajo Piura; and a non-river-channelled reach, a high sediment ejection source due to fluvial processes, in the middle basin, Medio Piura (Alvarado, 2020).

Peak events such as El Niño Phenomena produces flooding in the upper, middle and lower river basin: Alto, Medio and Bajo Piura, increasing the vulnerability of cities and agricultural areas like years 1983, 1998 and 2017. The deviation of the natural course of the Piura river in the lower river basin, which discharged into the sea in the past, a proper river mouth, to a new point of discharge, with a longer river length, in the last half century, has resulted in a complex problem in the river morphology of the lower river basin, thus, the process of sedimentation occurs in the lower basin, result of high suspended sediment transport rates activated mainly during El Niño Phenomena. As a consequence, an aggradation process is occurring in the lower river basin (Alvarado, 2020, 2022).

Simultaneously, the degradation of the upper and middle river basins, Alto and Medio Piura, sources of sediment ejection into the lower basin, has continued unchecked, leading to the necessity that mitigation measures be implemented to counteract the streambed and river bank level changes, if adequate measures are not taken to solve the problem.

An effective evaluation of the riverbed in this degradation-aggradation process mainly in the middle and lower river basins (Alvarado & Ettmer, 2007, 2008) requires an understanding of the morphological processes involved in river channel geometry, and peak flood dampening for flood vulnerability reduction, i.e. it needs a flood control integral view of the problem, i.e. focused not only in the Piura River lower basin after anthropogenic changes but also in the impact of these changes in La Niña anthropogenic basin, which is joined to the new alignment of the Piura River, impacting Ramón and Ñapique lagoons, Tres Brazos area, the Estuary of Virrilá, Ñamuc Ravine and La Niña Lagoon (Alvarado, 2020).

This document introduces to a detailed river bed and floodplains topography (Alvarado, 2004), fluvial-geomorphological and sediment transport research for understanding the impact of the anthropogenic changes on the high flood vulnerability of Bajo Piura and La Ñiña anthropogenic basin for a flood control and risk management plan.

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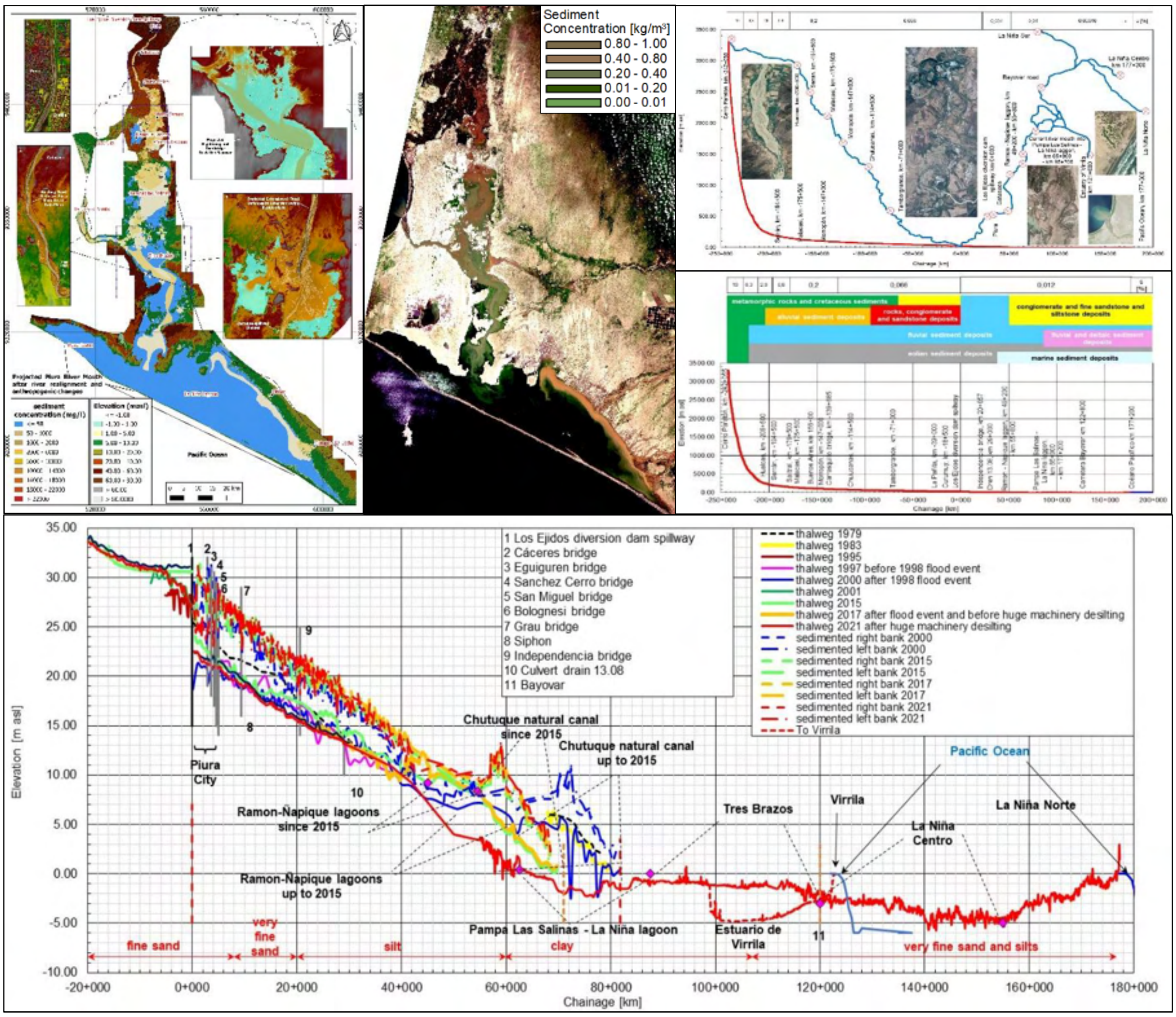

Figure 1. Plan and profile of Piura River and anthropogenic basin. High sediment yields, geology and morphological changes.

Introduction and study area

High sediment transport rates activated with El Niño event and anthropogenic changes after the last 50 years, causes a complex problem in the river morphology of the lower river basin, flooding Piura. The river origin is above 3370 m asl and it is an alluvial meandering river with a very low slope in 90% of its river length up to the anthropogenic La Niña Basin (Alvarado, 2020), with water releases to the Pacific Ocean in: (i) the estuary of Virrilá, and (ii) through several existing “tombolos” along the coastline in Reventazon, at La Niña Lagoon, with a total length alignment of 363 km and 420 km respectively.

Methodology

A historical review of the morphology changes between 1975 and 2022 was carried out, analysing the available topography, bathymetry, DTM 2011 & 2022 with 0,25 m res. satellite images, hydrological and sediment since 1925, geological, geotechnical, and geophysical data since 1930, and performing 1D/2D numerical hydraulic modelling, $t_{2017\ \text{flood wave}}$ = 6 months, with many simulations for different approaches.

Results

The anthropogenic changes in the current river alignment are impacted not only by the high suspended sediment transport rates activated during extreme rainfalls occasioned by El Niño Phenomena in the meandering Medio Piura Basin, producing the river aggradation in Bajo Piura basin, but also by the geology and tectonic tilting of the earth’s surface in the Antearc (Forearc) zone of northwestern Peru.

Acknowledgements

My sincerely thanks to my professor G. Klaassen, and E. Mosselman, B. Ettmer, R. Rothgiesser, G. Strübing, W. Trau, and my colleagues P. Castillo Zavaleta and E. Zegarra, for comments and extended discussions on several topics on Piura River research, and Piuran citizen groups for their support.

Poster Session 1

Netherlands
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River studies
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Bed topography and scour in sharp river bends - Curved flume models and river Ucayali evolution 1969-2023, Peru

Cesar Alvarado Ancieta[a,b,c,d]
Bernd Ettmer[b,c,e]
Jhonath Mejía[f]

Highlights

- A research focused on river Ucayali meandering performed during the last 20 years
- Analysing bed topography and scour in sharp river bends of the Peruvian Amazon
- The over deepening and damped oscillation of the bed topography adaptation has an approach which is not applicable under high curvature conditions, however transverse bed slope are fairly well predicted

Overview

The aims of this paper is the comparison of the bed topography and scour in a sharp bend flume from a relevant laboratory experiment performed by Alvarado (2004), and considering others as Struiksma, Talmon, Odgaard, Olesen and Blanckaert, with the in situ 2005 field campaign (Alvarado et al., 2007), and satellite images data of river Ucayali in his morphological evolution 1969-2023, focused on the over deepening and damped oscillation of the longitudinal profile of the normalized water depth, and considering that river Ucayali displays a progressive change in channel pattern, complex anastomosing channels, meandering and high suspended sediment yields.

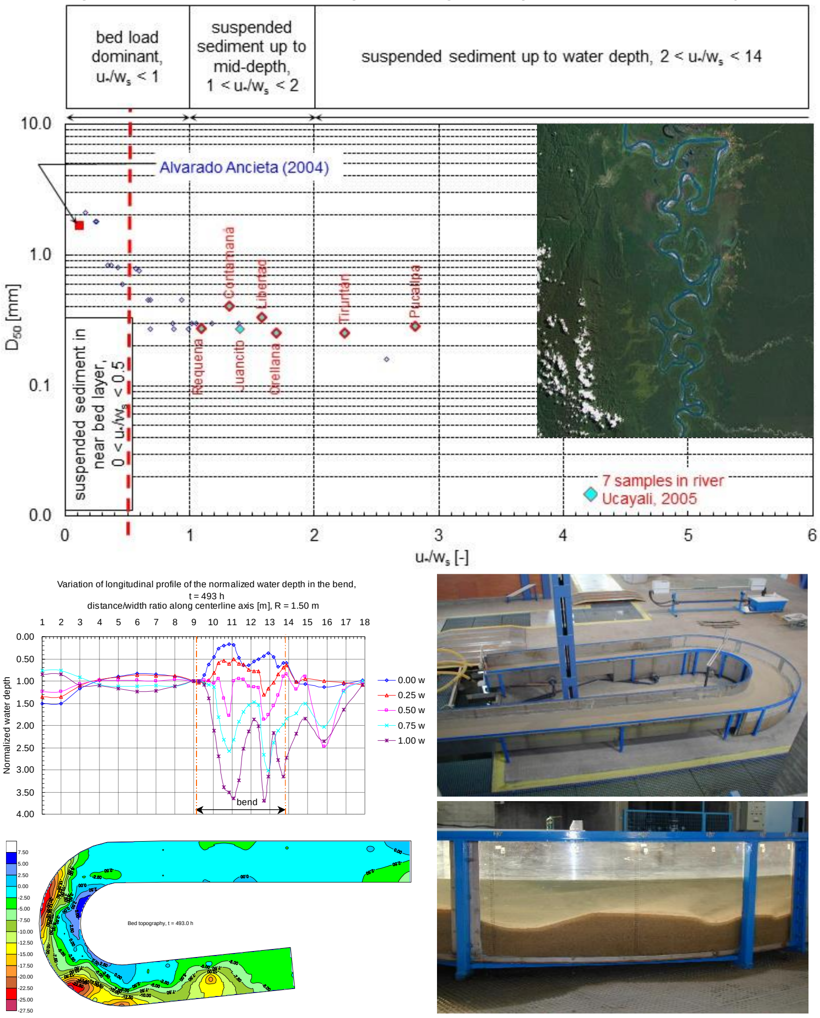

Figure 1: Comparison bed topography-scour evolution in sharp bends of curved flume models (Alvarado, 2004) vs. in situ (2007), and satellite data collection of river Ucayali.

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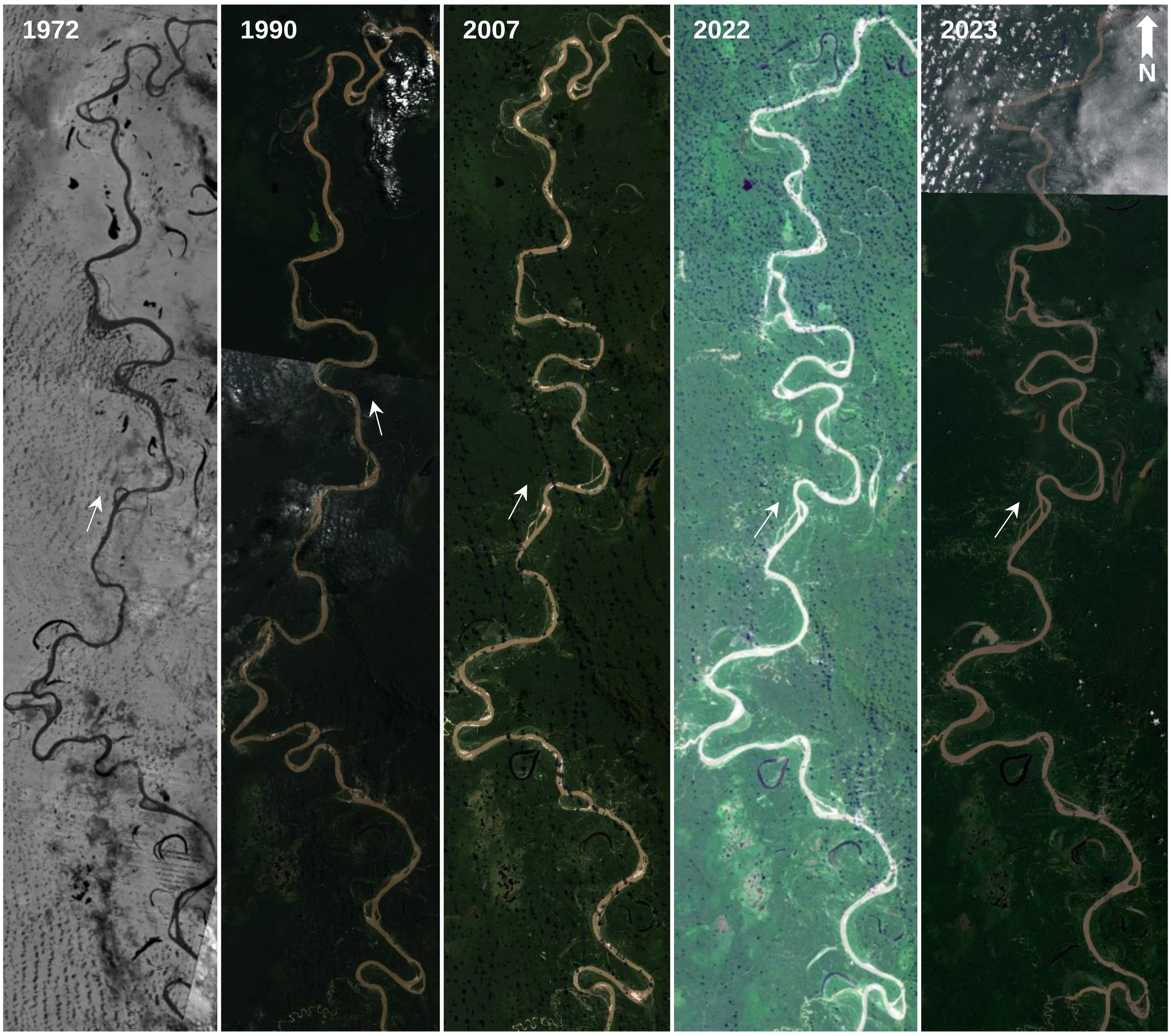

Figure 2. Morphological meandering evolution of river a reach of Ucayali 1972, 1990, 2007, 2022 and 2023.

Introduction and study area

Morphological changes in sharp river bends of river Ucayali are studied and compared with the results obtained by experimental model in a sharp curved flume. The area of study is the complete reach of river Ucayali in an extension of around 1000 km comprised from the city of Pucallpa up to its confluence by the left bank with the river Marañón, with a total amount of around 50 catalogued sharp bends, with a ratio R/B < 3.

Methodology

The experimental investigation in a sharp curved flume was rendered feasible by the availability of a 3D- and a 2D acoustic doppler velocimeter (ADV), (Alvarado, 2004). An in-situ field investigation performed the year 2005 with bed topography along the river, sediment data collected and acoustic doppler velocimeter in representative bends of Ucayali river (Alvarado, et al., 2007). A historical review of the morphology changes between years 1969 and 2023 of river Ucayali was carried out, analysing satellite images and applying a DTM of 0,30 m resolution for specific river bends.

Results

The over deepening and damped oscillation of the bed topography adaptation has an approach which is not applicable under high curvature conditions, however transverse bed slope are fairly well predicted.

Acknowledgements

My sincerely thanks to my professor G. J. Klaassen, for comments and extended discussions on several topics of the research on bed topography and scour in sharp bends, and river Ucayali.

Characterizing bed forms downstream Los Ejidos Diversion Dam Spillway, Bajo Piura, El Niño impact, Peru

Cesar Alvarado Ancieta[a,b,c,d]
Yoel Cordoba[d,e]

Highlights

- A research field campaign with aerial pictures of high resolution was implemented
- Analysing available dataset since 1973 and performing a sediment sample campaign dam downstream
- Middle and lower Piura river crosses a fluvial and eolian sediment deposit area which belonged early to the desert of Sechura, and bed forms are characterized as dunes and antidunes

Overview

One of the interesting bed forms in river Piura are those located downstream of the fixed barrage of Los Ejidos dam, at the right bank. The middle and lower Piura River is a fully alluvial system which has very fine grain bed sediments composed of very fine sand, silts and clays (Alvarado, 2007/2008). Considering the size of the characteristic bed diameter, shear stress, dimensionless Shield parameter and hydraulic characteristics, these bed forms have been characterized, identifying that they are mostly to dune type forms during lower flow regime, and antidunes during upper flow regime (Van Rijn, 2002), as El Niño flood event. This document is focused on his bed form characterization.

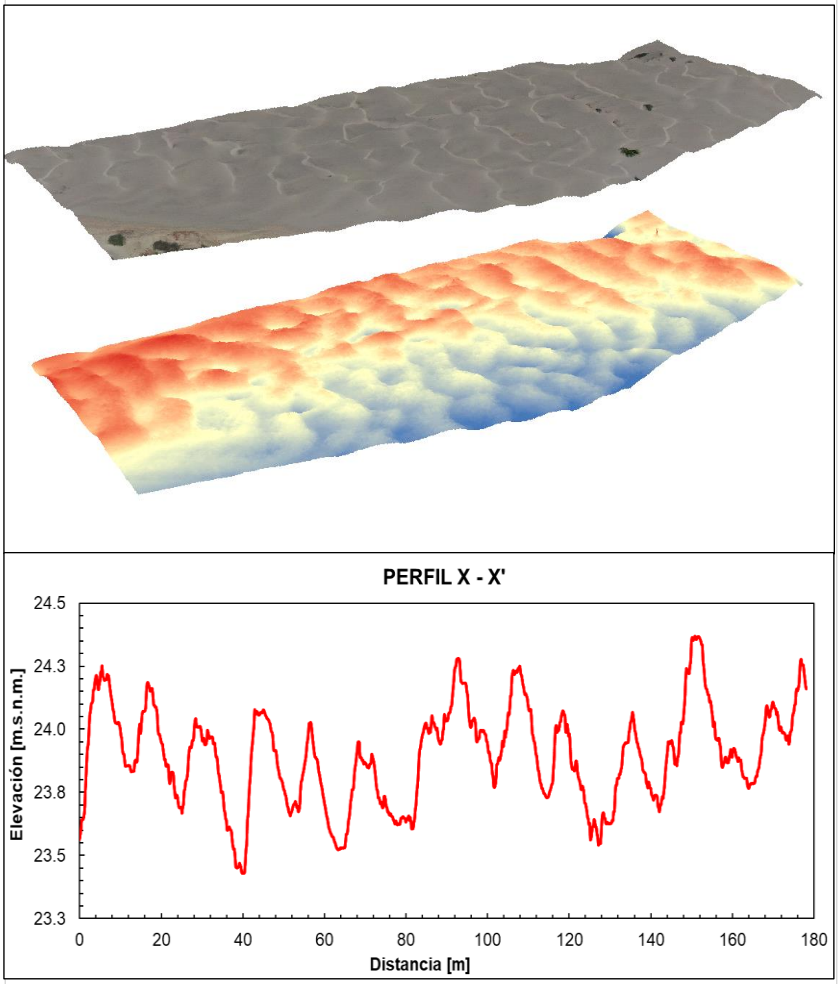

Figure 1. Aerial view and longitudinal profile of the ripples of the dunes located downstream of the fix barrage, right bank, of Los Ejidos dam in river Piura.

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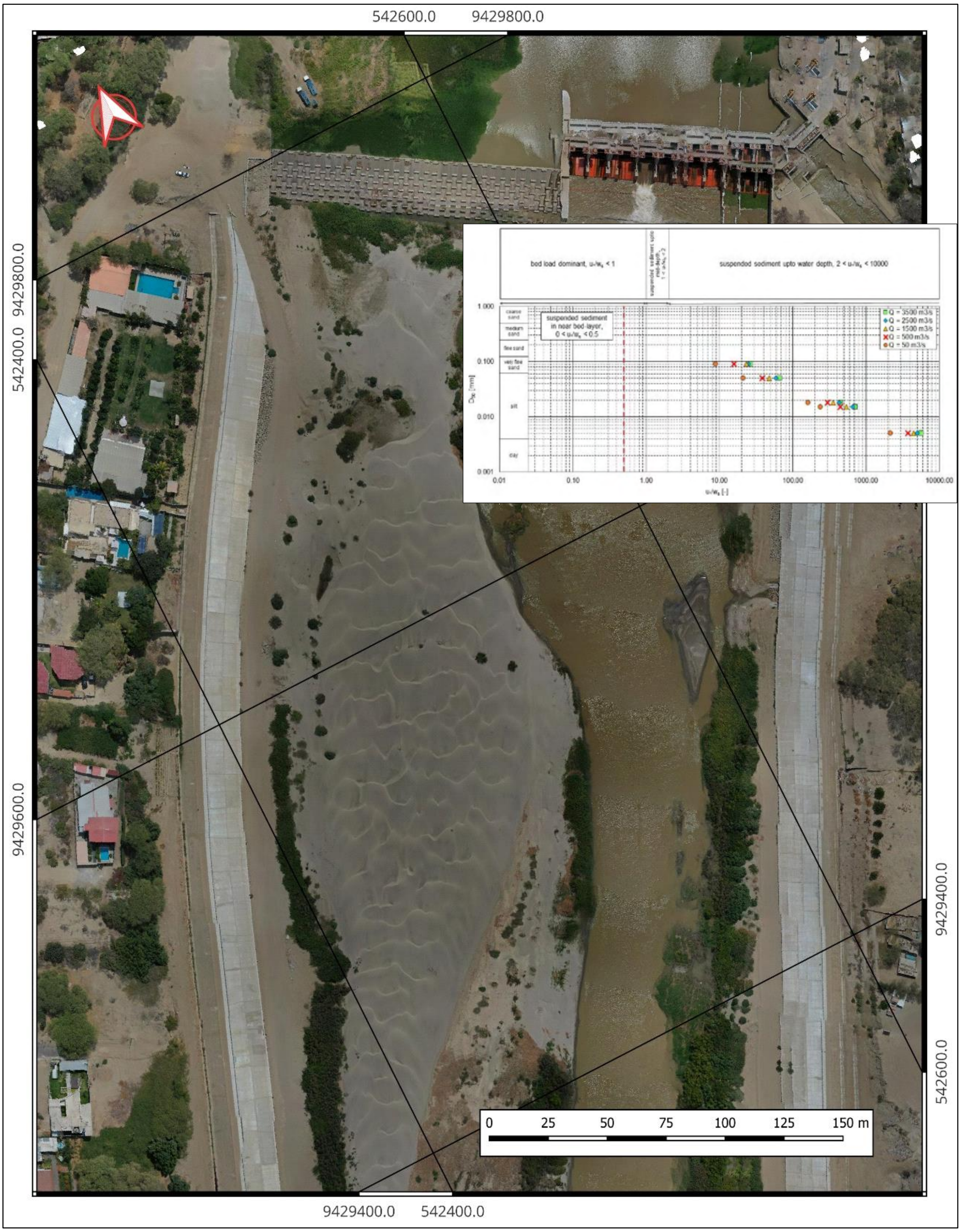

Figure 2. Aerial view of the dunes located downstream of the fix barrage of Los Ejidos dam in river Piura.

Methodology

Available dataset since 1973 on sediment concentration, performing an especial aerial and field observation campaign, year 2020, and performing a sediment sample campaign, year 2021.

Results

Bed forms shape and dimensions were identified and characterized, concluding that bed forms located on the right bank, downstream of the fix barrage of Los Ejidos dam, are dunes and antidunes.

Numerical study on the effects of river bank stabilization

Authors:
Maha Sheikh[a],
Alessandra Crosato[a,b]
Victor Chavarrias[c]
Micha Werner[a]

Highlights

- A 2D numerical model developed in Delft 3D to study the effects of river bank stabilization
- Stabilizing the outer river bends results in a less sinuous and narrower channel with sharper bends.
- The river morphological behaviour to bank stabilization should be kept in mind while planning the land use nearby rivers

Overview

The purpose of bank stabilization is to prevent lateral shift of rivers caused by bank erosion (Julien 2012). However, changes in river morphology after bank stabilization often result in damages and long-term drawbacks. For instance, shift in the river bank line increases the risk to nearby structures and agricultural land and the deepening of the river bed near the protected bank results in the failure of the bank protection structures (Minor et al., 2007; Tomohiro, 1996). Lack of knowledge about cross sectional and planimetric changes in rivers after bank stabilization intensifies the risk of damages to structures and land.

To the best of author's knowledge, no reliable numerical study is available till date to study the effects of bank stabilization on river morphology. This served as the main motivation of this study as this research aims at developing a numerical model for predicting the changes in river planform and thalweg profile after bank stabilization. We conducted a Delft 3D numerical study inspired by the work of Friedkin, (1945) . We set up model an initially straight channel with a transverse plate acting as forcing with the same bed materials, valley slope, variable discharge. Cycles of flow transformed the straight channel into a meandering river that reached a morphological state similar to that of Friedkin's experiment # 1 of Part-II as shown in Figure 1b. The results of calibrated model are shown in .a Results **of Calibrated model, b**a. The model was validated against Friedkin's experiment # 2 of Part-II. After it reached to a morphology as in the experiment, the banks were stabilized by revetment and differences were observed. This morphological configuration was then considered the starting point of the investigation. Several scenarios with longitudinal bank stabilization were simulated and the results were compared to base case with freely erodible banks.

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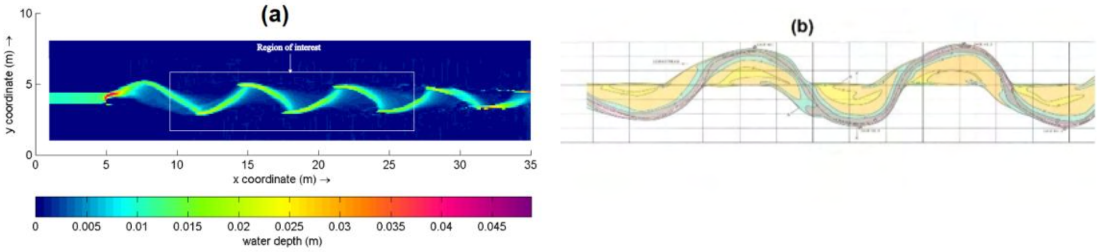

Figure 1.a Results of Calibrated model, b. Results of experiment # 1 of Part-II (source: Friedkin, 1945)

Preliminary Results

The model was used to analyze the effects of bank stabilization on different planimetric and cross-sectional parameters such as sinuosity, bend length, meander wavelength as chord lengths, meandering index, radius of curvature were compared with and without bank stabilization. Some preliminary results for the Friedkin's case i.e. case with each outer bend stabilized near the thalweg except the last one are reproduced in Figure 2 and Figure 3. In this case, it can be observed that bank stabilization restricts both the longitudinal and lateral movement of the river bends within a certain corridor and results in a smaller sinuosity as compared to a river without bank stabilization (base case). Therefore, bank stabilization on each outer bend results in reduced bend length, chord length and in some cases, it produces smaller sharp bends with reduced radius of curvature. In addition, decrease in the width of the channel and increase in the depth of thalweg was also observed.

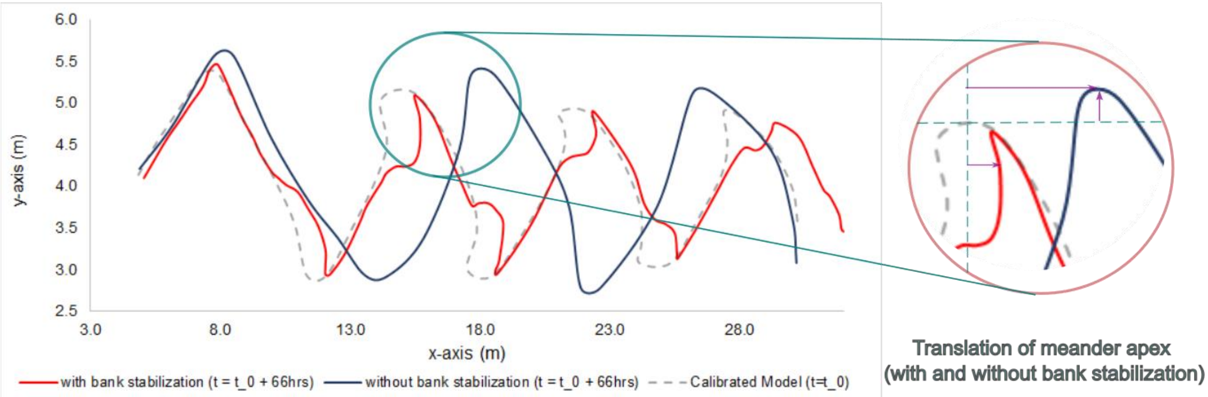

Figure 2: Planform changes (top view of thalweg) with and without bank stabilization

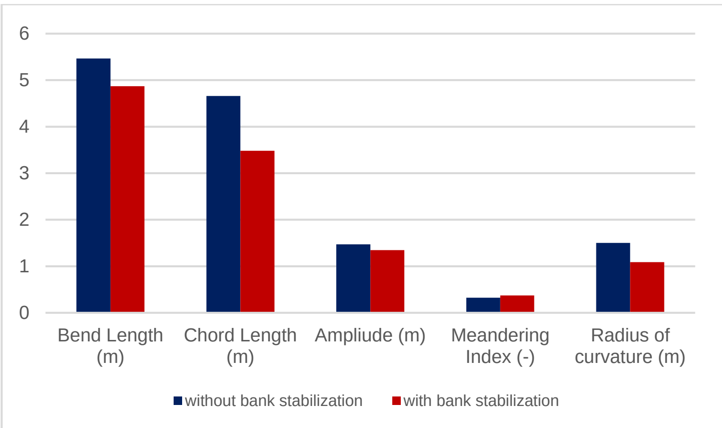

Figure 3: Comparison of modelled planimetric parameters with and without bank stabilization

The results produced by the model qualitatively agree with the experimental results of Friedkin and the field observations in real rivers. The analysis will be extended to analyze and compare the flood conductivity of rivers due to different configuration of bank stabilization. The study can also be extended further to validate the model against other experiments of Friedkin with different bed materials and sinuosity.

Application of machine learning for real-time prediction of dike breach inundation

Leon S. Besseling[a]
Anouk Bomers[a]
Suzanne J.M.H. Hulscher[a]

Highlights

- Hydrodynamic models do not allow flood scenario analysis of dike breaches during flood events
- Machine learning techniques promise fast computation, needed for real-time forecasting
- New machine learning models may be applicable to situations they have not learned or seen before

Overview

Floods are among the most destructive of all weather-related disasters. Because of this, humans have always had a desire to understand and predict floods. Dike breach floods have particularly sudden and severe consequences (Vorogushyn et al, 2010), so a fast and accurate understanding of the consequences is vital. This involves the expected discharge wave, the moment and mechanism of dike failure, and the propagation of the flood in the hinterland.

In recent years, numerical simulation tools like hydrodynamic models have become the most common and important strategy for simulating and understanding flood dynamics (Teng et al., 2017). Despite advances in parallel computing and other optimization methods, hydrodynamic models often have long computation times due to their physics-based nature and numerical solving of governing equations. In an emergency situation, water authorities are required to deliver relevant information on possible flood consequences in little time, so using hydrodynamic models is challenging (Leskens et al., 2014). For dike breach modelling, uncertainties in the expected discharge wave and the dike failure mechanisms should also be taken into account. Therefore, faster flood models are needed for real-time flood predictions, in which ensemble predictions and uncertainty analysis of possible scenarios allow for making informed decisions.

In this research, machine learning will be used for real-time flood inundation modelling in rivers, specifically for predicting the flood inundation after dike breach events. Machine learning techniques are data-driven and do not contain representations of physical descriptions from the original complex models (Razavi et al., 2012). They are trained to learn the relationships between input and output of complex models or observation data, after which they promise near-instant prediction times. Therefore they are a promising candidate for a flood model that can be used during an impending emergency situation. The objective of this research is to develop an operational real-time flood modelling system for flood prediction after dike breaches, that is computationally efficient and applicable for scenario-analysis during a flood event.

An important part of the objective is enlarging the applicability of machine learning models to situations that were not present in the data set used to create them, which is referred to as generalization. Such a generalized machine learning model can be of great value to water authorities to gain insight in flood consequences, and improve the emergency decision making process regarding possible disaster management strategies such as evacuation.

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Research approach

The research is conducted in the stages described below, each contributing to knowledge for creating a flood forecasting system based on scenario analysis that can be operated in real-time. The study area for the research will be dike ring 48 in the Netherlands, which is located between the Rhine at Lobith, the Pannerdensch Canal and the IJssel river (Fig. 1).

Uncertainty in outflow hydrographs

Modelling the effects of a dike breach in the hinterland requires a time series of discharge through the breach. This outflow hydrograph depends on the upstream discharge wave that acts as forcing on the dike, as well as the mechanism of dike failure (Fig. 1) (Vorogushyn et al., 2010). With the uncertainties present in both these factors, defining a deterministic outflow hydrograph is a challenge. To prepare for scenario analysis using fast overland flow calculations that are forced by the outflow hydrograph, a method to create a confidence interval around the outflow hydrograph is desired. To achieve this, a Monte Carlo analysis will be conducted on combinations of discharge waves and various failure mechanisms using a 1D river model of the Dutch Rhine branches.

Physical parameters in machine learning

For creating a generalized data-driven model for overland flow after a dike breach, a neural network should be able to handle hinterland characteristics of the study area, such as elevation, roughness based on land use and slope direction. This will make it applicable for more than one breach location in the area, and in varying scenarios such as winter/summer conditions. Two recent advances in neural network setup seem to have the ability to include such parameters, and have led to promising results in small-scale generalization experiments in fluid dynamics. Graph Neural Networks (e.g. in Pfaff et al., 2020; Liu et al., 2022) and Physics-Informed Neural Networks (Raissi et al., 2019) enable the use of machine learning on unstructured grids that are often used for flood modelling, as well as the ability for neural networks to learn the underlying physical processes from the input data. Using a hydrodynamic model of the study area, training data will be gathered to learn the neural network these processes in the context of dike breaches. Various combinations of physical parameters will be used to create neural networks, to assess which parameters are most needed to improve the accuracy of machine learning flood models.

Data requirements and application

The accuracy of a neural network depends on the accuracy of the hydrodynamic data it is trained on. Setting up an accurate hydrodynamic model requires a lot of input data, and running it for the creation of training data is very time consuming. Therefore, training data sets for neural networks should preferably be as small as possible. This research question evaluates how the performance of the best neural network from the previous section is affected by varying training data quantity and quality. The included amount of discharge scenarios and breach locations will be varied, as well as the completeness of the data in the hinterland. In the final phase of this research, the application capabilities of the created neural network will be evaluated. Tests on the inclusion of human interventions are conducted, and opportunities for the application in other study areas are explored.

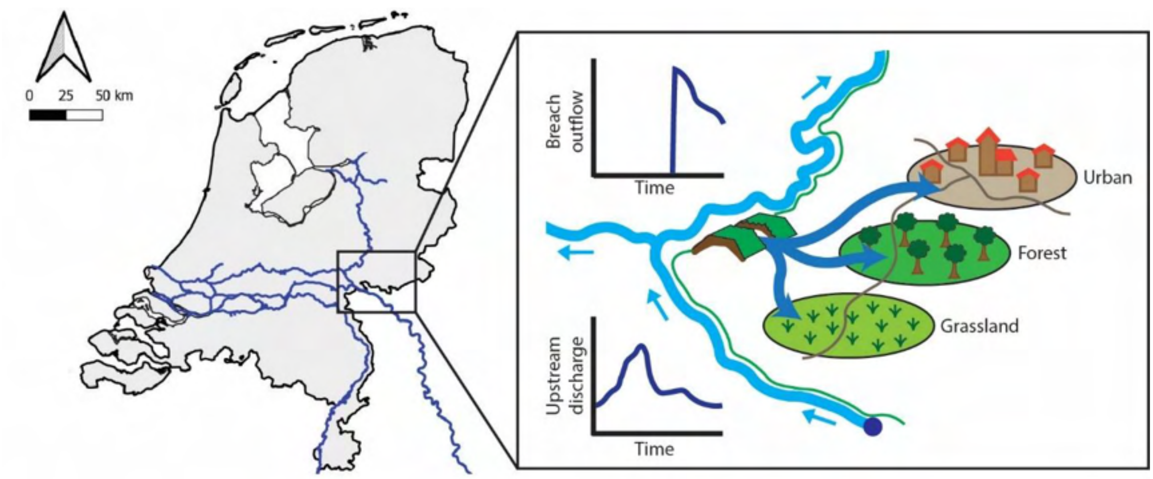

Figure 1. Study area with a schematic overview of the system of river dike breaching. An upstream discharge wave results in a dike breach and corresponding outflow. The flood propagation is affected by the topography and land use in the hinterland.

How to build vegetation patches in hydraulic studies: a hydrodynamic-ecological perspective on a biological object

Authors:
Loreta Cornacchia[a,b], Garance Lapetoule[a], Sofia Licci[a], Hugo Basquin[a], Sara Puijalon[a]

Highlights

- We collected morphological and biomechanical data on four macrophyte species (single plants to patches)
- This dataset aims to provide realistic vegetation characteristics for flume and modelling studies
- Significant allometric relationships between patch dimensions are described

Overview

Vegetation in freshwater and coastal ecosystems modifies flows, retains sediment, protects banks and shorelines from erosion (Haslam, 1978; Franklin et al., 2008). Hydraulic laboratory studies with live vegetation or artificial plant mimics, or numerical models with abstracted patches, are often used to quantify the effects of vegetation on water flow and sedimentation (e.g., Puijalon et al., 2008; Rominger and Nepf, 2014; Marjoribanks et al., 2017). However, the choice of plant and patch characteristics is often not supported by field observations of patch dimensions, density or spacing between consecutive patches. The discrepancy between plants in natural conditions and in flume experiments or numerical studies may affect the relevance of these findings for natural ecosystems.

This study aims to provide data for building realistic vegetation patches in ecohydraulic studies. We collected data on four species of fully submerged freshwater aquatic macrophytes that can grow into well-defined patches. We considered three relevant levels of organization: individual plants (inside patches), isolated patches and multiple neighbouring patches (full dataset is described in Cornacchia et al., 2023).

At the plant level, we observed significant differences in biomechanical traits (Young's modulus, flexural stiffness), resulting in stem Cauchy numbers ranging from 85.25 to 325.84, and leaf Cauchy numbers from 163.81 to 2003.97. At the patch level, we found significant relationships between patch length, width and height, showing covariation among different patch characteristics. The relationships among patch dimensions differed significantly among sampling sites for three of the four species, suggesting high intraspecific variability in patch sizes. By providing a first set of guidelines for choosing realistic and ecologically relevant plant characteristics, this dataset aims to improve our understanding of the complex processes occurring inside and around submerged vegetated patches.

Affiliations

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Introduction

Because of the importance of aquatic vegetation for hydraulics and ecosystem functions, many studies have explored the interaction between water flow and vegetation using either real plants (Puijalon et al., 2008) or artificial mimics (Kouwen and Unny, 1973; Rominger and Nepf, 2014). However, for freshwater species, there is a lack of data on the morphological and biomechanical characteristics of live plants and patches on which to base artificial mimics or for parameterization of numerical models. This highlights the need to collect field data on the relationships between plant and patch traits, and on both intra- and interspecies variability. By designing ecologically relevant vegetation patches, we can achieve a more realistic representation of vegetation and advance our understanding of plant-flow interactions.

Methods

The study was carried out on four species of fully submerged aquatic plants (*Callitriche platycarpa*, *Groenlandia densa*, *Elodea canadensis*, *Potamogeton crispus*) that show contrasting morphologies and grow into patches with well-defined edges. We focused on three relevant levels of organization: the individual plant within a patch, the patch, and the between-patch level. The collected parameters (Figure 1) were paired with data on local hydrodynamic conditions (water depth and flow velocity measurements).

Results

We found significant relationships between patch length, width and height for the species considered. The relationships between patch dimensions differed significantly among sampling sites for three of the four species, suggesting a high intraspecies variability in patch size (Figure 2). Significant differences in biomechanical traits (Young's modulus and flexural stiffness) were also observed. Depending on the species, shoot density varied from hundreds to a few thousand individuals per square meter, and the total dry mass per unit surface area tended to increase with patch length for all species. Distances between patches (gap sizes) and between patch centroids were on average 1.5 m.

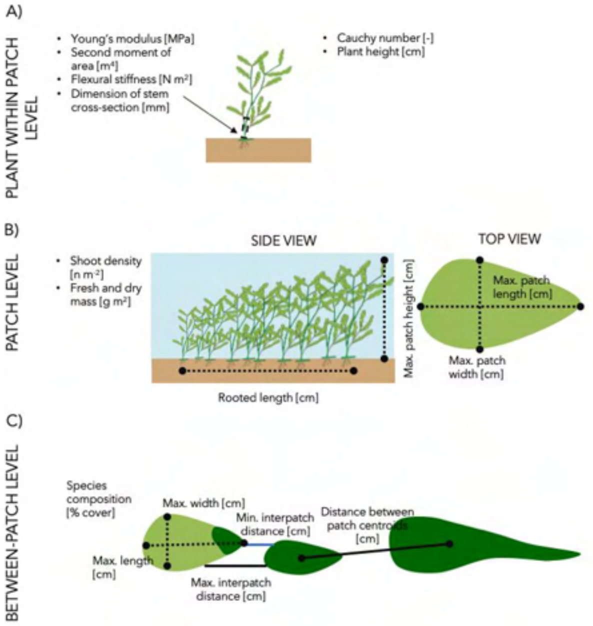

Figure 1. Overview of the measurements carried out on different aquatic macrophyte species at three levels of organization.

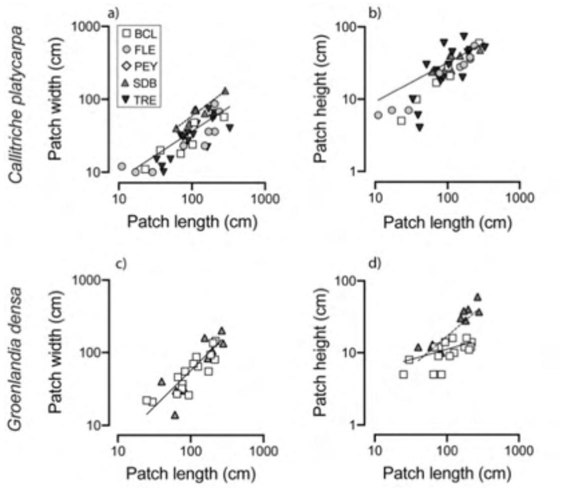

Figure 2. Allometric relationship between patch length, width and height for two of the studied species. The symbols indicate the sampling sites. Different regression lines are plotted if significant differences in the relationship were found among sites.

Conclusions

Results show that different plant characteristics covary in natural patches, as shown by the relationships between patch dimensions and by changes in dry mass with patch size. The covariation between different patch characteristics should be considered when building mimics, numerical models or planning experimental conditions, because not all combinations of parameter values might occur in nature. While the covariation between characteristics might seem to increase sampling efforts as there is a need to use paired data, it may also be a way to reduce sampling effort by using proxies. The statistical relationships presented in this study between patch dimensions are one example of how sampling can be reduced, by obtaining all required patch dimensions from aerial photographs.

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

Authors:
Evelien van Eijsbergen[a], Ralph M.J. Schielen[a],

Highlights

- 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

Introduction

The National Delta program 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.

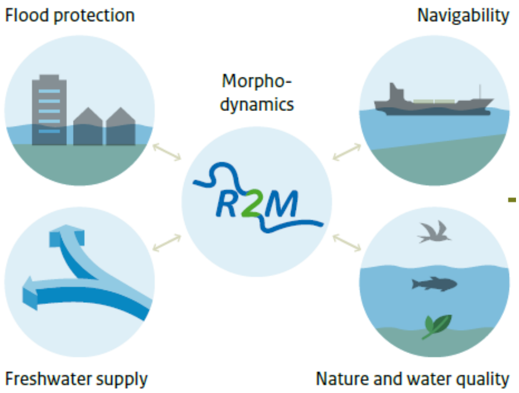

Figure 1. Policy themes of Rivers2Morrow.

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Website:
NCR knowledge base: Rivers2Morrow – NCR Knowledge Base (ncr-web.org).

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.

Within Rivers2Morrow three new PhD studies will start in 2023 on sediment dynamics of groyne field beaches and a combined study on the ecological and morphological characteristics of the Grensmaas.

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, Delft and Nijmegen 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 2023.
The studies contributes to the following programmes:

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

The steering comity decided at the end of 2022 to continue the R2M program with new research. At the beginning of 2023 it will be clear which topics these will be.

Mediated participation for integrated river management with Visual Problem Appraisal (VPA)

Jan. M. Fliervoet[a],
Loes M. Witteveen[a,b]

Highlights

- We used a Visual Problem Appraisal for mediated participation in river management
- VPA workshops are organized for students and the National Water Authority
- Using the VPA solves two problems: stakeholder fatigue and participation of usual suspects.

Overview

To address the current challenges in river management it is commonly recognised that integrated and multi-actor approaches are needed to sustain and maintain the diverse functions of a river landscape, such as safety against flooding, inland waterway, nature, freshwater supply and agriculture (Havinga, 2021; Den Haan et al., 2018). Simultaneously, citizens emphasize the need for participatory and deliberative approaches as river projects (e.g. dike reinforcements) often have a major impact on their living environment. Several reasons exist to engage diverse stakeholders in decision-making for integrated river management; the decision-making becomes better informed and creative, public problem awareness and commitment are increased, the democratic right of stakeholders is strengthened, and social learning is enhanced (Reed, 2008). Despite the advantages of stakeholder participation, it is not an easy task and it comes with diverse challenges. In such complex contexts some stakeholders might be 'overlooked' or do not participate for prevailing reasons such as shortage of time. To include their stories, perspectives and narratives mediated participation approach can be used, because *"it allows policy and decision makers to 'learn' in mediated interaction with distant stakeholders"* (Witteveen et al., 2009, p.32).

An example of a mediated participation approach is the Visual Problem Appraisal (VPA) method to support participatory and deliberative governance. VPA is a film-based learning strategy with ethnographic, deliberative, and artistic aspects, which aims to enhance the problem analysis of complex issues and to facilitate the development of actions. The characteristic component of a VPA set is a series of stakeholders' interviews or filmed portraits which creates a space for problem analysis, social dialogue, and policy design (Witteveen & Lie 2012).

Mediated participation workshops have been organized with employees of the National Water Authority and students to discuss and integrate the diverse discourses and perspectives for integrated river management in the Netherlands.
The results show that the VPA methodology offers an innovative tool for participatory and deliberative governance. Using the VPA solves two well-known problems: shortage of time and means for stakeholders to participate (stakeholder fatigue) and the fact that often the same people participate in diverse arenas (the usual suspects). To further explore the potential of the VPA methodology we will embark on experimenting with the VPA in relation to nature-based solutions, for example living dikes, in the context of river management (see below).

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Visual Problem Appraisal (VPA)

VPA is used in diverse arenas such as policy design and education in a structured way, consisting of three phases: (1) A scoping stage where participants become familiar with subject matter issues through facilitated scoping activities study and deliberation; (2) Stakeholder consultation, where participants select and view a number of filmed interviews and analyse the experience and the findings. 'Meeting' a number of stakeholders allows the participants to learn about the different perspectives of these interviewees and the way they frame their problems. (3) An ‘action’ stage, participants interpret and organize all information even when confusing, or contradicting information and consider recommendations for action. This can take various shapes such as scenario development, policy design or elaborated project proposals.

Research program Living dikes

In the Netherlands, there is a great interest to use nature-based solutions in river management, such as implementing living dikes (grass dikes with wetlands in front of them). However, the large-scale implementation of living dikes is hampered by among others a lack of societal, technological, and governmental knowledge on how to design, implement and maintain living dikes. The aim of this research program is to understand how to realize resilient and climate-proof living dikes (Figure 1). An important social question is how different discourses, narratives and perceptions influence the implementation of living dikes. Therefore, we use a Visual Problem Appraisal (VPA) methodology to connect and share various perceptions regarding the concept of living dikes to enhance sustainable river management.

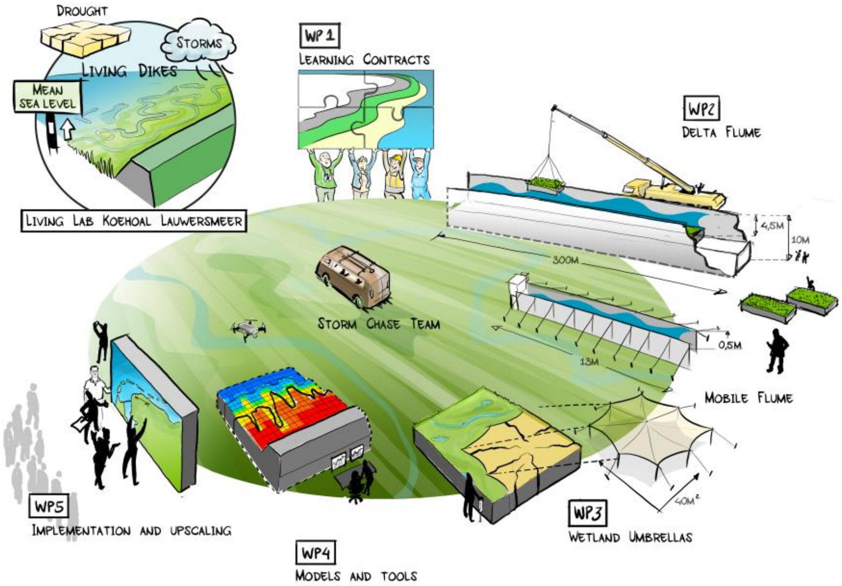

Figure 1. Overview of work package in the research program Living Dikes (source: Borsje et al., 2020)

Exploring changes in discharge distribution in the Rhine branches induced by extreme scour

Authors:
Bas Gradussen[a]
Gonzalo Duró[a]
Michiel Reneerkens[b]
Arjan Sieben[b]
Wim Ridderinkhof[a]

Highlights

- Exploratory study on shifts in discharge distribution induced by large scour holes in the Rhine branches
- Even extreme scour holes at the bifurcations of the Dutch Rhine branches have a limited effect on the distribution of water over these branches and therefore a limited effect on high water safety

Introduction

After the July-2021 flood in the Meuse River, scour holes with a depth of up to 20 meters were observed (ENW, 2021). Such features potentially have a severe impact on water safety (e.g. inducing dike instabilities). In the Rhine River, scour that develops during floods may have additional effects on water safety: local bed changes at the Rhine bifurcations (Pannerdensche Kop and IJsselkop) may cause changes in discharge distribution over the Rhine branches. This could result in higher water levels in a certain branch compared to the 'High Water Reference' (HWR) that is embedded in the current policy. In this study, realistic- and worst- worst-case scour events are evaluated. It is investigated to what extent extreme scour changes the discharge distribution over the Rhine branches.

Methodology

Changes in discharge distribution at the bifurcations are studied for scour holes that could develop (realistic worst case) at the bifurcation points during an extreme flood wave. Scour dimensions are based on several conservative assumptions: (1) scour pits develop only in the smallest branch downstream of bifurcations, where both flow velocities and energy head gradients are largest (observed from reference simulations); (2) during the flood event, the coarse top sediment layer of the riverbed is completely mobilized and the finer substrate layer (D_{50} ~100µm) is exposed to currents; (3) the scour shape (Fig.1) and its temporal development are based on Hoffmans and Verheij (1997); (4) scour develops under clear water conditions; (5) scour holes develop during the exceedance of 10.000 m^3/s in a theoretical flood wave with a peak discharge of 18.000 m^3/s (based on Hegnauer et al., 2014); (6) scour computations are done for conditions that occur during a discharge of 18.000 m^3/s. Changes in discharge distribution at the bifurcations are assessed using WAQUA-simulations of the Rhine model by imposing discharges 14.000, 15.000 and 16.000 m^3/s. The discharges through each branch are compared to the discharges in the branches that result from reference simulations (without scour). Four scenarios are simulated: a realistic-worst case (RWC) and a worst-worst case (WWC) at both bifurcation points (Fig.2). The WWC-scenarios are not realistic. Yet, it is investigated whether a significant increase in erosion volume would induce a severe shift in discharge distribution. In the WWC scenario the erosion volume is increased by a factor five with respect to the RWC.

Results

The impact of both RWC erosion scenarios on the discharge distribution at the bifurcations is limited. For the simulated discharges, the WWC scenario at the Pannerdensche Kop causes a shift of 90 - 100 m^3/s (+1,8%) towards the Pannerdensch Kanaal, leading to an increase in discharge through the Nederrijn and IJssel of 40-50 m^3/s (+2,0%) each. The WWC scenario at the IJsselkop induces a shift of 25-40 m^3/s (+0,6%) towards the Pannerdensch Kanaal, an increase through the IJssel of 100-125 m^3/s (+5,1%), and a drop of 70-90 m^3/s (-2,7%) through the Nederrijn.

Discussion and recommendations

Main uncertainties in this study stem from the sediment composition of the substrate sediments and the shape of the flood wave. This approach is relevant for a first quantitative assessment of potential risks. Subsequent studies will benefit from further information on substrate data. Insipient development of scour holes can be further investigated with e.g. morphological models, field observations or reduced-scale models.

Affiliations

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[b] Rijkswaterstaat

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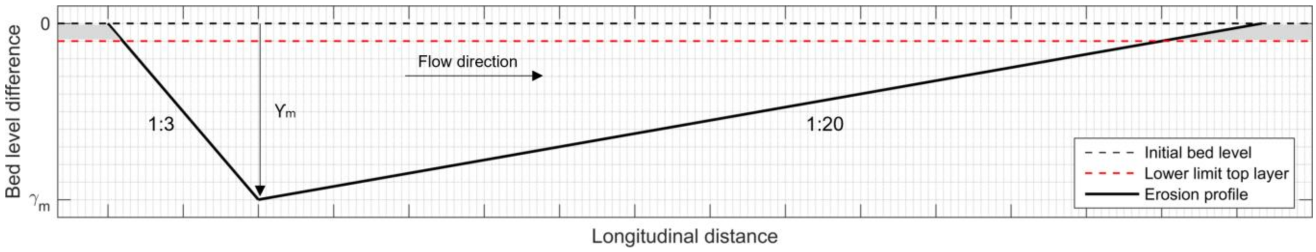

Figure 1. Theoretical longitudinal profile of scour holes

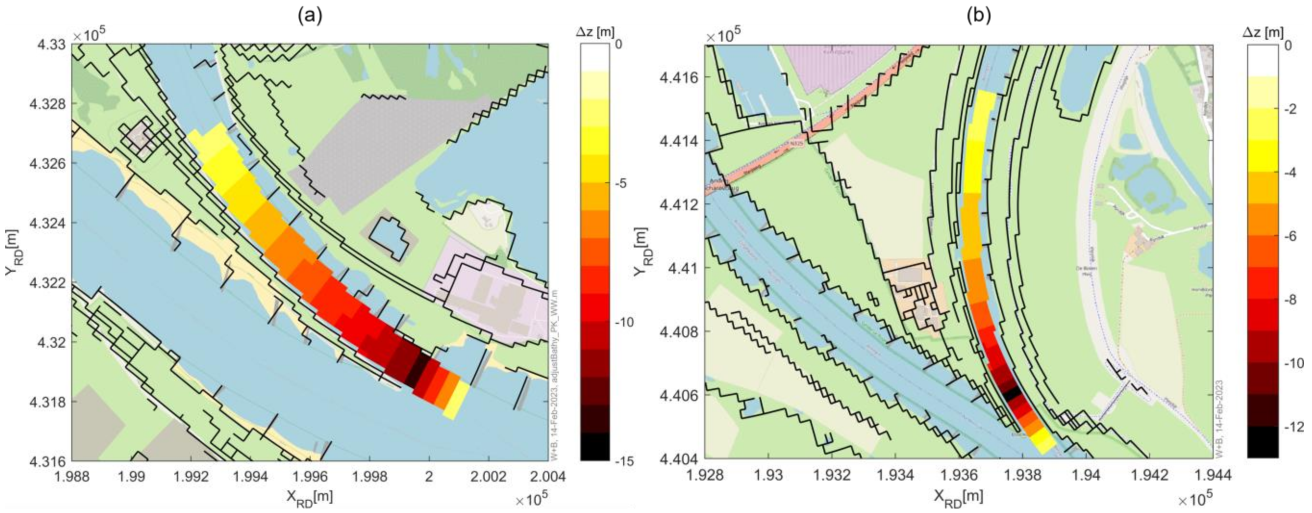

*Figure 2. Difference in bed level of the WAQUA-model bathymetry compared to the reference model for the worst-worst case scour holes at **(a)** the Pannerdensche Kop and **(b)** the IJsselkop*

*Table 1. Changes in discharge distribution over the Rhine branches for upstream discharges (at Lobith) of 14.000, 15.000 and 16.000 m^3/s in case of erosion at **(left)** the Pannerdensche Kop and **(right)** the IJsselkop. The RWC scenarios have a limited impact on the discharge distribution. The WWC scenario at the IJsselkop leads to an exceedance of the HWR-policy discharge in the IJssel at approximately 15.400 m^3/s (Lobith)*

		Erosion at Pannerdensche Kop		
Discharge at Lobith [m^3/s]		Reference [m^3/s]	RWC Difference [m^3/s]	WWC Difference [m^3/s]
14.000	Waal	8.967	-21 (-0,2%)	-91 (-1,0%)
	Pann.Kan.	5.033	+21 (+0,4%)	+92 (+1,8%)
	Nederrijn	2.978	+11 (+0,4%)	+49 (+1,6%)
	IJssel	2.055	+9 (+0,4%)	+42 (+2,0%)
15.000	Waal	9.569	-24 (-0,3%)	-96 (-1,0%)
	Pann.Kan.	5.431	+23 (+0,4%)	+96 (+1,8%)
	Nederrijn	3.190	+13 (+0,4%)	+52 (+1,6%)
	IJssel	2.241	+11 (+0,5%)	+45 (+2,0%)
16.000	Waal	10.166	-26 (-0,3%)	-99 (-1,0%)
	Pann.Kan.	5.835	+26 (+0,4%)	+97 (+1,7%)
	Nederrijn	3.404	+15 (+0,4%)	+53 (+1,6%)
	IJssel	2.431	+10 (+0,4%)	+45 (+1,9%)

		Erosion at IJsselkop		
Discharge at Lobith [m^3/s]		Reference [m^3/s]	RWC Difference [m^3/s]	WWC Difference [m^3/s]
14.000	Waal	8.967	-4 (-0,0%)	-26 (-0,3%)
	Pann.Kan.	5.033	+4 (+0,1%)	+26 (+0,5%)
	Nederrijn	2.978	-12 (-0,4%)	-76 (-2,6%)
	IJssel	2.055	+16 (+0,8%)	+103 (+5,0%)
15.000	Waal	9.569	-6 (-0,1%)	-30 (-0,3%)
	Pann.Kan.	5.431	+5 (+0,1%)	+30 (+0,6%)
	Nederrijn	3.190	-13 (-0,4%)	-85 (-2,7%)
	IJssel	2.241	+18 (+0,8%)	+115 (+5,1%)
16.000	Waal	10.166	-7 (-0,1%)	-36 (-0,4%)
	Pann.Kan.	5.835	+6 (+0,1%)	+34 (+0,6%)
	Nederrijn	3.404	-12 (-0,4%)	-90 (-2,6%)
	IJssel	2.431	+18 (+0,7%)	+124 (+5,1%)

Multi-model simulation of wadi flash floods using global data

Robert Groenewege[a,b]
Amgad Omer[a]
Mohamed Yossef[a]
Geert Prinsen[a]
Bert Jagers[a]
Victor Chavarrias[a]

Highlights

- We test the performance of Delft3D modelling of wadi flash floods with global data
- Simulated hydrographs and flood extents showed good agreement with measurements
- Delft3D FM can be successfully employed to model the wadi flash flood hydraulics

Overview

A wadi (from the Arabic wādī or wād) is the valley or bed of an ephemeral river that forms as the result of heavy rain during a short period in an otherwise year-round (semi-)arid region. Wadi flash floods (WFFs) are regularly and increasingly occurring especially in the Middle East and North Africa (MENA) region. Their impact can be devastating to the social environment, due to loss of lives and displacement, and to buildings and infrastructure. Other common problems include dam reservoir siltation from high sediment yields and contamination of bays and rivers.

Despite the high disaster risk, a comprehensive and holistic hazard risk assessment framework for wadis is still lacking (e.g. Kantoush et al., 2022). In general, there is a lack of observational data and monitoring, which limits our understanding of WFFs and capabilities of flash flood prediction and risk assessment (Kantoush et al., 2022). Therefore, there is a great need for WFF modelling solutions tailored to ungauged basins. The primary objective of this research was to validate and assess the performance of the 2D morphodynamic solver Delft3D Flexible Mesh (FM) for WFFs using global data as input. This advanced modelling suite developed by Deltares is the successor to Delft3D 4 and includes recently added modules for rainfall and infiltration, among other capabilities that make the software promising for WFF modelling. Results from Delft3D FM were compared with other 2D suites, i.e. wflow, Deltares' solution for hydrological modelling at the catchment scale, and HEC-RAS, which has previously been used for rain-on-grid simulations and cases like WFFs and was therefore used as reference. Measurements of flow and sediment concentration were also available with which the models were validated.

Delft3D FM and HEC-RAS can be successfully employed to model the hydrology and hydraulics of wadi flash floods in detail. The most important processes can be included and modelled, i.e. precipitation, infiltration, evaporation, runoff, and flow resistance. It is recommended to increase the reliability and scalability of Delft3D FM for two-dimensional wadi flash flood modelling:

- More validation and calibration studies are needed to ensure reliability.
- Further development of the model setup automation is recommended to improve the scalability.

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Modelling methods

Two case studies of wadi systems were selected (one highlighted here), for which typical flash floods were modelled as they propagate through the catchment over an initially dry bed. The prime focus of the modelling was schematisation and investigation of the following physical wadi flash flood processes: rainfall-runoff, infiltration, soil erosion, and sediment transport under overland- and stream-flow conditions. The input data consisted mostly of preprocessed global data retrieved through Hydro Model Tools (MT) in Python (Table 1). At least for large wadi catchments (>100 km^2), the datasets showing most usability were the Copernicus DEM for terrain and wadi basin delineation, ESA WorldCover for land cover and associated terrain roughness, and SoilGrids soil texture for modelling diffuse infiltration. However, the quality and spatial resolution of the global rainfall data were found to be lacking, which is regarded as the main limitation preventing exclusive use of global data.

Table 1. Model input components.

Model input	Source	Resolution
DEM	Copernicus DEM	30 m
Basin perimeter	MERIT Hydro	-
Rainfall Evaporation	ERA5 reanalysis + calibration	hourly 30 km
Infiltration	Copernicus Global Land Cover + SoilGrids soil texture + lookup table	250 m
Roughness	Copernicus Global Land Cover or ESA WorldCover + lookup table	100 or 10 m

Case study: Wadi Aday, Muscat

Wadi Aday is located in Muscat, Oman (Fig. 1). It originates in a relatively flat plain and flows through a narrow gorge towards Qurum, the "most important urban area of the country" (Al-Rawas et al., 2015) before discharging into the sea. Its watershed has an area of approximately 365 km^2 (Al-Rawas et al., 2015; Saber et al., 2022) and is mostly unvegetated. In recent decades, Muscat has undergone rapid and extensive urban growth, significantly increasing the flood risk. This became apparent when in 2007 Oman was hit by the strongest tropical cyclone recorded in the Arabian Sea (Fritz et al., 2010) called Gonu. Large low-lying areas of Muscat became inundated as the result of WFFs and storm surge, causing over 4 billion USD in damages and 49 deaths (Fritz et al., 2010)

For the wadi Aday flash flood (Fig. 2-3), Delft3D FM and HEC-RAS were similarly valid (R^2 = 0.87, using the same input data) and more accurate than wflow. Although HEC-RAS was found to benefit from its subgrid bathymetry approach, allowing for coarser model grids, it had more instability issues that slowed down computation. With optimised settings in HEC-RAS, Delft3D FM was still twice as fast as HEC-RAS while its volume accounting error was 130 times smaller. Sediment transport and erosion modelling in the other case study was comparatively less successful. It is less straightforward and requires more calibration, tuning, and stabilisation to achieve acceptable results.

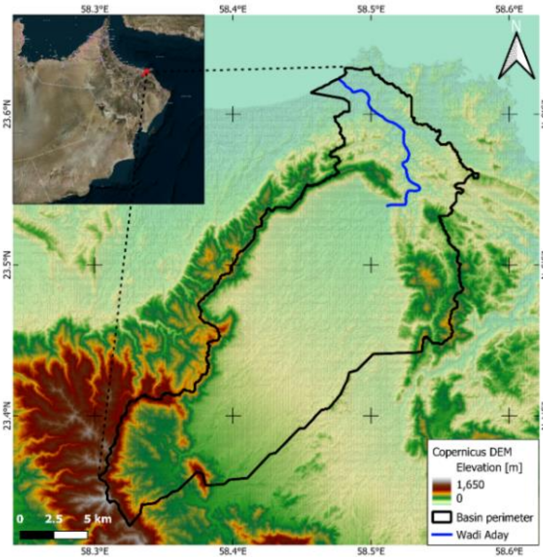

Figure 1. Wadi Aday study area.

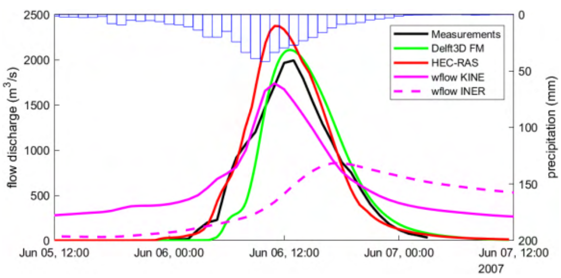

Figure 2. Hydrographs of the wadi Aday Gonu flood event. KINE: kinematic wave approach; INER: local inertial approach.

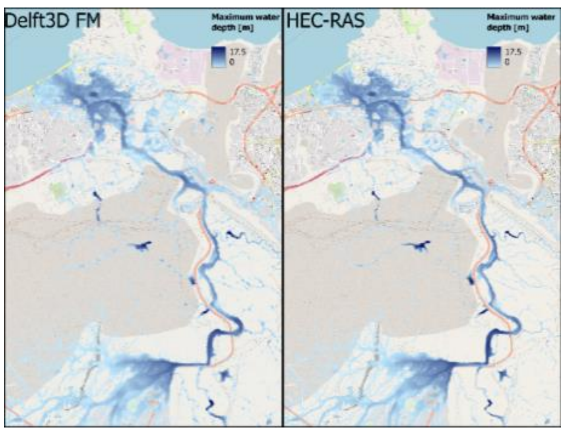

Figure 3. Simulated inundation of wadi Aday and Qurum, Muscat, as the result of the Gonu flood event.

Analysing the spatio-temporal variability or river dune induced bed roughness for the Midden-Waal

Joël. R. Haase[a,b],
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Roy J. Daggenvoorde[b],
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Highlights

- We analyse the spatio-temporal variability in dune induced bedform roughness
- The spatio-temporal variability in dune induced bedform roughness is high
- Roughness sections in hydrodynamic river models should be as small a possible

Overview

Rivers are an important part of the Dutch landscape. Proper management protects us from floods and mitigates the effects of low flows. In order to adequately deal with the effects of climate change on the discharge regime, accurate predictions of future water levels are needed to avoid over- or undersized interventions with their financial and societal consequences. Hydrodynamic river models, commonly used for water level prediction, are calibrated using a main channel bed roughness parameter. Once calibrated, no distinction can be made between the contributions of sources such as groins, bed forms, grainsizes and other unidentified sources into this calibration. The roughness caused by these sources changes with discharge and varies along the rivers, introducing model errors.

Spatio-temporal variation of river dune induced roughness is analysed in order to reduce the uncertainty in the main channel roughness parameter in hydrodynamic river models. By decomposing the contribution of dune-induced roughness to this parameter, a first step is made towards reducing the uncertainty in the prediction of extreme reach water levels. This will be part of further research.

River dunes are subject to changes in flow and associated sediment transport and their geometry depends on the flow conditions. Warmink (2014) observed hysteresis in dune height and length and dependence on flood wave characteristics. Lefebvre & Winter (2016) showed that the lee side angle determines the magnitude of flow separation and Lokin et al. (2022) concluded that dunes become longer during low flow, contrary to the common assumption at the time that the aspect ratio between dune height and length is constant.

We re-analysed the response of dune height and length to changing discharge and mapped the spatio-temporal variability of river dune induced roughness by averaging the dune field over sections of different size.

In line with existing literature, we showed that dune height is positively correlated with discharge while dune length increases with decreasing discharge. The spatio-temporal variability in river dune induced roughness increases with increasing discharge and decreases when the dune field is averaged over larger river sections. River dune induced roughness is strongly location dependent.

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Response of dune dimensions to discharge

Dune dimensions respond to changes in discharge. Figure 1 shows the response of dune height to discharge. Dune height is positively correlated with discharge, but does not follow the small deviations from the overall trend. The confidence interval in dune height is larger during periods of approximately constant discharge compared to the transition periods between low and high discharge. The response of dune length (figure not shown here) is somewhat different. Dunes become longer as discharge decreases. Compared to dune height, dune length is more sensitive to small variations in discharge. In contrast to dune height, the confidence interval of dune length increases during the low discharge. Translating these results using the formula of van Rijn (1984), $k_s = 1.1H\left(1 - e^{-\frac{25H}{L}}\right)$, shows that river dunes cause higher roughness heights during higher discharges. At low flow rates, the roughness height decreases with increasing dune length.

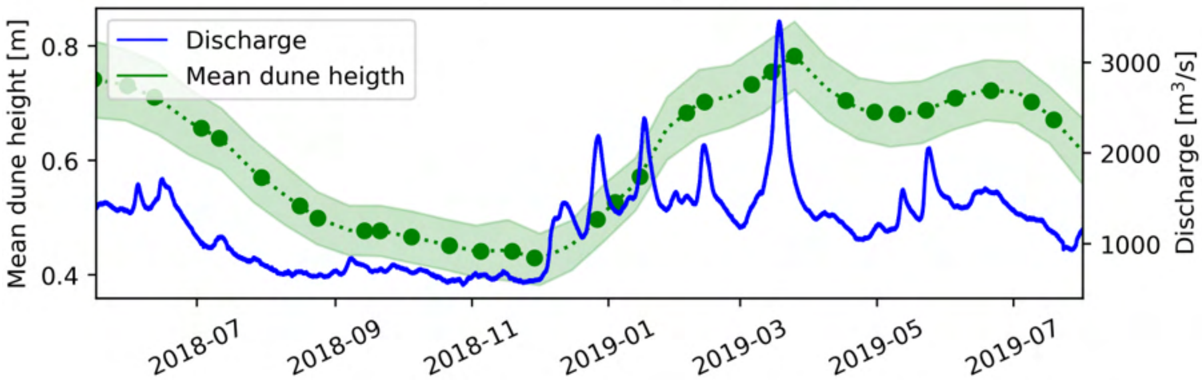

Figure 1 Mean and 95% confidence interval of dune height calculated over the whole Midden-Waal. The green dots show the dates on which the bed measurements are done. The blue line corresponds to the dischargpe

Spatio-temporal variation in roughness height

Figure 2 shows the spatio-temporal variation in river dune induced roughness in the Midden-Waal. The spatio-temporal variation is relatively small during low discharge periods. When the river is divided into more sections, over which the roughness height is calculated using averaged dune field statistics, more spatial variation appears. At the end of the low flow period, the roughness height has decreased compared to the beginning of the low flow period. After the discharge has increased, the spatial variation has become much larger compared to the period of the low flow. Apparently, dunes become much higher and/or shorter at some locations along the river. It can be concluded that the river dune induced roughness height is location dependent, both in length and width direction.

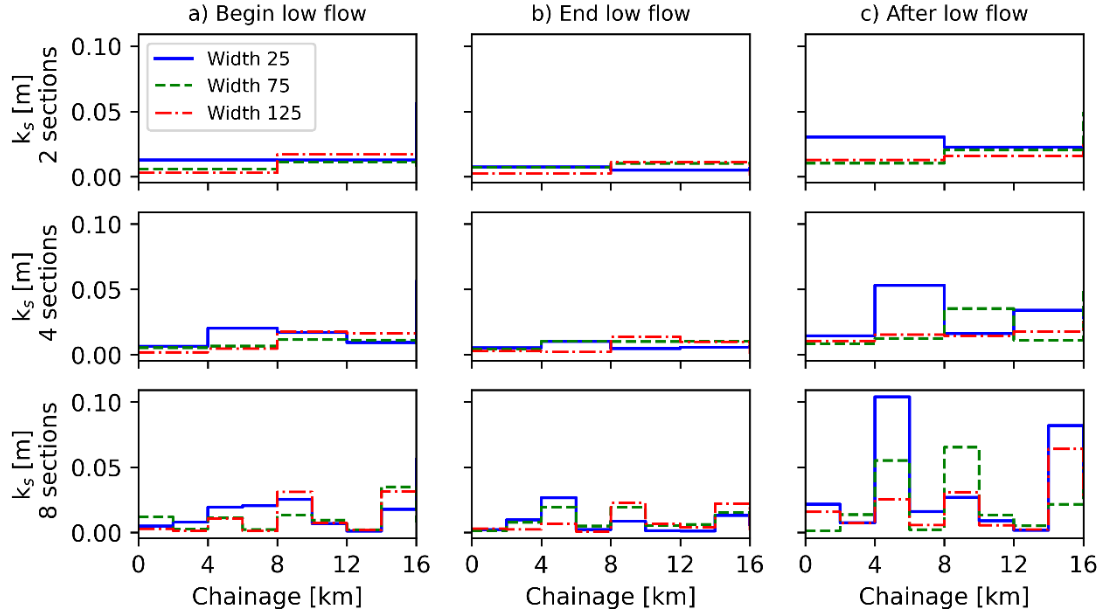

Figure 2 Spatio-temporal variability in river dune induced roughness in the Midden-Waal. Calculated at three locations [25, 75, 125] meter in the fairway of approximately 150 meters wide. Columns a) and b) show the spatial variation at the start and end of the low flow (Q = ~800 m³/s): 2018-08 – 2018-11. Column c) shows the spatial variation two months after the low flow (Q = ~2000 m³/s): 2019-01. The Midden-Waal is approximately 16 km long. The three rows show the spatial variability in river dune induced roughness when using dune dimensions averaged over 2,4 and 8 sections of equal length.

Flood forecasting for the Rur: preliminary results for the 2021 flood event (MSc thesis)

Sebastian Hartgring[a]
(Mark Hegnauer[b])
(Daniel Bachmann[c])

Highlights

- An ensemble flood forecasting model is developed for the Rur-catchment following the 2021 floods.
- Preliminary results are promising and show the advantages of using an extended catchment-wide model.
- Next step is to use ICON and ECMWF ensemble forecasts and determine model sensitivities.

Overview

During the 2021 flood event, water level and discharge predictions for the Rur formed the basis for reinforcement and evacuation. However, these predictions changed rapidly as they relied on data from failing near-border gauge stations in Germany (COT 2022). Additionally, existing models in Germany and the Netherlands stop at the border, and thus rely on each other for providing boundary conditions.

A possible solution is to develop a catchment-scale inundation model and combine existing hydrological and hydrodynamic models to improve lead times, and extend it using ensemble members as forcing data. This raises the following question: Could an extended hydrological-hydrodynamic model driven by ensemble predictions improve flood forecasting for the Rur catchment?

For this research, the distributed hydrological Wflow model (van Verseveld et al. 2022) is combined with the 1D2D-hydrodynamic ProMaIDes-model (Bachmann 2012) for the Rur catchment. Anthropogenic influences such as reservoir management are included in discharge predictions of the hydrological model. The model is calibrated using historical E-OBS data (2014-2020) and validated for the 2021 flood event using a reanalysed weather dataset from the Royal Meteorological Institute of Belgium (RMI).

As a second step, short range and medium range ensemble weather forecasts are used as input data to simulate flood predictions prior to the flood event. Two datasets are considered: European ECMWF forecasts and German ICON forecasts. Consequently, model sensitivity is analysed by varying spatial resolution, varying temporal resolution, reducing model complexity (e.g. reservoir modelling and tributary inclusion) and comparing flow propagation schemes for the hydrological model.

Calibration results show improvement for the hydrological model after incorporating local datasets and anthropogenic influences. Reservoir modelling significantly improves model results when using a volume-based discharge approach for the reservoirs based on operation plans. Additionally, hydrodynamic results show flood maps coinciding with results from similar studies, with a peak discharge of Q = 350 m^3/s at Stah.

These results show that the current model setup provides a solid basis for further steps in this investigation. However, run times of 10+ hours for a single 1D2D-hydrodynamic simulation indicate that a sub-selection of the ensemble members may need to be considered.

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The flood event of July 2021 in the Rur catchment

In July 2021, a major flood event surprised Western Europe, resulting in over 200 fatalities. The Rur river, a tributary of the Meuse, was also affected by flooding in Germany and the Netherlands. This catchment is characterized by a strong distinction between steep, impermeable, and forested slopes upstream and a flat, permeable, and industrialized area downstream (Bogena et al. 2005). Furthermore, 7 reservoirs and dams are managed by local authorities with improving flood safety as main function. These dams played an important role in preventing a full flood disaster in July 2021, as 40 million m3 was stored behind the dams (Asselman and van Heeringen 2023). Therefore, including and predicting reservoir management is considered a key aspect of developing the flood forecasting model, as shown by results in figure 1. Maximum discharge at Stah is overestimated for both 1-dimensional simulations as storage in floodplains is not taken into account. The 1D-2D hydrodynamic model does include this storage component and thus produced a peak discharge of Q = 350 m^3/s.

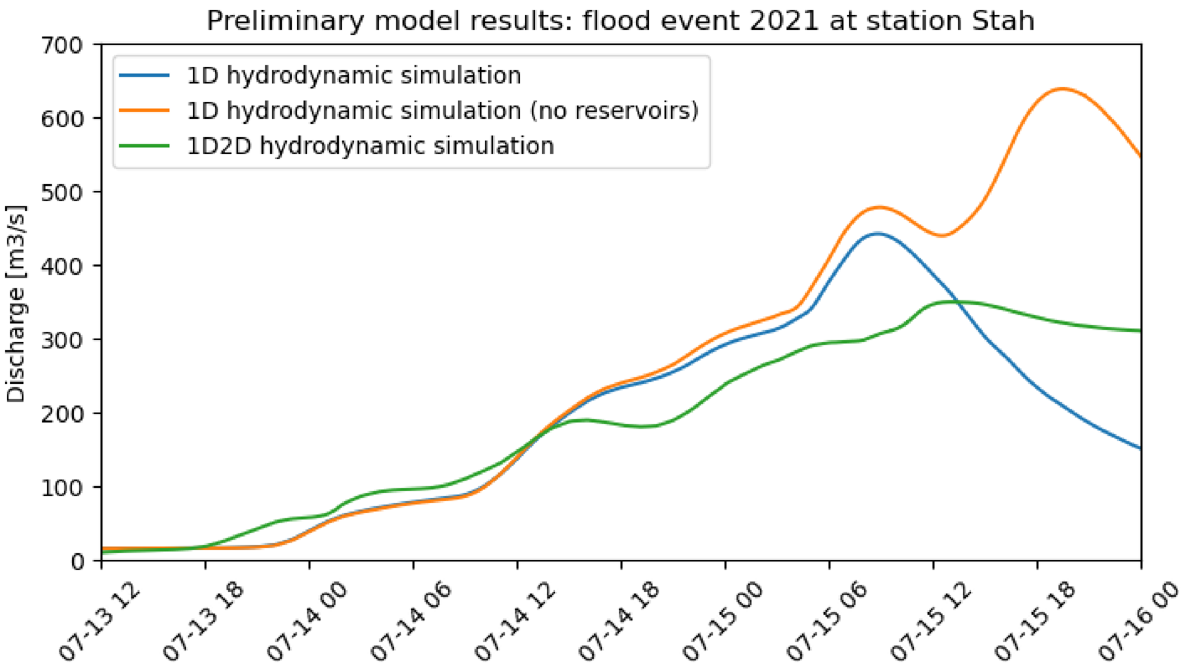

Figure 1. Results of the hydrodynamic model for the 2021 flood event at Stah. RMI dataset is used for precipitation and boundary conditions are determined using the hydrological model.

Addressing model sensitivities

Ensemble forecasting produces members with diverging outcomes, resulting in a suitable test case for addressing model sensitivity. On one hand, the Rur-system may be sensitive to locality of the precipitation event with respect to the reservoirs, as flows passing through the reservoirs will be stored or dampened out compared to non-reservoir tributaries. Additionally, surface and subsurface flow is affected by local characteristics such as terrain slope, vertical conductivity of the soil and the presence of mining industries, which vary in the catchment. However, the Rur river contains wide floodplains in the downstream area. Therefore, variation in discharge patterns and volume may still result in similar inundated areas and therefore limit flooding to the known floodplains. Our hypothesis is that analysis of the ensemble members will still show variations in downstream inundations as not all tributaries are connected to the reservoir systems.

Additionally, the following model configurations will be analyzed:

- Spatial resolution: 200m, 1km, 3km
- Temporal resolution: 1h, 6h, 24h
- Model complexity: tributary and reservoir inclusion
- Flow propagation schemes: kinematic wave, local-inertial flow, diffusive wave

Future dikes: species rich and sustainable river dike grass covers

Steven H. Huls[a],
Eric J. W. Visser[a],
Hans de Kroon[a]

Highlights

- In October 2022 we constructed four small-scale river dikes and seeded them with ten seed mixtures that increase in species diversity.
- Using msGBS (Wagemaker et al., 2021), we can quantify root abundance in mixed root samples in high taxonomic resolution.

Overview

Without proper protection from the water, roughly 60% of the Netherlands would flood on a regular basis. Climate change causes sea levels to rise in one hand, and peak river water discharges in the other, thereby pressuring water safety. The severe summer floods in July 2021 affected several European, signaling that high water events are no longer limited to the winter season.
Over 3.700 kilometres of primary embankments protect the Netherlands from floods from the major rivers, lakes and the sea (Rijkswaterstaat, 2022). To maintain protection from the water in the Netherlands, safety standards are specified in the Water Act (Dutch: Waterwet) (Rijkswaterstaat, 2022), and dikes that do not meet the prevailing safety norms, need to be fortified. Conventional dike reinforcement involves widening and/or heightening the dike and is therefore a costly and time consuming procedure. The new safety norms for wave overtopping tests have resulted in the necessary reinforcement of 1.300 kilometres of Dutch river dikes in the next 30 years (Rijkswaterstaat, 2022).
The majority of Dutch river dikes is currently covered with a species-poor grassland vegetation, which is characterised by more shallow-rooting plant species, such as grasses like *Lolium perenne* and *Festuca rubra.* These species are selected in the seeding mixtures as they germinate and develop rapidly (Handreiking Grasbekleding, 2021). We hypothesise that due to the more shallow roots, the vegetation is more vulnerable to: (1) wave overtopping erosion in periods of high water, and (2) longer periods of drought, as grass roots are incapable of reaching deeper soil layers where water is still present. In periods prolonged drought, grasses are withering and dying. The major risk hereof is the development of large, open spots in the vegetation cover in the next winter period. Moreover, these open spots are vulnerable to unwanted plant species.
Prior research has shown that a species rich grass cover translates into stronger, more intertwined root mats and consequential lower soil erosion (Berendse et al., 2015; Gyssels et al., 2005; Liebrand & Sykora, 1996; Mommer et al., 2015), as well as a higher drought resistance (Hoekstra et al., 2015). However, which species make up the ideal composition of seed mixtures for river dikes and which traits correspond with these plant species still remains unclear. Moreover, little is known about the belowground root processes that could contribute to river dike fortification.
In this research project, our aim is to demonstrate that a higher species richness of the vegetation composition contributes to the erosion and drought resistance of Dutch river dike vegetation covers, by studying below-ground plant interactions on root proliferation and translating those findings into practical recommendations for sustainable dike construction and vegetation maintenance.

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Proposed research

In this research project, our aim is to demonstrate that a higher species richness of the vegetation composition contributes to the erosion and drought resistance of Dutch river dike vegetation covers, by studying below-ground plant interactions on root proliferation and translating those findings into practical recommendations for sustainable dike construction and vegetation maintenance. In order to do so, the following research questions have been formulated:

1) What are the effects of soil nutrients and neighbouring plant species on root proliferation on the intra- and interspecific interactions of common grassland species?
2) To what extent can the aboveground biomass and vegetation coverage be used as predictor for belowground root abundance and biomass?
3) Which combination of drought response mechanisms of commonly occurring plant species on Dutch river dikes lead to a sustainable and drought tolerant grass cover? To what extent and in what way do these plants differ regarding their resilience and recovery capabilities to periods of drought?
4) Which traits of which plant species contribute to the coagulation and stability of Dutch river dike top soil, thereby reducing soil erosion?

Scientific impact

Our research will work towards a better understanding of belowground inter- and intraspecific plant interactions, as well as their response to environmental stressors as drought. By studying spatiotemporal variations of root distributions of different species compositions via minirhizotron imaging, we can shed light on plant-plant interactions occurring in the soil. Repeated soil coring sampling in combination with high throughput sequencing can help in understanding the belowground processes of root-root interactions and show niche differentiation over time. Moreover, we can quantify the root mass per species and monitor their response to stressors such as drought. As such, we will work towards new insights on root traits, priority effects, soil legacies and vegetation succession, and thereby contribute to the growing field of plant phytology and newly constructed grasslands.

Societal impact

River dikes are widespread across the Netherlands. As such, flower rich river dikes can function as ecological corridors by connecting nature areas. With the current biodiversity crisis, (local) governments and other organisations strive to halt this decline. With over 17.000 kilometres of embankments, there is a lot of room for biodiversity restoration. Additionally, as river dikes also have a cultural value and a function in leisure time (e.g., hiking or cycling), increasing the species diversity maintains and could even increase these values. Moreover, as we hypothesise that an increase in flower richness will lead to an increase in drought tolerance and erosion resistance, river dike reinforcements with species richness can contribute to a cost effective way of dike reinforcement.

Methods

Four small-scale river dikes were constructed behind the Radboud University greenhouse (Figure 1). Here, we seeded ten different seed mixtures, all based on the commonly used D2-mixture. Based on data from earlier experiments, we chose 24 plant species (8 grasses and 16 forbs) from a pool of frequently occurring plants on Dutch river dikes to create a gradient of grass species richness (SR: 2, 4, 8), forb functional group richness (SR: 4, 8, 16), and the ratio of grasses: forbs (80:20, 50:50, 20:80) on 80 plots of 2x1 m. Two of the four dikes were fitted with minirhizotrons for root imaging. In the summer of 2023, we are planning to conduct a drought experiment to monitor the drought tolerance of different seed mixtures using msGBS as well as minirhizotron images.

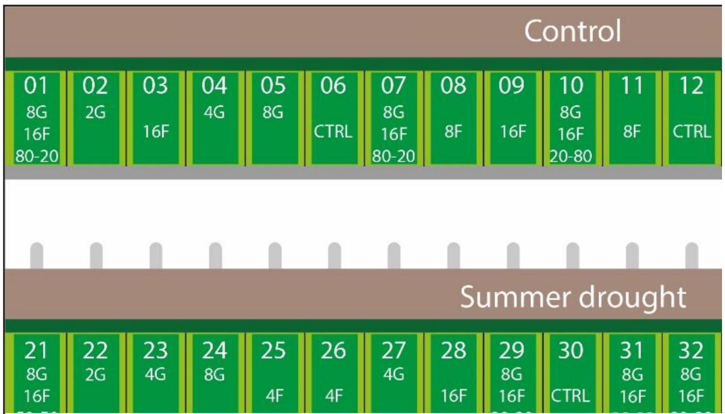

Figure 1. Partial schematic overview of the experimental setup.

Improving mesh set-up to increase discharge capacity accuracy for water level prediction

Parisa Khorsandi[1], Anouk Bomers[1], Martijn J. Booij[1], Jord J. Warmink[1],and Suzanne. J. M. H. Hulscher[1]

Highlights

- The study examines the importance of selecting a suitable mesh for hydraulic modelling close to the real discharge capacity.
- The improved mesh set-up produces comparable accuracy to high-resolution meshes under stationary discharge conditions.
- The study's findings show that the improved mesh set-up provides a faster alternative to high-resolution meshes for modelling large-scale rivers.

Overview

Accurate prediction of river water levels is essential for effective river management and decision making. Among the available modelling approaches, 2DH models are preferred for simulating river hydraulics, because they offer more detailed and accurate water level and flood pattern simulations compared to 1D models (Bomers et al., 2019). The river's bathymetry is described using a continuous mesh covering the main channel and floodplain. However, mesh set-up can significantly affect simulation results, and selecting a suitable mesh is as important as choosing an appropriate calibration method (Hardy et al., 1999). Mesh resolution impacts the discretization of river bathymetry, discharge capacity, and ultimately, simulated water levels. Although higher resolution meshes can yield more accurate outcomes, using them for large scale rivers can be time-consuming (Caviedes-Voullième et al., 2012).

The objective of this study is to develop an improved mesh with a relatively low mesh resolution using the actual cross-sectional area's discharge capacity, which is represented by the highest available bathymetry data resolution. The study was conducted in two steps. In the first step, the modified mesh set-up was applied to a simplified river.

The study's findings of the first step show that the differences between simulated water level using the current mesh set-up methods (e.g. averaging method) and the modified mesh set-up are around 3 to 10 centimetres in the equilibrium situation for different discharge levels. However, for different types of cross-sections and discharge levels, the modified mesh and the high-resolution mesh (created from available bathymetry data) produce the same simulated water level. This shows that the modified mesh provides a faster alternative to the high-resolution mesh while maintaining comparable accuracy.

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The modified mesh

The modified mesh set-up is improved using an algorithm that changes the nodes of the mesh vertically in order to find a mesh with the same discharge capacity as the high resolution bathymetry data. Fig. 1 illustrates a cross section represented by the high resolution bathymetry data, the currently used mesh set-up, and the modified mesh set-up.

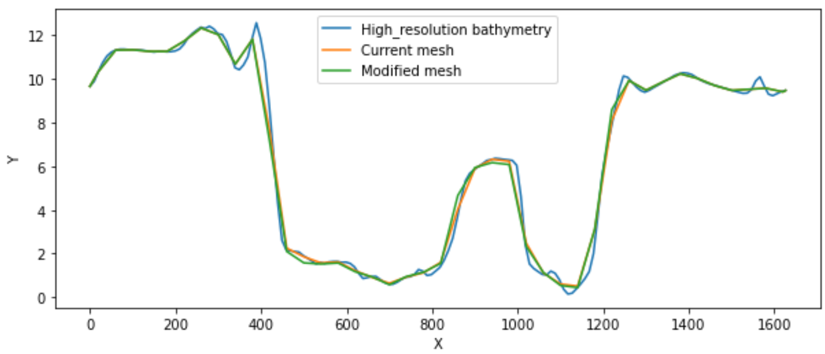

Figure 1. An example cross section represented by the high resolution, current and modified mesh.

Simplified river

The first step is to apply the modified mesh to a hypothetical simple river and assess its effectiveness on the simulated water level. The bathymetry of the simple river is created by duplicating one of the cross-sections of the Waal river (Fig. 2). The water level is simulated under different constant discharges ranging from low to high flows, with three different mesh set-ups: high resolution mesh created from bathymetry data, currently used mesh set-up and modified mesh.

The differences between simulated water levels using the high resolution and current mesh versus the differences using the high resolution and modified mesh for three different types of cross sections duplicated in the longitudinal direction are presented in Fig. 3. The results show that, for almost all simulations, the simulated water level with the modified mesh is closer to the one with the high-resolution mesh (representative of the real river) than the model with the current mesh.

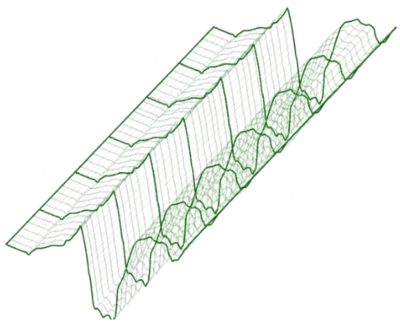

Figure 3. Simplified hypothetical river

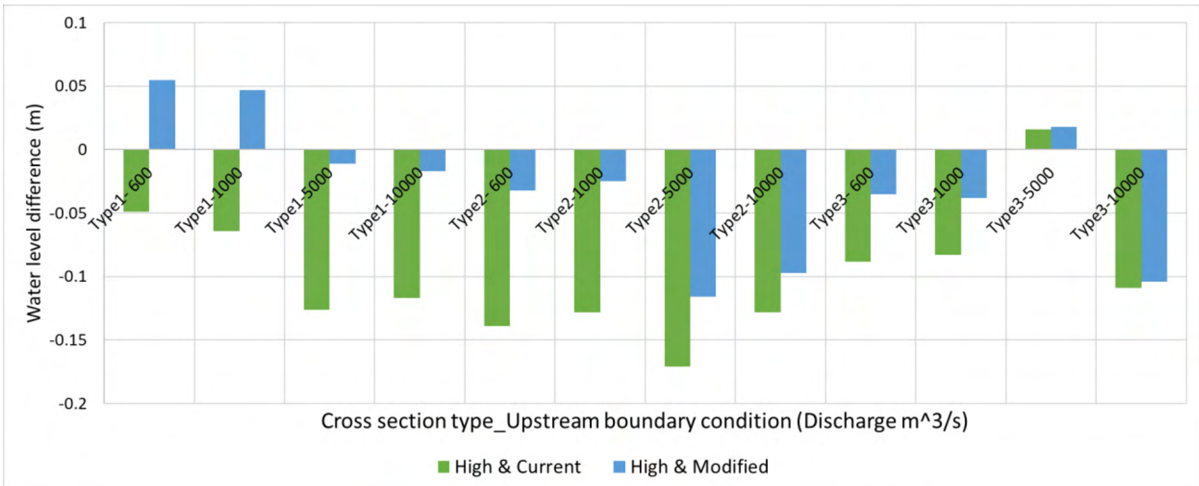

Figure 2. Differences between simulated water levels using the high resolution and current mesh versus using the high resolution and modified mesh for three type of cross sections.

Conclusion and future work

In conclusion, the study's findings underscore the significance of utilizing a discharge independent mesh in hydraulic modelling and the subsequent effects on simulation outcomes. The modified mesh offers a more efficient alternative to high-resolution meshes, while still achieving comparable levels of accuracy in water level predictions. This ongoing research project has progressed through its first stage, with the improved mesh being applied to a simplified river system. The next step in the research is to apply this mesh to a more complex hypothetical river, paving the way for more robust and accurate hydraulic modelling in the future.

Assessment of vegetation modelling approaches in simulating suspended sediment transport in Delft3D

Jiaqi Liu [a,b],
Alessandra Crosato [a,b]
Francesco Bregoli [a,c]
Giulio Calvani [d]

Highlights

- Experiments are reproduced in Delft 3D to simulate suspended sediment transport in aquatic flow
- The three selected approaches represent the flow field better than suspended sediment transport
- The "3D vegetated" approach is the best one in reproducing fine sediment deposition

Overview

The presence of vegetation increases the water depth, reduces the flow velocity and changes the turbulent structure of the flow influencing the sediment transport capacity (Purich 2006 and Nepf 2012). Because of it, vegetation can be regarded as a geo-enhancing tool that influences the river morphology by preventing erosion, but also as a filtering tool that improves the water quality by removing fine particles from the flow. The physical processes inside the flow-sediment-vegetation interaction have been investigated in the last decades. Theoretical models simulating the effects of vegetation on flow field and morphodynamics have been developed and applied using different software, such as Delft 3D (Crosato and Saleh 2011 and Best et al. 2018). Most studies focused on large-scale issues assuming sediment to be transported as bedload, whereas suspended solids processes have received less attention.

This work aims to compare the performance of 2-dimensional (2D) vegetation modelling approaches implemented in Delft 3D in reproducing the interaction between suspended solids and the flow in vegetated channels. The comparison is based on a set of flume experiments (Sharpe 2003) with emergent plants represented by rigid cylinders. Three approaches are considered in this study: the Baptist approach, based on the assessment of roughness coefficients; the 3D vegetated approach including some effects of turbulence; and a detailed description of the flow with each rigid cylinder being represented by either a dry point or described by thin dams around it. The flow is calculated by shallow water Navier-Stokes equations and the suspended sediment transport is calculated as advection-diffusion equations.

After a proper roughness coefficient calibration, the results shown that all the three approaches perform well in reproducing the flow field. However, only the detailed description (Dry Point and Thin Dam) approach can describe the flow field around the rigid stems. The three approaches can well reproduce the longitudinal distribution of sediment deposition with the calibrated settling velocity. For the deposition in transverse direction, the 3D approach performs the best, the detailed description approach can only partly reproduce the distribution, whereas the Baptist approach, based on the assumption of uniform flow between the plants and high vegetation density, can't reproduce any differences in sediment deposition in transverse direction. The results of validation emphasize the impact of turbulence on suspended sediment transport through vegetated channels.

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Results

Each approach needs a specific calibration of Manning coefficient, drag coefficient and horizontal eddy viscosity. The calibrated values are determined by minimizing the relative root mean square error (RRMSE) between measured and modelled water depths (Table 1). All the three approaches show high accuracy in water depth prediction. About the detailed description, the results are the same for the Dry Point and Thin Dam approaches.

Table 1. Calibrated parameters for three vegetation modelling approaches

Calibrated parameter	Vegetated modelling approach					
	Baptist		3D vegetation		Dry Point and Thin Dam	
	Value	RRMSE	Value	RRMSE	Value	RRMSE
Bottom Manning coefficient ($s/m^{1/3}$)	0.021	0.087%	0.021	0.087%	0.021	0.087%
Drag coefficient	1.15	0.257%	1.35	0.440%	-	
Horizontal viscosity (m^2/s)	10		10		0.00008	0.290%

The velocity and water depth distributions obtained with the Baptist and the 3D vegetated approach are uniform, because these approaches do not consider the single cylinders. However, the detailed description allows obtaining that the water flow passes around each stem leading to local differences in water depth and velocity (Fig. 1).

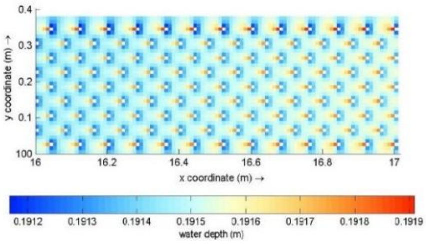
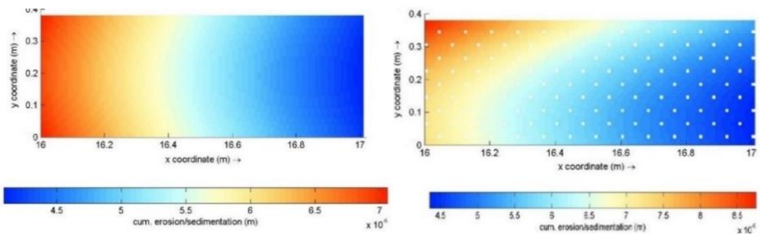


Figure 1. the section of water depth distribution in a Dry Point model

As in Sharpe's experiments, sediment is added to the flume after getting uniform flow conditions. Morphodynamic calibration is obtained by adjusting the value of the settling velocity based on the comparison between the computed longitudinal sediment deposition to the experimental data.
The different approaches result in different distributions of sediment deposition. It is uniform when using the Baptist approach. However, for the 3D vegetated and detailed description approaches deposition is higher near the walls than in the central area. More specifically, the distribution obtained with the 3D vegetated approach is symmetric (Fig. 2a), which is in accordance with the experimental observations. Instead, the sediment deposition is asymmetric for the detailed description approach (Fig. 2b).



(a) (b)

Figure 2. Sediment deposition distribution obtained with (a) the 3D vegetated approach and (b) the detailed description approach

Conclusions

The 3D vegetated model approach can be regarded as the best one in reproducing suspended solids transport in aquatic systems at the flume scale. However, the sub-grid turbulence may impact the accuracy of the results with respect to sediment deposition.

Acknowledgments

The authors would like to thank Dr Richard Sharpe from Griffith University, Australia, for providing the experimental data.

Sedimentary characteristics of channel bars and banks along the Roer River, Netherlands: linkages with meander dynamics of a 'rewilded' river

Authors:
Paul F. Hudson[a], X. Martinez[a*], Y. Reniers[a], D. Jones[a]

Highlights

- Sedimentary characteristics of recent channel bars and older bank material, and lateral migration along the Roer River between Germany and Roermond, NL are examined by field work and GIS spatial analysis
- Particle size of channel bars decreases downstream, from a D50 of 5.2 mm to 4.2 mm
- Lateral migration rates of meander bends is correlated to emergence of channel bars

Overview

The sinuous lower Roer River (2,354 km^2) in Limburg meanders for 22.9-km from the DE-NL border to the Maas River. In addition to human impacts, meandering of the Roer River is likely influenced by neotectonics and older sedimentary deposits (Woolderink et al., 2021). A new management scheme in the 1990s removed hard erosion control structures that greatly restricted lateral migration, with the intention of allowing the river to once again freely meander. Subsequent geomorphic adjustment of the Roer River provides an ideal opportunity to examine sedimentary and morphometric processes along a relatively naturally functioning meandering river, and to contextualize the success of the new management program. In this study we utilize field data and geospatial analysis to examine sedimentary characteristics of active channel bars and channel bank erosion to assess meander dynamics of a "rewilded" river in Limburg, the Netherlands.

Affiliations

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**presenter*

References

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Woolderink, H.E.G., Cohen, K.M., Kasse, C., Kleinhans, M.G., and Van Balen, R.T. 2021. Patterns in river channel sinuosity of the Meuse, Roer and Rhine rivers in the Lower Rhine Embayment rift-system, are they tectonically forced? Geomorphology 375https://doi.org/10.1016/j.geomorph.2020.107550.

Methods

Some 107 bulk sediment samples were obtained from 19 channel bars in May and June 2022, including point bars and emerging lateral and mid-channel bars (Figure 1). The sampling strategy enabled lateral and longitudinal (down bar) variability in particle size to be determined for each channel bar. At most bars seven surface samples (10 cm by 10 cm by 2 x particle B-axis) were obtained along three lateral transects, including at the upstream (< 0.25 of bar length), widest (~mid), and downstream (> 0.75 of bar length) portions of the bar. We recorded length and width of sample locations atop the bar to calculate longitudinal and lateral spatial rates (mm/m) of particle size change. Over 60 channel bank samples were obtained at the surface and variable bank depths to assess the sedimentary resistance to erosion and changes in meander pattern. Bulk samples were returned to the lab for sieving and hydrometer analyses to calculate particle size indices (D10, D16, D50, D84, D90, sorting coefficient).

The channel planform was digitized in GIS for different periods using topographic maps and lidar DEMs to obtain meander morphometric indices (W, Rc) spanning from the late 1800s to 2021. Overlay analysis in a GIS enabled lateral migration (erosion) rates to be calculated for each meander bend (i.e., Hudson and Kesel, 2000). These data are examined in association with the channel bar and bank material data.

Results

Channel bars (point bar, lateral, and mid-channel bars) are actively increasing in frequency and size along the Roer River and storing coarse bed material. The average D50 (of 7 samples) of bars is 5.6 mm upstream (of Vlodrop, NL) and decreases to 2.4 mm in the downstream section (near Lerop, NL). Spatial variability along and across (lateral) individual channel bars is much greater upstream, particularly for the coarse (D90) component of bed material. The spatial rate (mm/m) of particle fining of D90 along (bar head to tail) upstream bars was 0.11 mm/m. Lateral variability at the widest portion of channel bars was much higher upstream, being 1.6 mm/m upstream and 0.02 mm/m towards the river mouth.

Figure 1. Examples of recent channel dynamics along the Roer River, Netherlands. Author photos except where noted.

Lateral migration is highest upstream at 0.5 m/yr and decreases downstream towards Roermond at < 0.1 m/yr. Spatial variability in erosion rates is high, however, with several active bends having lateral migration rates approaching 3 m/yr near the NL-DE border. Channel banks comprised of buried sandy point bar deposits are especially susceptible to erosion and meander development, regardless of the texture of surface deposits. Temporally, the average size (area) of lateral and mid-channel bars increased between 2012 and 2018, from 516 m^2 to 524 m^2. The modest increase in average area, however, is masked by the presence of many new smaller (emergent) bars that represent additional forms of coarse sediment storage.

Spatially, the average size of bars was 1,150 m^2 in the upstream reach and decreases to 225 m^2 in the downstream reach. The location of laterally active channel banks is statistically related to the growth of channel bars, including both point bars and lateral bars, and suggests the importance of bank erosion and lateral migration in stimulating channel bar development.

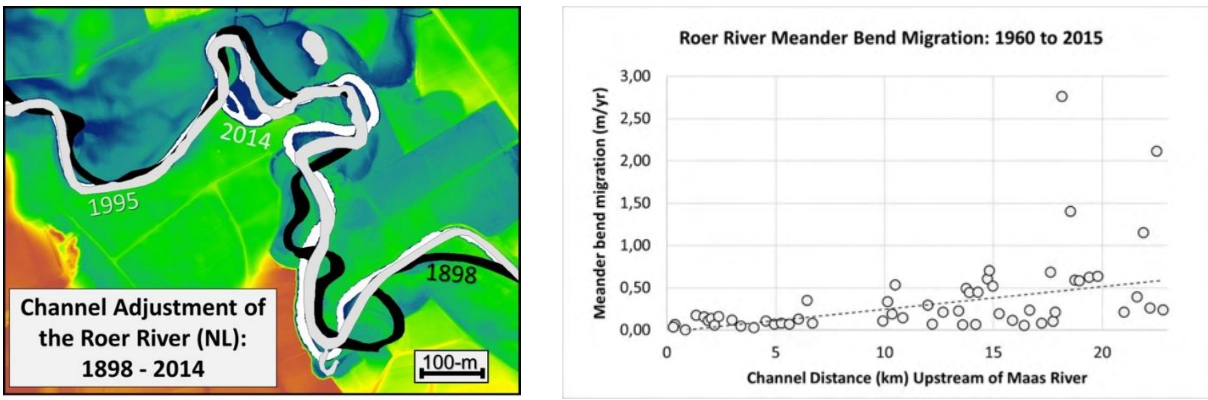

Figure 2. A. (left): Overlay of Roer River channels, from late-1800s to 2014 with AHN2 lidar DEM. B. (right): Meander bend migration rates (m/yr), 1960 to 2015.

Investigating the effectiveness of Nature-Based Solutions (NBS) for climate change adaptation using coupled MIKE SHE-MIKE11 model

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Ioana Popescu[a]
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Highlights

- We modelled NBS using coupled MIKE SHE-MIKE11 model & performance of NBS have been studied under different climate change conditions.
- Preliminary results show NBS perform very well to coup water stressing at the local scale but at catchment scale they have certain limitations of extents and scales.
- NBS have ability for climate change adaptation in long-term under changing climate patterns.

Overview

Anthropogenic Climate Change has caused an increase in frequency, intensity and impact of hydro-meteorological-hazards (HMHs) such as floods, droughts, wildfire, and sea level rise. Prior to the 21st century, most policies and strategies to deal with water-related climate risks were based on conventional or grey solutions without considering Nature-Based Solutions (NBS) as potential measures

In recent past, NBS have gained prominence over conventional measures in the long run, owing to multi-functionality, flexibility, and cost-effectiveness, providing inter-related and multi-scale benefits to deal with water-related climate hazards.

However, the efficiency and robustness of NBS are still under question because of the lack of specialized models and tools to assess them throughout the life cycle and under varying climate patterns. A solid framework of Key Performance Indicators is needed to progress further in promoting NBS at larger scales.

In this study, we have explored a set of potential NBS for the Aa of Weerijs catchment, in the Netherlands, which is sometimes under water stress. The performance of NBS to deal with water-stress related challenges in the catchment are investigated using a fully distributed physical coupled MIKE SHE-MIKE11 model previously developed. Different set of scales and extents and combinations of NBS have been modelled in the MIKE SHE model of the catchment, ranging from wetlands, afforestation and river meandering. Performance of NBS are evaluated both for the present and for future climate change conditions, using two sets of climate change projections, the KNMI ’14 scenarios, developed by the Koninklijk Nederlands Meteorologisch Instituut (KNMI), and the RCP 6.0 and RCP 8.5 scenarios, provided by Copernicus.

To assess the performance of each NBS set-up and support informed decision-making for stakeholder, a suite of defined KPIs, including surface and groundwater availability in the catchment, water stress ratio, and soil moisture deficit index, are being calculated for each NBS simulation run and used for comparison with base results.

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The implementation of Nature-Based Solutions (NBS) varies in scale based on their characteristics and the context of the application. NBS also involve multiple stakeholders at the different levels which requires thorough consultations during all stages of the NBS life cycle. According Somarakis, et al. (2019), the evidence base framework to assess the effectiveness of NBS, analysis of co-benefits, and their long-term reliability under future climate conditions is still lacking.

The main focus of the study is the realization of the role of Nature-Based Solutions in developing an adaptation strategy for Aa of Weerijs Catchment. Aa of Weerijs is a transnational catchment spanning the Flemish region of Belgium and Noor Brabant province of the Netherlands.

The data provided by to KNMI'14 scenarios (Attema, et al., 2014) and Climate Impact Atlas predict acceleration in annual evaporation from 560 mm/year to 600 mm/year by the end of 2050, the same data has been used to present drought stress in the study area in Figure 1 below.

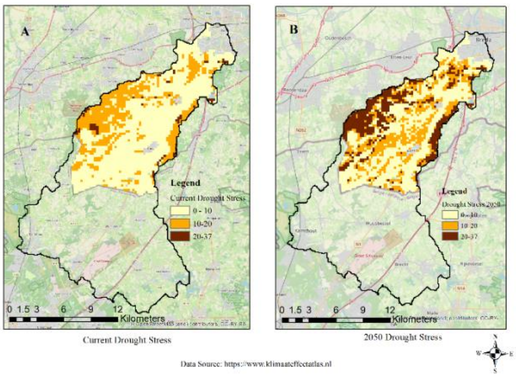

Figure 1. Current Drought stress (A) & 2050 High Drought Stress (B) in the Dutch part of the Catchment (Data Source: Climate Impact Atlas)

In order to decide on potential NBS locations a set of rules was devised based on existing land use type, distance from nearest river branch, road network and urban settlements to ensure coherence with existing infrastructure and land use types. 108.0 km^2 have been identified as potential NBS area.

To measure the NBS performance a set of Key Performance Indicators (KPIs) have been devised based on the model results to see NBS impact in the catchment. These KPIs include, Water Stress Ratio, Surface Water Availability, Groundwater Water Availability, Soil Moisture Index, Selected Cell Based ET, GW & WC

As shown in Figure 2 below in the case of groundwater elevation, all proposed measures have positive impact on groundwater storage throughout the year in the area of application of NBS measures.

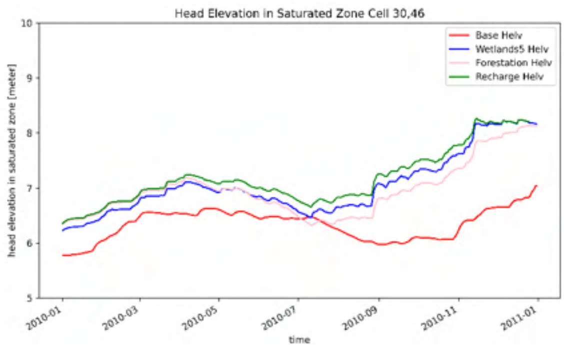

Figure 2. Local impact of NBS cases on head elevation

Preliminary simulation results for base model with NBS and without NBS under KNMI projections for precipitation and evapotranspiration has shown that different sets of NBS solutions and combinations have varying impact under changing climate patterns.
The study is still on-going and results are intended to support NBS impact evaluation as adaptation strategy for the long-term recommending optimal number and scales of NBS measures .

Conclusion:

Evaluation of NBS measures prior to implementation is a must as not all NBS are equally effective at catchment scale to coup with the issue of water stressing in different water balance components.

Macroplastic concentrations in the water column of the river Rhine increase with higher discharge

Paul Vriend[1*], Margriet Schoor[2], Mandy Rus[2], Stephanie B. Oswald[2,3], Frank P. L. Collas[3,4]

Highlights

- Macroplastic (>0.5 cm) concentrations in the water column of the river Rhine increased with higher discharge
- Combination of higher discharge and higher concentrations leads to considerably higher transport during high discharge
- Even during low discharge transport in water column substantial compared to floating plastic transport

Overview

Riverine macroplastic pollution (>0.5 cm) negatively impacts ecosystems and human livelihoods. Monitoring data are crucial for understanding this issue and designing effective interventions. Macroplastic pollution floating on the river surface and plastic deposited on riverbanks are studied relatively often. Data on riverine plastics in the water column remain scarce. In this study, we utilize trawl nets at different depths to sample plastic pollution in the water column at the entry point of the river Rhine to the Netherlands. We show that plastic concentrations in the water column increased during higher discharge. The combination of higher macroplastic concentrations and higher discharge leads to considerably higher plastic transport during high discharge events. Moreover, the results indicate that the vertical distribution of macroplastic pollution changes during different flow conditions. Significantly higher concentrations of macroplastic can be seen near the riverbed during low discharge conditions, while no significant differences in concentration are observed between the bottom, middle, and surface samples during high discharge conditions. These findings provide first insights into the key role of hydrology in explaining macroplastic transport in the water column. These insights can be used to improve future monitoring and intervention strategies.

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Results and discussion

1. Macroplastic concentrations increase with higher discharge

- Plastic concentrations ranged from 0.78 – 24.23 items per 1000 m^3.
- Positive relationship found between discharge and plastic concentrations (Figure 1A).

2. Hypothetical effects of high discharge on plastic flux

- We use found relationship between discharge and plastic concentrations to extrapolate to flux during high discharge events (Figure 1B)
- Daily plastic transport during observed period ranged between 300000 – 4.5 million items per day.
- Flux during high discharge event (6100 m^3/s, 2.1 year recurrence time) could be up to 129 million items per day

3. Macroplastic transport in the water column substantial, even during low discharge

- Floating plastic transport was observed at Emmerich am Rhein, 6 km upstream from sampling location. Observed floating flux is plotted using the red dots on Figure 1B.
- Macroplastic transport in the water column is several orders of magnitude higher compared to floating macroplastic flux during similar discharge conditions

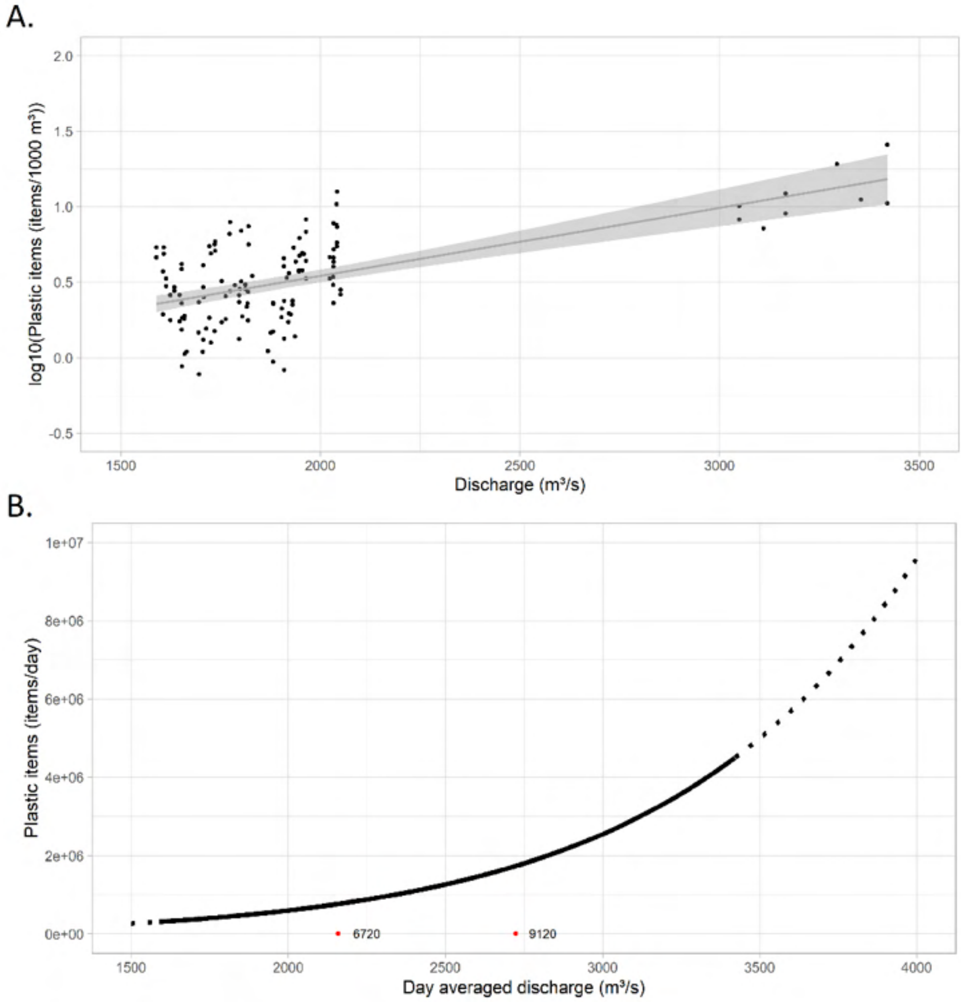

Figure 1. Macroplastic concentrations in the river Rhine, with A: the linear relationship between discharge during sampling and the log10 transformed macro- and mesoplastic concentration per 1000 m^3, and B: Riverine transport of macro- and mesoplastic in items per day for day averaged discharges with the dotted line representing predictions outside of the sampled discharge. The insert shows expressed as red points with values a comparison with measured fluxes of floating plastics counted on bridges (source: van Emmerik et al. 2022)

Repeat sedimentation measurements for large floods along the lower Mississippi River and comparison with older events (2020, 2018-2019, 2011, 1973)

Authors:
Paul F. Hudson[a], F.T. Heitmuller[b], J. Costello[b], R. Kelk[b]

Highlights

- Sedimentary characteristics of recent large floods are examined along the lower Mississippi near the delta apex at the same locations
- Sedimentation from recent long duration floods is greater than recent high magnitude flood
- Comparison of recent flood deposit thickness with deposits from a large flood in 1973 suggests that overbank sedimentation may have declined in response to a great reduction in Mississippi River suspended sediment loads

Overview

As most flood sedimentation studies are focused on discreet events it remains challenging to distinguish the importance of different processes on overbank sedimentation, particularly flood duration relative to flood magnitude. New field data is reported pertaining to sedimentation thickness (mm) and particle size (mm) for the 2020 hydrologic year along the lower Mississippi River, which extends studies reported from large flood events in 2018-2019, 2011, and 1973 (Heitmuller et al., 2017; Kesel et al., 1974). Study results are further contextualized by considering (upper basin) sediment province and event-based discharge – suspended sediment dynamics (Figure 1). This study benefits from having repeat measurements at the same location for different flood events (Figure 2), which enables consideration of flood magnitude relative to flood duration.

The study area is a ~25 km long segment of the lower Mississippi alluvial valley between Natchez, Mississippi and Red River Landing, Louisiana, a reach that includes the entire 3,200,000 km^2 of North American drainage of the Mississippi basin. The study area annually undergoes extensive flooding, and has the highest range in annual flow levels of the entire Mississippi basin. Flooding in hydrologic year 2020 (at Natchez, MS) occurred from January 15 to June 21, an event of 159 days that is nearly two months longer than the average flood duration. The 2018-2019 compound flood event was overbank a record 286 days. These two sequential events are of much greater duration than the notorious high magnitude events of 2011 and 1973 with a flood duration of 53 days and 90 days, respectively.

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[b] *School of Biological, Environmental, and Earth Sciences, University of Southern Mississippi*

References

Heitmuller, F.T., Hudson, P.F., and Kesel, R.H. 2017. Overbank sedimentation from the historic A.D. 2011 flood along the Lower Mississippi River, USA. Geology 48. G38546.1.

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Methods:
The 2020 flood deposits were sampled at stations established in autumn 2017 and were located at exactly the same positions as overbank sedimentary deposits collected for the 2018-2019 floods. This included artificial grass mats and additional locations where the recent flood sedimentation could be discerned from the older deposits (Heitmuller et al., 2017). As these field sites are similarly located to where flood deposits were collected by Heitmuller et al. 2017 and Kesel et al., 1974, combined they represent a nice historical window in which to reflect upon changes in overbank sedimentation for the lower Mississippi.

Results:
Particle size of flood deposits from the 2020 event varied most within the first ~200 m of the channel, and then somewhat by depositional setting, including fine-sand (d50 = 0.17 mm) at natural levee crest to fine silt (d50 = 0.011) atop natural levee backslopes, meander scroll -ridge, meander scroll-swale, abandoned channel, and backswamp environments. Despite differences between the 2018-2019 and

2020 events, the average particle size in 2020 is 0.040 mm, somewhat coarser than 0.029 mm of 2018-2019.

Recent long duration flood events have finer grained deposits than sedimentary deposits from the record 2011 flood, which averaged 0.049 mm. Additionally, recent long duration flood events (2018-2019, 2020) produced less sand than the 2011 flood, averaging 32% (2011), 14% (2018-2019), and 22% (2020). This points to the importance of flood magnitude in distributing sand across a wider swath of the floodplain (Heitmuller et al., 1973), while the high energy event likely flushed fine-sediment downstream and inhibited slackwater sedimentation, which characterized the 2018-2019 and 2020 events.

Flood deposit thickness at 41 sites in 2020 averaged 33 mm, notably less than 2018-2019 event (85 mm avg.). Flood deposits from the 2011 event averaged 39 mm in thickness. Sediment thickness, however, should be contextualized against the period over which flood sedimentation occurs. The influence of flood duration results in unit (daily) sedimentation rates for the 2020, 2018-2019, and 2011 flood events being 0.21 mm/day, 0.30 mm/day, and 0.74 mm/day, respectively. Across large lowland floodplains, flood duration is more important than flood magnitude to the total amount of sedimentation.

Regardless of flood magnitude or duration, a comparison of recent flood sedimentation amounts with sedimentation from the infamous 1973 flood event (Figure 2) likely reveals the persistent decline in Mississippi sediment loads since dam construction of the mid-1900s.

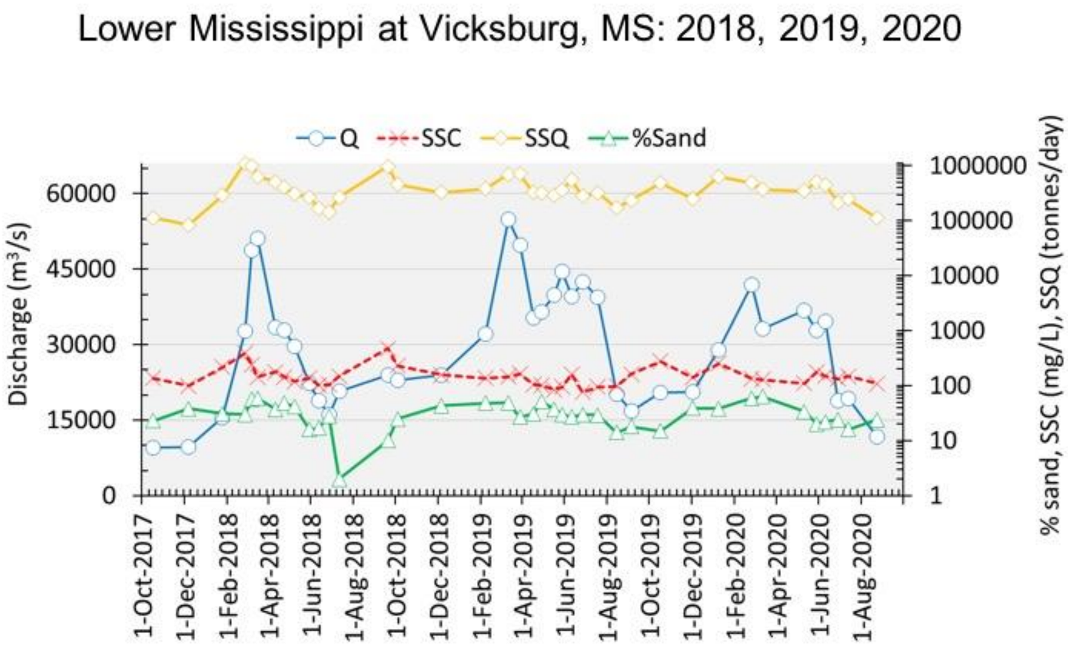

Figure 1. Discharge and suspended sediment characteristics of recent floods with field data at the lower Mississippi River above Vicksburg, MS (USGS # 322023090544500), hydrologic years 2018 to 2020. Data source: U.S. Geological Survey.

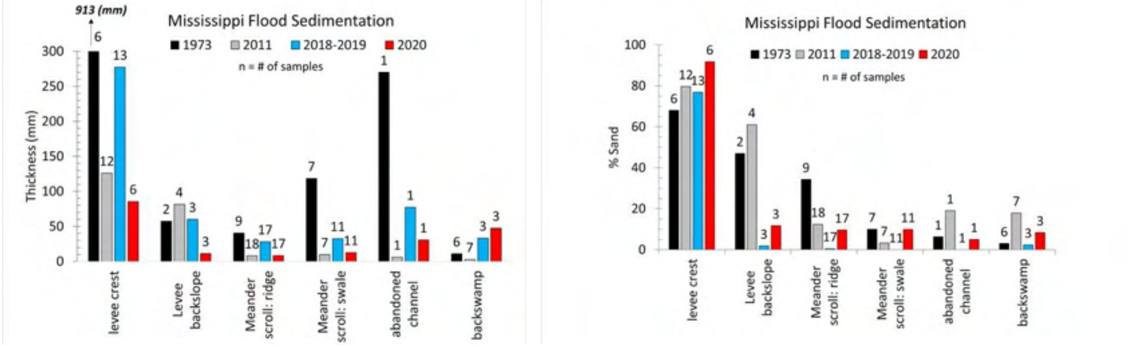

Figure 2. A. (left): Sedimentation thickness (mm) per depositional environment for floods of 1973, 2011, 2018-2019, and 2020. B. (right): Percent sand of sedimentary deposits per depositional environment for floods of 1973, 2011, 2018-2019, and 2020. Data source for Fig. 2-A and 2-B: 2018-2019 and 2020 data is authors unpublished data; 2011 data is Heitmuller et al., 2017; 1973 data is Kesel et al., 1974.

Session 3

Long term changes in rivers

Netherlands Centre for River studies NCR

Keynote Presentation Session 3


Rob Lenders **Esther Stouthamer**

Historical-ecological lessons for future river management

Rob Lenders – Historical-ecological lessons for future river management

Sustainable functioning of river catchments requires robust design and management of the river ecosystem. In recent decades much progress has been made, but quite a few necessary steps remain. Knowledge and understanding of the historical ecology of rivers is a must, as it can teach us about mistakes made in the past and thus how we can do better in the future. Using a number of concrete examples, this lecture will outline for the Rhine the historical-ecological development of the last millennium and provide lessons for river management in the 21st century.

Rob Lenders is an animal ecologist and environmentalist by training, and a specialist in the historical ecology of north-western Europe, especially from the perspective of human-animal relationships (notably fish, amphibians, reptiles and mammals). He approaches these relationships from both an ecological and a humanities perspective. In his research, he collaborates with archaeologists, historians, sociologists, anthropologists, linguists and philosophers. His work contributes to a deeper understanding of the factors that wrought major changes in riverine ecosystems and such understanding provides an essential basis for the effective ecological rehabilitation.

Esther Stouthamer

Prof. dr. Esther Stouthamer is a full professor in Delta evolution and subsurface processes at Utrecht University. Her fields of expertise are: delta evolution, subsurface architecture and properties, land subsidence, fluvial morphology, Quaternary geology, and physical geography. Research within her group focusses on understanding Holocene delta evolution and its resulting subsurface build-up and properties, post-depositional processes, and determining the susceptibility of the subsurface for post-depositional processes (impacts) and application of this knowledge in the development of sustainable delta management strategies. She initiated and leads the NWA-Living on Soft Soils: Subsidence and Society and NWO-TTW Piping in Practice research projects and participates in the STW-AllRisk project (subsurface-related failure mechanisms).

The Holocene development of the Rhine-Meuse delta has been externally controlled by changing climate, sea level, tectonics, water and sediment supply. In turn, internal processes, like avulsion, compaction, and morphological succession have determined the distribution of water and sediment over the delta and the storage and (temporary) preservation of sediment within different delta compartments. The combination of these external forcings and internal processes has determined the development of the delta over time and has resulted in a complex subsurface build-up.

Subsurface build-up and the associated distribution of properties is a critical control of the natural functioning of a delta, its sensitivity to natural and human-induced change, and the success of technical and nature-based measures in delta management. With regard to river management, subsurface properties play a key role in determining the potential for subsurface-related failure mechanisms of water defenses and channel stability.

The rhythm of the river: variability in Meuse deposition identified from the meta-analysis of radiometric data

Willem H.J. Toonen[a], Hessel A.G. Woolderink[b], Harm Jan Pierik[c], Kees Kasse[a]

Highlights

- Phases of clastic and organic deposition were based on 427 radiometric dates.
- Persistent multi-centennial cyclicity existed during the early and late Holocene.
- Human influence changed the Meuse flooding regime significantly.

Overview

The global frequency and impact of riverine floods has increased in recent decades, but how flood regimes and the magnitude of extreme events will change in the future is still uncertain as suitable reference data remains scarce. Although data from the past does not appear to be the perfect analogue for current rapid climate change, it can provide critical knowledge on the direction and amplitude of riverine responses to climatic and human perturbations and can help to understand the severity and pacing of future changes.

For the alluvial reach of the Meuse River, located in the Netherlands, a dataset of 427 radiometric dates derived from its fluvial setting was compiled from existing literature. A cumulative probability density function was deployed to reconstruct the phasing in periods of enhanced *clastic* deposition or *organic* deposition. An additional group of *change* dates was compiled, which contains all dates in proximity of a lithological transition and thus coinciding with sudden changes in the distribution of sediments at that specific location. Previous CPDF studies focused specifically on such change dates to identify phases in flooding (Jones et al., 2015). Wavelet analysis was used to identify persistent periodicities, related to long-term hydroclimatic drivers of the Meuse flooding regime.

In its natural early Holocene regime Meuse deposition was strongly constrained by the buffering capacity of the vegetation cover in the upland areas, and an entrenched valley setting. Only during episodes of significant climatic cooling there is evidence for increased wetness (Fig. 1). Deforestation of the hinterland may have had its first notable effects on the Meuse flooding regime around 6 ka BP, but became a catalysator for flooding after c. 4 ka BP. The increasingly reduced buffering capacity of the catchment amplified flooding and increased sediment supply to the lower reaches, leading to bed aggradation that further facilitated overbank deposition. Late Holocene cold episodes are still reflected in the Lower Meuse CPDFs, but in the altered system there is evidence for enhanced flooding in a wider range of conditions, also during warm intervals and periods of rapid climate change.

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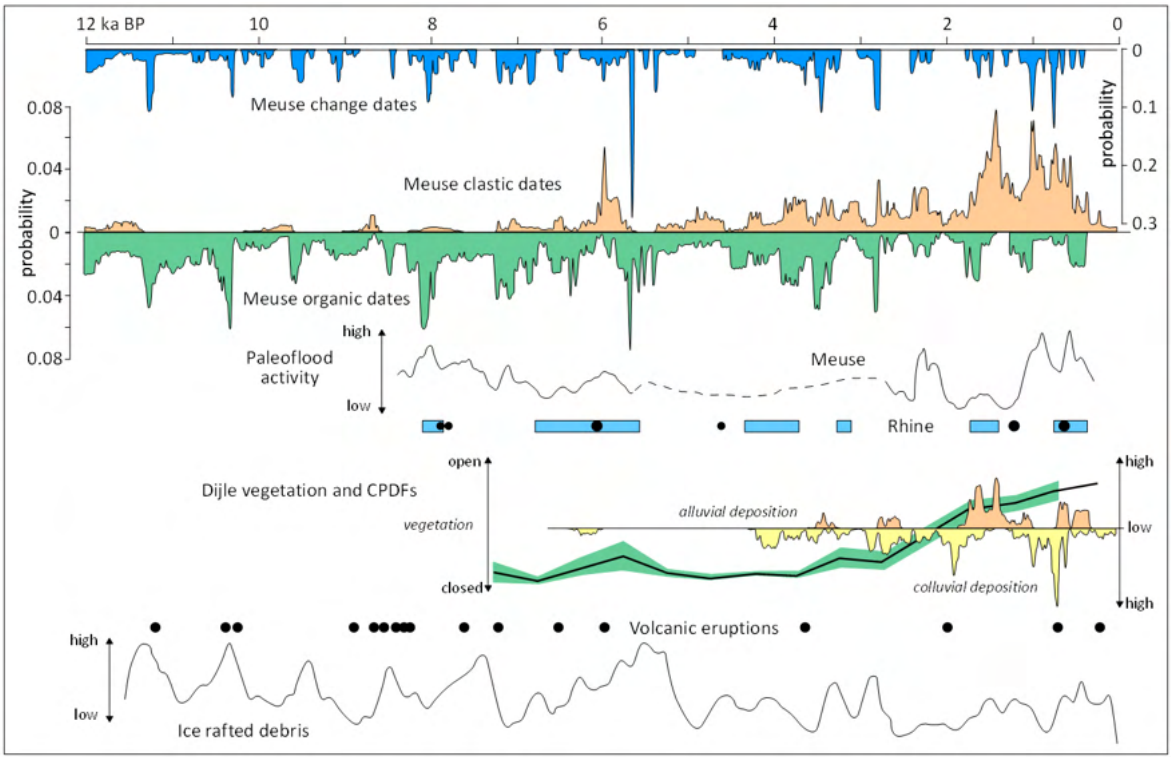

Figure 1: CPDFs of change dates, and clastic and organic dates of the Meuse. Top to bottom: comparison with palaeoflood records of the Meuse (Peng et al., 2019), the Rhine (Toonen et al., 2017), vegetation reconstructions and CPDFs for alluvial and colluvial deposition in the Dijle catchment (NE Belgium; Hoevers et al., 2022), and suspected climatic forcings such as major volcanic eruptions and the ice-rafted debris record, as a proxy for disturbed N-Atlantic ocean circulation (in Mayewski et al., 2004).

CPDF data as support for modern flood risk assessment

Despite fundamental changes between the climate of the past and the projected future, CPDFs can convey information that is useful for flood risk assessments and mitigation strategies. Increased flood activity during the Medieval Warm Period and periods of anomalous climate variability, such as at 6.0, 4.2 and 3.1 ka BP, could add to our understanding of system responses and the specific conditions that generated largest peak discharges. CPDFs, in combination with targeted paleoflood studies (Toonen et al., 2019), could greatly supplement our knowledge on such events. Although CPDFs are not a direct proxy for the forcings that cause hydroclimatic variability, they do provide valuable insight in the overall conditions and drivers that led to changes in the river system. Persistent multi-centennial cyclicity during the early and late Holocene (Fig. 2) points at a driver of Lower Meuse setting that is associated with variability in North-Atlantic climate system. Moreover, potentially there is a correlation between various episodes of enhanced flooding and the timing of major volcanic eruptions (Fig. 1). Therefore, it would be recommended to further investigate the potential effect of such black swan events on peak discharges of the Lower Meuse and other river systems in the region.

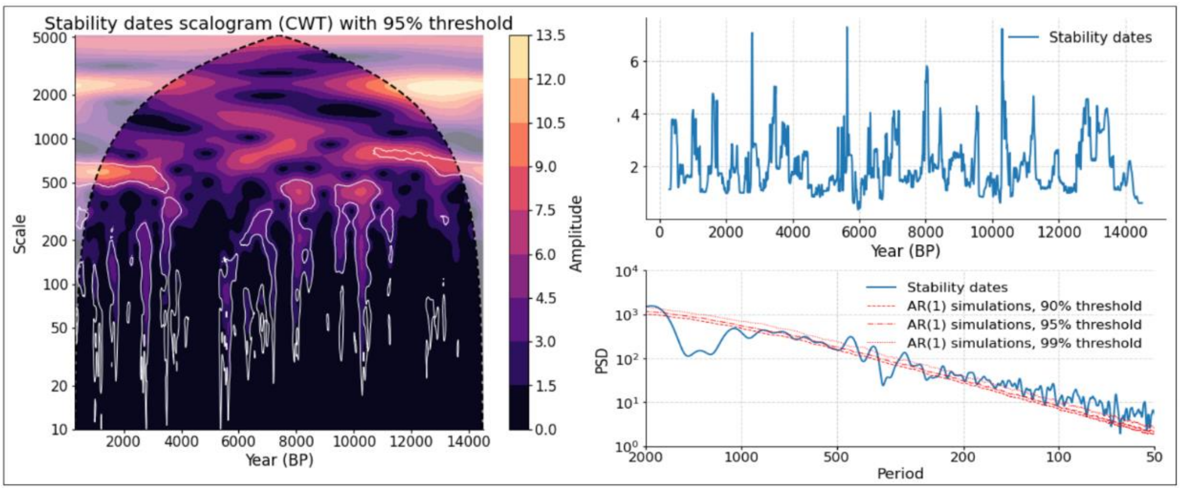

Figure 2: Wavelet power spectrum for the organics CPDF of the Meuse.

Filling the food web: restoration of ecological functioning temporary water bodies in river floodplains

Marijn. E. Nijssen[a,b], G. Kurstjens[c], A. van Winden[d], M. Dorenbosch[e], H. Moller Pillot, C. van Turnhout[f], P. Veldt[d] & G. Geerling[b,g]

Highlights

- Production of plankton and macrofauna as staple food for vertebrates in temporary floodplains is studied
- Period of flooding, connectivity with permanent waters and gradients in meso-relief are important drivers
- Results are used to select most potential floodplain areas for restoration

Overview

Natural floodplains inhabit zones that are temporarily inundated (almost) yearly during late winter and early spring. Physical and chemical conditions result in a characteristic community of fauna species with adapted life strategies. These temporally inundated floodplains have a high periodical productivity of both plant and faunal biomass, explained by the Flood Pulse Concept (Junk et al., 1989), contributing significantly to the food web of the river ecosystem. The base of the food web is formed by detritus, periphyton and phytoplankton, with day length and water temperature as important thriving factors. The detritus and plankton is consumed by herbivorous and omnivorous zooplankton such as rotifers, water fleas and copepods, which are consumed by fish, larvae of amphibians and invertebrates, and subsequently larger predatory fish and birds. Connectivity and isolation of the waterbody strongly determines aquatic species community and productivity, while development of breeding bird communities depends both on timing and duration of inundation, as well as the presence of meso-relief. High sand riches that fall dry early April form safe, predator-free breeding locations, while surrounding shallow waterbodies provide food.

A field validation of these processes was conducted in the area Buiten Ooij (Nijmegen, The Netherlands) in the spring of 2020, after a late winter inundation. After the floods receded, the water bodies returned to isolation from the main channel and high densities of epiphyton, zooplankton and macroinvertebrates developed in these temporal waters. Densities of both fish larvae and juvenile fish in permanent waters in the floodplain were considerably higher in 2020 in comparison with years without spring inundations (Dorenbosch et al. 2020). Variation in meso-relief influences both duration of inundation and connectivity between temporal and permanent waterbodies, appeared to be a major explaining factor for differences between development of zooplankton, aquatic macroinvertebrates, and fish communities (Kurstjens **et al**. 2021).

Restoration of large natural temporal inundated floodplains is hardly possible in the modern Dutch river system, but there are smaller scale opportunities to recover ecological processes that characterize temporal inundated floodplains, thereby completing the food web of the river system. Based on the ecological requirements a GIS-analysis was conducted to select potential restoration areas. This selection is used in the EU Horizon 2020 MERLIN project which aims to help implement rewetting of floodplains (**https://project-merlin.eu**).

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Biomass production of aquatic macrofauna in temperate floodplains

The production of biomass of phytoplankton, zooplankton and aquatic macrofauna is studied at five locations in the river Rhine floodplain of Buiten Ooij near Nijmegen (The Netherlands), respectively 4, 5 and 7 weeks after the waters became isolated from the main channel. Biomass was low (± 0,5 gr.drw/m^2) after 4 weeks, except from locations which are connected to permanent water with reed beds (3 and 4). Biomass was raised a factor 6 to 10 (3-5 gr.drw/m^2) in all locations within one to three weeks. This probably an underestimation since some taxa (e.g. *Corixidae* and *Chironomidae*) developed to adult stage in this period and migrated from the water bodies. The exceptional increase of biomass at location 1 between week 5 and 7 is caused by drying up of the temperate water, thereby concentrating the fauna.

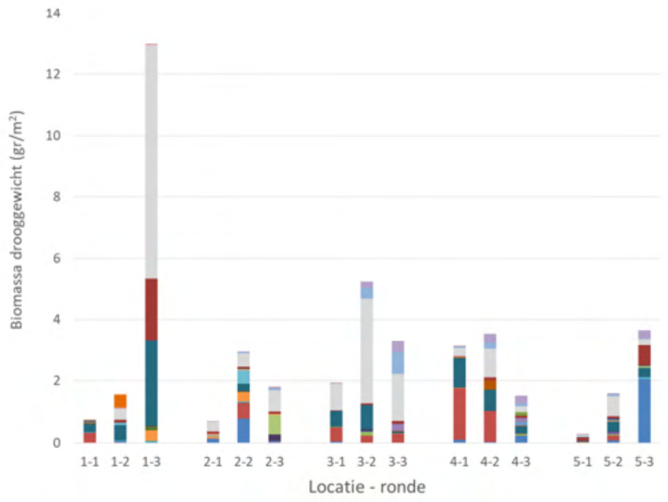

Figure 1. Biomass (gram dry weight/m^2) of aquatic macrofauna in 5 temperate waters in floodplain Buiten Ooij at week 4, 5 and 7 after isolation from the river. Different colors indicate different taxa (order or family).

Selection of sites with high potential for restoration

Based on the ecological insights from the literature review and the field study, three selection steps were defined. Areas within the Rhine branches were selected which 1) are characterized by a ring of (summer) embankments to hold the water in the floodplains; 2) have a minimum inundation frequency once every two years, a minimum inundation duration of eight weeks and a minimum surface of 20 ha; 3) comply with the present nature and water policy. For the final selection of areas with restoration opportunities, also the cluster effect of floodplains is considered, i.e., multiple floodplain locations at close distance of each other increase the success of the establishment of populations of characteristic species such as breeding birds. The results have been made available for managers and governance on maps (figure 2) in a GIS environment.

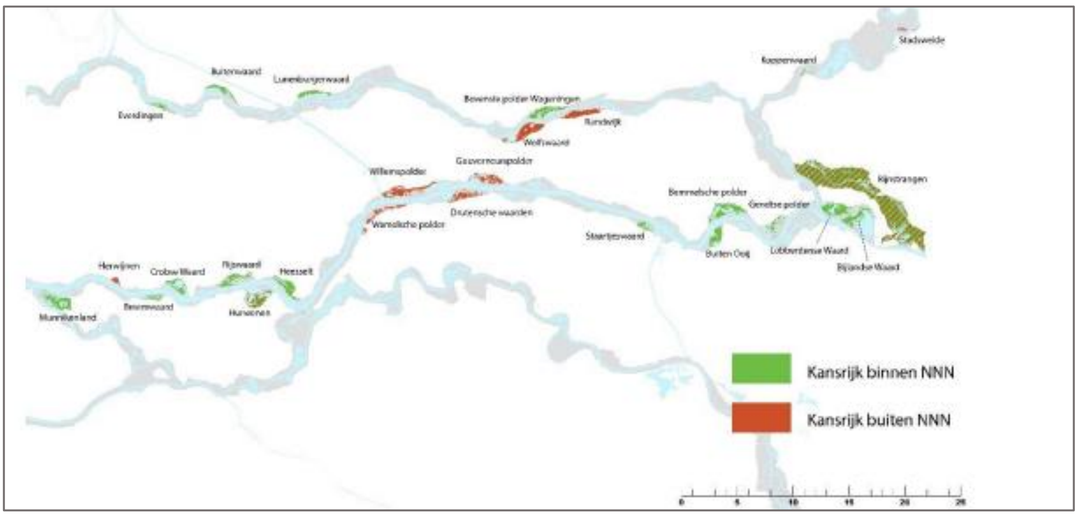

Figure 2. Map of floodplain areas with potential for restoration of temporal waters along the Dutch southern river Rhine branches, within the Dutch Nature Network (green) and outside this network (Red).

Effects of vegetation on gravel-bed river channel formation

Yasir Munir[a,d]
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Sandesh Paudel[e]
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Highlights

- The channel formation is strongly influenced by vegetation in addition to the river water and sediment discharge regimes
- Pluvial forest and taiga affect the channel development in different ways depending on sediment supply and discharge regime
- Without sediment supply both types of floodplain forest strongly reduce the river planimetric changes and the channel width

Overview

Gravel-bed rivers are extremely dynamic systems. They are characterized by alluvial coarse material, relatively steep slopes, high velocities and display a development of recurring bars transforming the river into a braided system. In addition to water and sediment supply, both flood plain vegetation and riparian vegetation play a role in determining the river planform due to their capacity of retaining sediment and stabilize bars and river banks. However, vegetation is often not considered for the river channel formation and does not appear in most regime formulas describing the equilibrium river width and depth.

This research aims to establish the effects of vegetation on the river channel formation focusing on the development process and, in particular, to determine if the final characteristics of vegetated channels retain the footprint of their initial conditions. The tool of investigation is a 2-dimensional morphodynamic model developed using the Delft3D-4 code (https://oss.deltares.nl/web/delft3d). It is based on the model developed by Paudel et al. (2022) who simulated the formation of gravel-bed rivers without vegetation, and on Baptist's (2005) approach to reproduce the effects of vegetation. Plants are represented as rigid cylinders, and the parameters such as height, diameter and spatial density are determined based on the features of pluvial and taiga forests described in the literature.
Scenarios with a different type of floodplain forest (pluvial or taiga), initial channel width, discharge regime and sediment input rate are simulated based on the previous simulations carried out by Paudel et al. (2022). The relationship between vegetation characteristics and river morphology development is analysed focusing on channel width and bar characteristics. The results of this study are finally compared with the previous the non-vegetated ones obtained by Paudel et al. and other previous works.

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Model set up and simulation scheme

The model reproduces the evolution a hypothetical straight river channel 3.5 km long and 500 m wide. The simulations include bank erosion and accretion, the latter obtained by introducing vegetation on emerging bars and point bars. Here we compare the preliminary results of the scenario with an initial width of 30 m and 235 m wide floodplains on both sides and a constant discharge of 300 m^3/s. The bed sediment is made of cobbles with a D_{50} of 8 cm, the same as in the model of Paudel et al. (2022), the sediment input from the upstream boundary being 0.1 m^3/s. Three scenarios with different types of vegetation conditions are designed. In Scenario A, vegetation is set to mimic a generic pluvial forest. Scenario B is without floodplain vegetation (base-case model), whereas in scenario C vegetation is set to represent a generic boreal forest, a taiga. The vegetation characteristics for each scenario are listed in Table 1.

Table 1. Description of the three Scenarios

Input Description	Scenario A	Scenario B	Scenario C
Representative Vegetation	Pluvial	No Vegetation	Taiga
Plant Height (m)	5.0	N/A	16.0
Intensity (m^{-2})	10.2		0.055
Plant Diameter (m)	0.015		0.28
Density (m^{-1})	0.153		0.015

Preliminary results

Figure 1 shows the final water depth for the three scenarios.

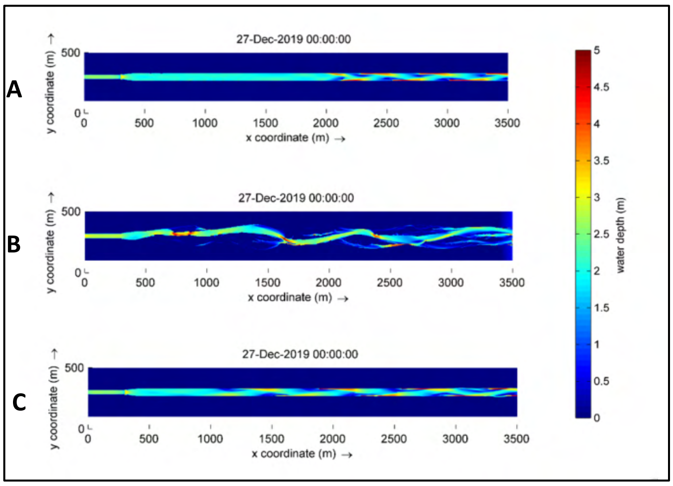

Figure 1: Water depth for scenario A (pluvial forest), B (no vegetation) and C (taiga)

The results profiles show that floodplain forests strongly restrict bank erosion. In both scenarios A and C the channel remains straight with free migrating alternate bars (Crosato and Mosselman, 2020). Pluvial forest and taiga result in different bar wavelengths and celerity, the latter being higher in scenario A (pluvial forest). The case without floodplain vegetation (B) presents bank erosion, with the main river channel becoming sinuous, and the formation of numerous side channels, transforming the straight river into a braided system.

Conclusions

Vegetation plays a significant role in the evolution of river channel as it provides a stabilising factor to the river banks. Studies of Allmendinger, et al. (2005) and Zong and Nepf (2011) have found that flood plain vegetation influences the river formation at both the local and the cross-sectional scale. Preliminary results indicate that boreal and pluvial forests reduce bank erosion in a similar way, but the different types of vegetation result in different bar characteristics.

3D modelling of Saltwater Intrusion into the Haringvliet to support Evidence-based Policy Development

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S. Muurman[d]

Highlights

- We use measurements and model results to explore stratified salt intrusion into the Haringvliet estuary.
- Wind conditions – and especially specific wind directions – dominate distribution of salt water intrusion.
- 3D simulations are indispensable in policy decisions regarding putting the 'Kierbesluit' into practice.

Overview

The Haringvliet estuary was once a vibrant ecosystem with a diverse range of species that included migratory fish such as salmon and trout. The construction of the Haringvliet sluices in 1970 as part of the Delta works has severely limited the migration of fish from saltwater to freshwater for spawning. The resultant loss of biodiversity has been extensive, with many species of plants and animals disappearing (Winter et. al, 2001). In recent years, Rijkswaterstaat has implemented a testing campaign to open the sluices during floods with the aim of promoting international fish migration and improving biodiversity. However, this results in an increase in salinity in the western part of the Haringvliet. To address this, the Kierbesluit decree stipulates that fresh water intake must be guaranteed east of the (imaginary) Middelharnis-Spui line, limiting the opening of the sluices to times when the river discharge is large enough to push back any intruding salt. This study – commissioned by Rijkswaterstaat – aims to use a validated 3D model of saltwater intrusion in the Haringvliet estuary to support evidence-based policy development on the management of sluice openings.

We used the D-HYDRO (DFlow-FM) modelling software to simulate the complex process of salt dispersion unique to the Haringvliet, with its deep pits, channels and intertidal shoals. The model (Tiessen, et. Al, 2023) used and further developed, consists of a horizontal unstructured grid with typical cell side lengths of 60 m and a combination of z- and σ-layers in the vertical with a typical thickness of 0.125 m (the combination of which makes the model particularly suited to simulating stratified flows in estuaries). The model was calibrated and validated against observational data, including water level, salinity, and current velocity data collected by Rijkswaterstaat, and was able to describe situations of both open sluices where saline water flows into consecutive deep pits, and closed sluices where salt is (or is not) stirred up from those pits and transported due to wind forcing.

Our scenario analyses show that salt water intrusion may occur beyond the Middelharnis-Spui line under east and south-east wind conditions. We also found that a combination of floodgate discharges and wind are the main forcing mechanisms that control the salt transport and mixing in the Haringvliet. Finally, scenarios have been applied to investigate for what rates of seawater inflow and outward floodgate discharges dynamic equilibria can be reached between incoming (during flood) and outgoing (during ebb) salt mass. These insights are used to develop management strategies for the sluice system and understanding the response of other semi-enclosed estuaries where such interventions are considered (e.g. the Lauwersmeer).

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Closed sluices

By defining scenarios we explore the various measures and operations that put the Kierbesluit into practice. Model simulations have shown that horizontal recirculation in the system as a result of specific wind conditions is a determining factor for the risk of salt transport eastwards towards the Middelharnis-Spui line. This has also been shown previously in analyses of observations (Kranenburg et. Al, 2023). The inclination of the salt water interface in pits and the overflow of salt water between pits during such wind conditions are key processes. See Fig. 1 for an example of eastern winds leading to eastern directed flow in the main channels, inducing inclination of the salt water interface.

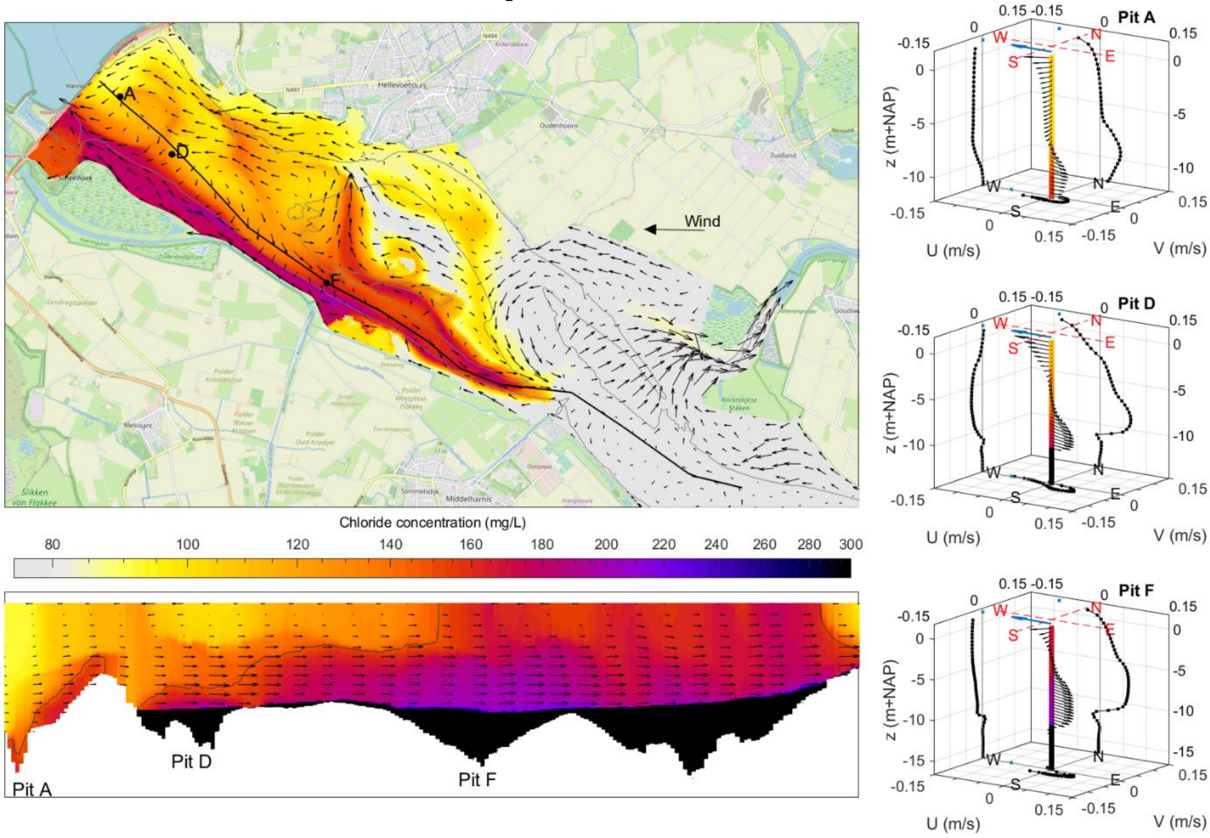

Fig. 1: Snapshot in time of wind driven circulation with closed sluices. Top left: mean chloride concentration and mean velocity in arrows in the part of the water column above -4m+NAP. Bottom left: cross section of chloride concentrations and velocities along Pits A, D and F. The location of the cross section is indicated in the top left plot with the black line. Right: vertical velocity profiles of flow in designated locations, with chloride concentration in the coloured dots.

Open sluices

Measures to push back the salt towards the sluices or to contain the salt in the pits are examined. The challenge is to find a dynamic equilibrium between incoming (during flood) and outgoing (during ebb) salt mass, see Fig. 2 for an example of influx of salt water during a period with open sluices.

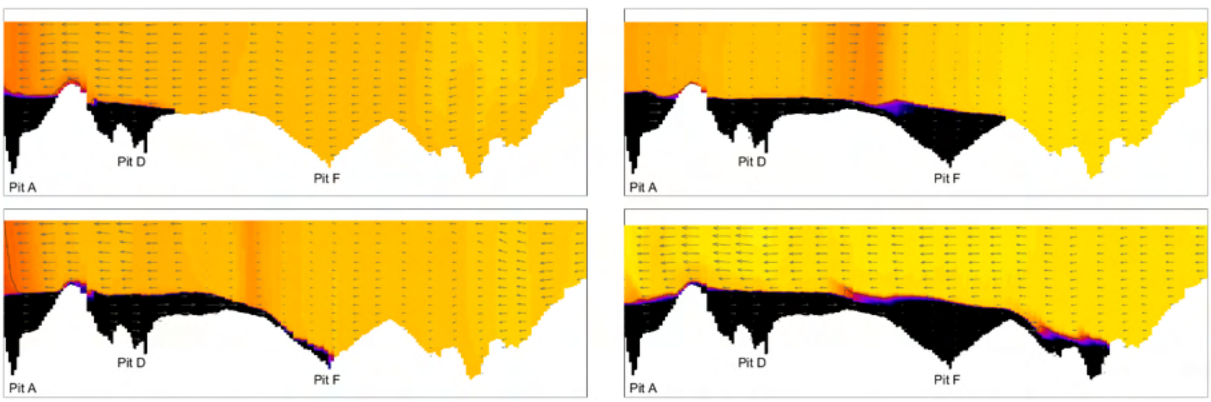

Fig. 2: Snapshots in time of saline water (black) entering the Haringvliet, during a period with open sluices during both flood and ebb flow. The location of the cross section is indicated in the top left plot in Fig. 1.

Session 4

Nature based solutions

Netherlands Centre for River studies NCR

Keynote Presentation Session 4

Bregje van Wesenbeeck – Nature based solutions 2.0

Nature-based Solutions (NBS) are increasingly popular for mitigation of and adaptation to climate change and can be applied across different landscapes. In rivers we can learn from past successes and mistakes to improve the way we work with NBS in the future. Moving beyond project scales in space and timem and making use of old and new river management practices is needed to fully embrace NbS power.

Dr. Bregje van Wesenbeeck is the scientific director of Deltares, a Dutch research institute for water management, and a senior expert in nature-based solutions. She also is an associate professor at the Delft University of Technology in nature-based solutions for climate change adaptation and disaster risk reduction with a focus on salt marshes and mangroves. She strives to both strengthen the scientific foundation and further practical application of nature-based solutions. At Deltares she has over 15 years' experience in working with development banks, UN, NGO's and governments in Asia, Africa, USA and the Netherlands, for whom she provides advice on flood risk reduction, erosion mitigation and climate change adaptation. As scientific director she chairs the science council of Deltares, which advices on quality and direction of the work and organization.

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Ralph Schielen – NBS in practice: upscaling and mainstreaming

In this presentation in will focus on what is needed to apply Nature based solutions in operations and management practice of water authority organisations. There are already many frameworks, best practices and guidelines available (see e.g. https://ewn.erdc.dren.mil/?page_id=4351) but which steps need to be taken to connect this to mainstreaming NbS? And perhaps even more ambitious: can NbS also fulfill a role in achieving the Sustainable Development Goals in low and middle income countries?

Ralph Schielen holds a PhD in Mathematics from Utrecht University. He is a senior advisor on Hydraulics, Morphology and Water Management at Rijkswaterstaat, the main governmental Water Management Authority in the Netherlands. He also holds a position as senior researcher at Delft University of Technology. Ralph Schielen's research concerns the behavior of lowland rivers under climate change and anthropogenic interventions, with a focus on Rhine and Meuse. He is co-author of the river-chapters of The International Guideline on Natural and Nature Based Features for Flood Risk Management, and is also involved in the application of Nature Based Solutions (NbS) to establish resilient and robust river-landscapes. An important subject in his research is the connection between science and practice in applying NbS, and stimulating mainstreaming and upscaling of NbS.

RiverWorks: from river DNA to sustainable soil winning

Maria Barciela-Rial[a,*], Bart Peters[b] & Jeroen Rijke[a]
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Keywords — system-based, river DNA, nature restoration, sustainable management, local reuse of soil

Introduction

Many functions come together in the river area (e.g. flood protection, waterway management, nature development). Consequently, many projects with different goals take place in a limited space. In many of these river projects, earth moving is one of the larger parts. Among other things, it determines the costs, the CO2 footprint, the environmental nuisance and the spatial quality of the river landscape. Furthermore, in recent years, sand and other coarse raw materials have become scarce while the demand of raw materials continued to increase (e.g. Barciela-Rial et al., 2022). This highlights the need to develop re-use scenarios and sustainable raw materials sources.

In the Netherlands, around 1500 km of the dikes must be reinforced before 2050 to comply with new safety requirements. At the same time, the Dutch floodplains have silted up over last centuries as a consequence of flood events and space narrowing caused by dikes. Therefore floodplain nature restoration requires excavation for the Dutch case. Consequently, linking soil supply (nature restoration) and demand (e.g. dike strengthening) seems logical from a sustainable river management perspective.

The RiverWorks (In Dutch: *Rivierwerken*) project (mid-2022 – mid-2024), is a collaboration between 20 partners across academia, public and private sectors. RiverWorks applies a system based approach and nature-based solutions for floodplain restoration, quantifying and assessing the soil becoming available and developing knowledge to locally reuse it in dike strengthening projects.

Method

We define the natural characteristics of specific river stretches as the *DNA of the river*. With the DNA as basis, we designed nature restoration interventions for four different stretches with different DNA in the rivers Waal, Meuse (*Zaandmaas* and *Bedijkte Maas*) and IJssel.

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Therefore applying the Smarts Rivers Approach (Peters et al., 2021), which is based on a design strategy for spatial quality in river floodplain development projects, with starting point the landscape and ecological layer of the river.

Results

Figure 1 shows, as an example, the final design for one of the four locations studied. In this case Waal, near Winssen.

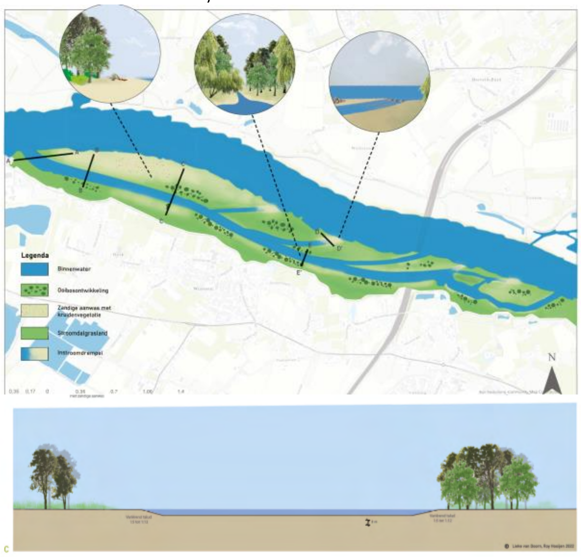

Figure 1. Aerial view (top panel) and example of a cross section (bottom panel) for the stretch studied in the Waal river (courtesy of Lieke van Doorn and Roy Hooijen)

For the presented the design, it was calculated that 4010438 m3 of mineral resources can be won. These consist of 82,7% clay, 15 % sand, 2% loam and 0.3% gravel.

Conclusion

There is room for sustainable winning of mineral resources on the floodplains of Dutch rivers while contributing to nature restoration (win-win). Sustainable local (re)use of sediment and soil contributes to a circular economy by reducing waste and regenerating natural systems. 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. The won material could also be used for other purposes, such as river bed suppletion as part of a short term strategy to palliate river bed erosion.

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Response of the Upper Dutch Rhine Bifurcation Region to Peak flows

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Highlights

- We analyze historical hydraulic, bed level, and bed texture data from the Pannerdense Kop bifurcation region
- Discharge fraction into the Waal branch has slowly increased over the last three decades at the expense of the Pannerden Canal.
- In-channel sediment deposition due to a rapid succession of peak flows likely triggered this change in flow partitioning.

Overview

Flow partitioning at a river bifurcation influences navigation, freshwater supply, and flood risk. Such flow partitioning is strongly related to the bed level development within the bifurcation region. Here we analyze the response of a bifurcation region in a river system with a fixed planform to engineering measures over the last century.

We address this by assessing measured data on water level, bed level, and bed surface grain size within the Pannerdense Kop bifurcation region (Fig. 1a) over the last century. We use data on water discharge both upstream (4 km) and downstream (1 km) of the bifurcation. Data on water discharge, water level, bed surface texture, and bed level for the Dutch Rhine originate from Rijkwaterstaat.

We show that the Waal branch has gradually received an increasing discharge fraction relative to the Bovenrijn over the last 30 years. This slow change in flow partitioning is associated with the Waal branch eroding faster than the Pannerden Canal branch.

Aggradation in the upstream part of the Pannerden Canal due to the rapid sequence of peak flows in 1993 and 1995 (and possibly 1998) seems to have triggered this gradual change in flow partitioning and erosion rate difference.

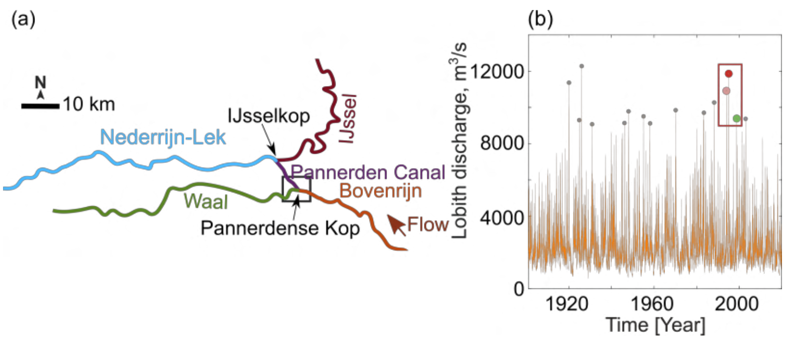

Figure 1. (a) Field site, Pannerdense Kop bifurcation in the upper Dutch Rhine and (b) measured water discharge at Lobith since 1901. The dots indicate peak flows with magnitude larger than 9000 m^3/s.

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Flow Partitioning at the Pannerdense Kop Bifurcation

Figure 2a shows that, despite a relatively large scatter, the Waal fraction of the Lobith water discharge follows a relatively constant trend between 1970-1990. The Waal fraction of the Lobith water discharge appears to start to change following two (or three) consecutive peak flows in 1993 and 1995 (and 1998). Subsequently, the annual mean Waal fraction of the Lobith discharge has gradually increased (by 0.2-0.4% per year) since the mid-late 1990s for two discharge regimes (low, $Q_{Lobith} < 1500$ m^3/s and high, $Q_{Lobith} > 2500$ m^3/s). The operation of the Driel weir influences flow partitioning in the medium flow regime $1500 < Q_{Lobith} < 2500$ m^3/s and is not discussed here.

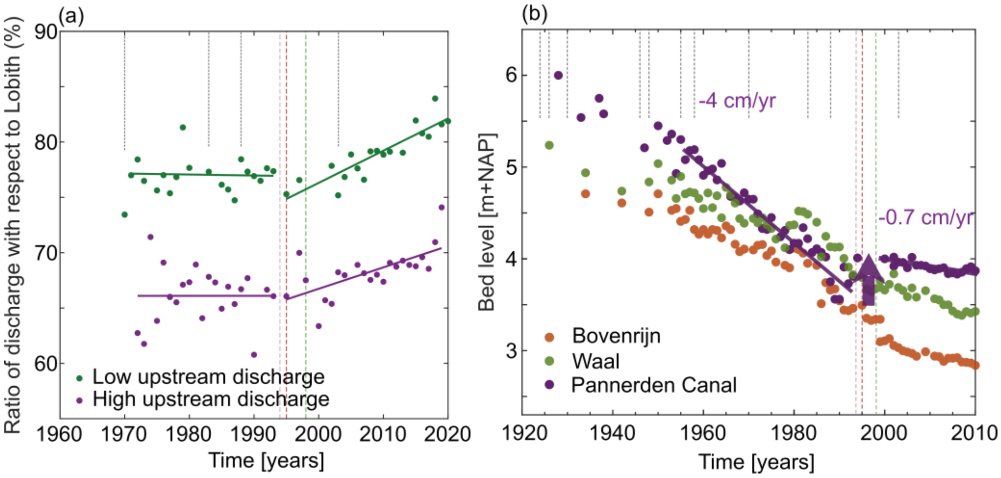

Figure 2. (a) Waal fraction of the Lobith water discharge and (b) bed level at a position 0.5 km upstream and downstream of the bifurcation as a function of time. Vertical lines indicate peak flows shown in Fig. 1b.

Change in Bed Level at the Bifurcates

The channel bed of the Waal and the Pannerden Canal branches has eroded over the last century primarily due to channelization measures (e.g., Havinga, 2020). Before the mid-1990s, the channel bed at the upstream end of the Pannerden Canal had eroded faster than the Waal. After the peak flows, we see rapid aggradation at the upstream end of the Pannerden Canal (Fig. 2b). Furthermore, right upstream of the bifurcation, the channel bed in the Bovenrijn rapidly eroded following the peak flows.

This rapid deposition at the upstream end of the Pannerden Canal seems to have triggered the slow change in flow partitioning in favour of the Waal branch. And it seems that the larger the Waal share of the Lobith water discharge, the more the upstream part of the Waal branch erodes.

Since the consecutive peak flows, the upstream end of the Waal branch has eroded faster than the Pannerden Canal. As a result, the Waal depth gradually increases with time relative to the Pannerden Canal. The consequence is a gradual increase in the Waal discharge fraction. These changes have also resulted in a reduction of the erosion rate at the upstream end of the Pannerden Canal compared to the situation before the peak flows (Fig. 2b).

Discussion

The Waal discharge fraction increasing with time suggests that the Pannerdense Kop bifurcation is currently unstable. An unstable bifurcation is defined as one where the water discharge in one branch increases at the expense of the other branch. The rapid deposition at Pannerden Canal following the peak flows likely triggered the instability. Previous research also suggested that large peak flows could unbalance a bifurcation and cause a change in flow partitioning (Kleinhans et al., 2007). We want to understand why the 1993-1995(-1998) peak flows have resulted in a different bifurcation response than other peak flows (Fig. 1b). We hypothesize that the response is likely associated with the following: 1) the duration, magnitude, and sequence of the peak flows and 2) the temporal coarsening of the bed surface sediment and sediment flux in the bifurcation region.

The observed bifurcation response may influence river functions in the future. Future research will investigate the bifurcation response to climate change.

Acknowledgement

This study is part of the research program Rivers2Morrow, financed by the Dutch Ministry of Infrastructure and Water Management. We thank the technical staff of Rijkswaterstaat for sharing the data used in this study.

Towards a holistic economic assessment of integrated river management strategies

Authors:
Sien Kok[a,b]

Highlights

- The EU promotes integrated river management and use of nature-based solutions.
- A more holistic economic assessment is needed for sound decision support.
- The ecosystem services framework is a good starting point to demonstrate the various benefits and trade-offs.

Overview

To make river basins more climate resilient and generally healthier for people and species, the EU is progressively encouraging more holistic river management. In this context, ambitions regarding the restoration of aquatic ecosystems and mainstreaming the use of nature-based solutions are increasingly embedded in policy, such as the Water Framework Directive, the European Green Deal and the proposed EU Nature Restoration Law. At present, the majority of policy appraisal studies focusses on impacts of interventions on single domain (hydrological) services such as flood risk reduction, water quality or impacts on navigation, or on (a limited set of) other ecosystem services (ES) such as agricultural production or recreation (Hanna et al., 2018; Le Coent et al., 2021). Assessment of a wider scope or impacts is essential to gaining insight in the various benefits and trade-offs of using conventional, single-purpose versus more nature-based, multifunctional river management strategies: appraisal studies with a smaller scope tend to skew results towards conventional approaches (Grossman, 2012; Le Coent et al., 2021).

In this study, we address this gap by analyzing benefits and trade-offs of a wide array of ES under alternative river management strategies for the Rhine Branches in the Netherlands. Current challenges in river management include ongoing river bed incision, low ecological quality and increasing high – and low discharge conditions related to climate change which affect navigability, fresh water supply and flood risk (Klijn et al., 2022). At present, various organizations work towards a new policy for the Rhine and Meuse to address these challenges under the Integrated River Management program (IRM, 2022). By aligning where possible with decision support analyses under development in IRM, we aim to offer new insights in ES benefits and tradeoffs. In a later stage the research will integrate these insights in an economic assessment and address funding and financing strategies for freshwater restoration, in view of the investment and implementation gap for freshwater restoration and the need for co-financing strategies.

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Acknowledgements

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Introduction

The concept of ecosystem services (ES) provides a suitable and widely accepted framework for weighing impacts of policy changes and interventions (including e.g. Nature-based solutions) in a more holistic/ integrated framework. However, most studies analyzing ES in river management have a relatively limited scope: an integrated analysis across a wide set of ES, across provisioning, regulating and cultural services is lacking (Hanna et al., 2018). At the same time, there is limited research comparing conventional versus nature-based strategies at a large-scale (river-stretch to basin-level). Studies that do review a wide(r) range of ES in economic analysis of different river management strategies (e.g. work of Grossman (2012) for the Elbe) demonstrated that a small scope skews results to promote conventional, mono-functional approaches. In this study we review the impact of different management strategies for the Rhine Branches on a broad range of ES.

Methods

Five river management strategies were selected based on existing material to increase relevance to current policy developments. The strategies represent more 'regular/ single-purpose' versus more integrated/ natural river management strategies, inspired by the 'Business as Usual' (as established in the IRM programme) (V0), the situation before Room for the River programme was executed (V1); the preferred strategy of the Delta Programme Rivers in 2015 (Staf Deltacommisaris, 2015) (V2) and the 'Plan Room for Living Rivers' (ARK Natuurontwikkeling et al., 2018)' with limited (V3a) and no (V3b) room for agriculture in the floodplains. **Error! Reference source not found.** shows the alternatives across the spectrum of discharge capacity of the system and desired elevation level of the river bed (in relation to reference year). ES and indicators were selected based on expected impact of interventions; relevance to national and international policy objectives; expected impact on cost-benefit-analysis and co-financing potential (Table 1). At the basis of the ES analyses lies a GIS-based analysis of land use; elevation; water level/ discharge relationships (modelled using D-HYDRO and SOBEK) and potential ecotope development (modelled using HABITAT).

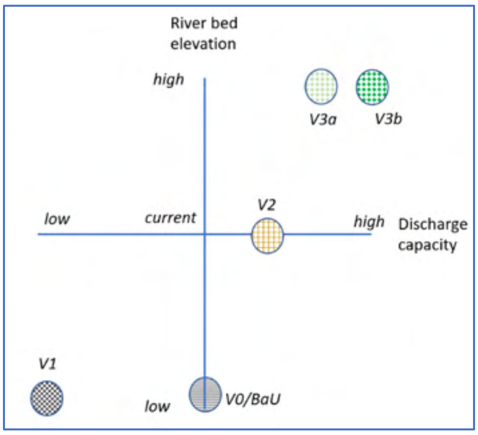

Figure 1 Schematic depiction of strategies along the axis discharge capacity/ river bed elevation. Colors represent vegetation management / room for agriculture (black: predominant land use is agriculture, and roughness generally low; yellow: less room for agriculture, roughness still low; light/ dark green limited/no agriculture in floodplains, more room for increased roughness).

	Geo/Ecosystem service	**Indicator**
Provisioning	Crop & fodder production	Agricultural yield (t/y)
	Provision of construction material	Tonnes construction material (sand/gravel)
	Biomass production	Ton/ year wet & dry biomass
Regulating/ maintenance	Flood mitigation	Dike reinforcement needs (€) to meet flood safety norms
	Boatable navigation network	Revenue of shipping sector (€)
	Pollination	Agricultural yield (t/y)
	Land cover stability	Building damage in € related to subsidence in/near floodplains
	Carbon sequestration	Ton C/ sequestered
	Provision of clean water	Ton N/P removed from water/y
Cultural	Recreation	# of walking/ hiking trips # of suitable sport fishing locations
	Aesthetic value	Increase in property values (€)
	Bequest & Existence value	Degree to which nature development goals are met (van der Sluis et al, 2020)

Table 1: overview of geo/ecosystem service and indicator analysed in this study

Results

This study is providing a framework of analysis on how to approach ES assessment in a more holistic manner. Expected results in the next stage of this study will 1) contribute to research gaps regarding ES trade-off analysis in the context of river management, 2) support development of an integrated assessment framework for river management and 3) offer insights for policy makers in river management in the Netherlands and beyond.

To what extent is morphodynamics of Terai Arc Landscape rivers altered by human actions?

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Astrid Blom[a]

Highlights

- Analysis of extreme flows and images of the Karnali and the Koshi rivers
- Increased sedimentation affected by channelization and dam construction
- River morphodynamics affected by combination of natural and anthropogenic activities

Overview

Most of the Himalayan rivers emerge out of the mountains into the flat lands of Nepal, India and Bhutan. This landscape is called Terai Arc Landscape (TAL), where these rivers release a large quantity of sediment forming fertile alluvial fans. The rivers in TAL are crucial for both the environmental conservation and continuity of socio-economy in countries such as Nepal. However, the increased demands for the socio-economic activities have highly influenced the TAL rivers. Increased anthropogenic interventions such as hydropower and irrigation projects, flood protection structures, and sediment mining alter the flow, sediment transport and hence the morphology of the TAL rivers. This research makes an attempt to identify the impacts of such anthropogenic activities on the hydro-morphodynamics of the TAL rivers. Here we discuss the morphodynamics of the Karnali and the Koshi rivers in Nepal.

The yearly maximum discharge in the Koshi River and yearly minimum discharge in the Karnali River show a decreasing trend. Meanwhile, the trend of the minimum discharge in the Koshi River and the maximum discharge in the Karnali River do not show significant change (Figure 1).

Analysis of remote sensing data and historical maps for both rivers within the stretch of TAL show that they have changed their flow course multiple times. Often, the course switches between former channels (Chakraborty et al., 2010; Dingle et al., 2020). Records and image analysis show that these avulsions are usually abrupt and occur during high flood. Channelization has affected the morphodynamic processes in both rivers. The western branch of the Karnali River (the Kauriala), channelized on both banks, has low braiding index than its eastern branch (the Gerua) which is embanked only on right bank. The embankments and barrage construction in the Koshi River has increased the river sedimentation by more than double in about 54 years (Sinha et al., 2019).

Rivers in TAL are naturally dynamic braided systems. The changing hydrological conditions and the human interventions have restricted this dynamic behaviour. As an example, channelization and controlled flow have reduced the channel-floodplain connectivity. They have also altered morphodynamic processes such as channel shifting and flow partitioning as observed in the Koshi River. There may have been a paradigm shift from natural to human induced morphodynamic processes. Identifying, distinguishing and studying the extent of impact caused by these processes, be it natural or anthropogenic, has become of utmost importance to help in maintaining the river functions in TAL and this needs extensive exploration and research.

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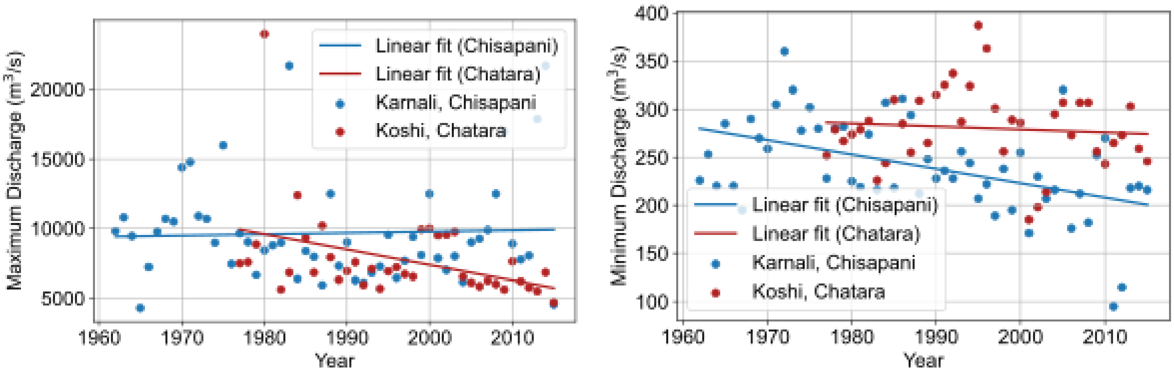
Hydrological Analysis

Hydrological analysis (Figure 1A) shows decreasing trend in maximum discharge of the Koshi River at Chatara. Hydropower development may be one of the factors influencing this decline. The extent of hydropower and associated river dams in the Koshi river basin has increased since the past two decades. This development has played role in attenuation of the flood peaks and hence altered the natural discharge as well as sediment transport in the Koshi River. The future of the Karnali River, which thus far is one of the least altered rivers by anthropogenic intervention in TAL, may resemble the current state of the Koshi River, as multiple hydropower projects are in construction or planned. The declining trend in minimum discharge of Karnali (Figure 1B) may be due to changing precipitation dynamics, land use change or increased consumptive use of water in the catchment and this needs further research.

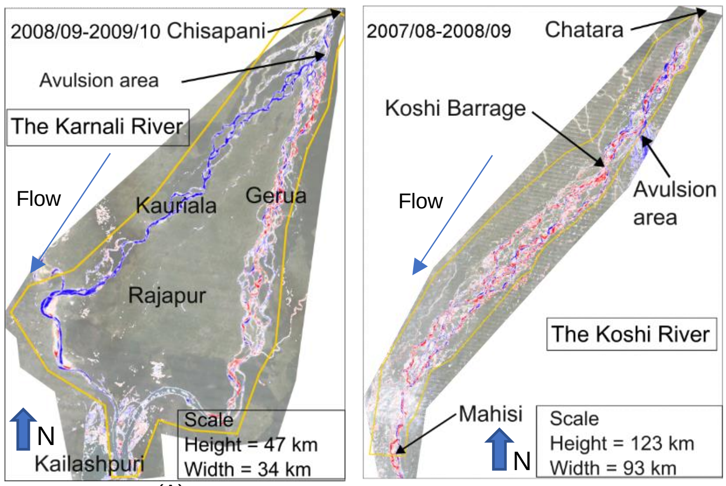


(A) (B)

Figure 1: (A)Yearly minimum and (B) yearly maximum values of discharge and its trend in the Karnali at Chisapani (blue) and the Koshi at Chatara (red).

Channel Migration

We use difference of Normalized Difference Water Index (NDWI) in Google Earth Engine (GEE) to identify the change of river course over time. Figure 2A shows the switching of channel in Karnali River in 2009. The river changed its major flow path from the eastern branch (red colour indicates the areas where the river used to flow before the 2009 avulsion) to the western branch (blue color indicates the flow path after channel switching). The avulsion took place at the apex of the island, Rajapur and the two branches join back at Kailashpuri. These avulsions can be characterised as nodal (occurring around same area) and partial (take away a part of discharge) (Slingerland & Smith, 2004). This avulsion has significantly reduced the flow in the eastern braided branch (Gerua) which flows through the Bardiya National Park. Subsequently, the main river course has followed a narrower and mostly single threaded western channel (Kauriala). The embankments on both banks of the western branch has channelized it. Similar is the case of the Koshi river. Figure 2B shows the NDWI difference image of the Koshi River from Chatara to Mahisi. The Koshi River is confined by embankments on both banks and flows through the Koshi Tappu Wildlife Reserve and is regulated by the Koshi Barrage. The operation of the barrage gate determines the flow path of the river in the downstream channel. In 2008, an eastern embankment breach resulted in an avulsion which rejuvenated a paleo channel. This led to casualties and significant damage.



(A) (B)

Figure 2: NDWI difference image showing channelization and channel switching of (A) the Karnali river in 2009 and (B) the Koshi river in 2008. The red areas show the old flow path and the blue are the flow path after channel switching.

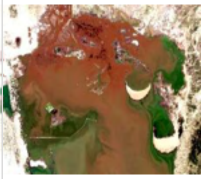
Acknowledgement

This research is a part of “Save the tiger! Save the Grassland! Save the Water!” project funded by Dutch Research Council (NWO) with co-financing partners VanderSat (currently Planet), Rotterdam Zoo, Himalayan Tiger Foundation and Practical Action.

Poster Session 2

Netherlands Centre for River studies NCR

Discovering the ancient outlet to the sea of river Piura due to anthropogenic changes - La Niña basin - El Niño, Peru



Cesar Adolfo Alvarado Ancieta[a,b,c,d]

Highlights

- Deviation of the natural course of river Piura in the lower basin force it to claim a new outlet to the sea
- Existing dunes of south-north direction using very fine sand, silts and clay material of ancient paleo-geo-planform of river Piura of north-south direction.
- Anthropogenic changes together with El Niño Phenomena and the tectonic tilting of the earth's surface in the Antearc (Forearc) zone, discover the ancient outlet to the sea of river Piura as his new river mouth

Overview

The deviation of the natural course of the Piura river in the lower river basin, which discharged into the sea in the past, to a new point of discharge, with a longer river length, has resulted in a complex problem in the river morphology, thus, the process of sedimentation occurs in the lower basin, result of high suspended sediment transport rates during extreme flood events as El Niño phenomena (Alvarado, 2020). Flood discharges and suspended sediments yields are transported South direction, through the new man-made river alignment, impacting the Ramón-Ñapique lagoons, Pampa Las Salinas, Tres Brazos, the estuary of Virrilá, ravine Ñamuc and La Niña lagoon, which between the Pleistocene and Holocene were part of old channel of river Piura, which gradually hung up and retreated from the South to the North, also with interaction of river Cascajal mainly, being the estuary of Virrilá and old paleo channel of river Casacajal, and due to this interaction river Piura finally found his sea outlet, after retreating more to the north at Sechura, at the West, which is the shorter way to the sea. In addition, the geology and tectonic tilting of the earth's surface in the Antearc (Forearc) zone of northwestern Peru impacted in the past and in the present the river Piura alignment and now the anthropogenic alignment looking as a result for a new final sea outlet after La Niña lagoon, in Reventazon, through several existing "tombolos" at the coastline (Alvarado, 2022).

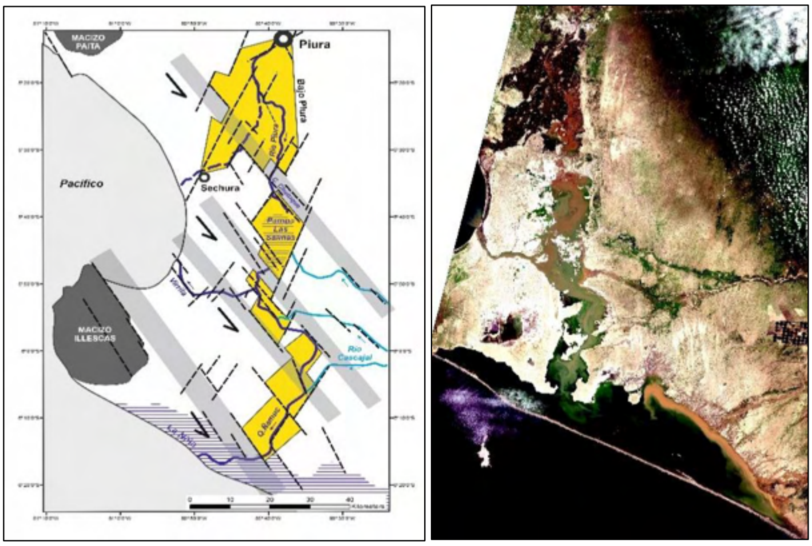


Figure 1. Simplified tectonic scheme of Bajo Piura and La Niña anthropogenic basin, showing the tilting East direction of the earth's surface in the Antearc (Forearc) zone, forming the North-South direction for the new alignment of river Piura.

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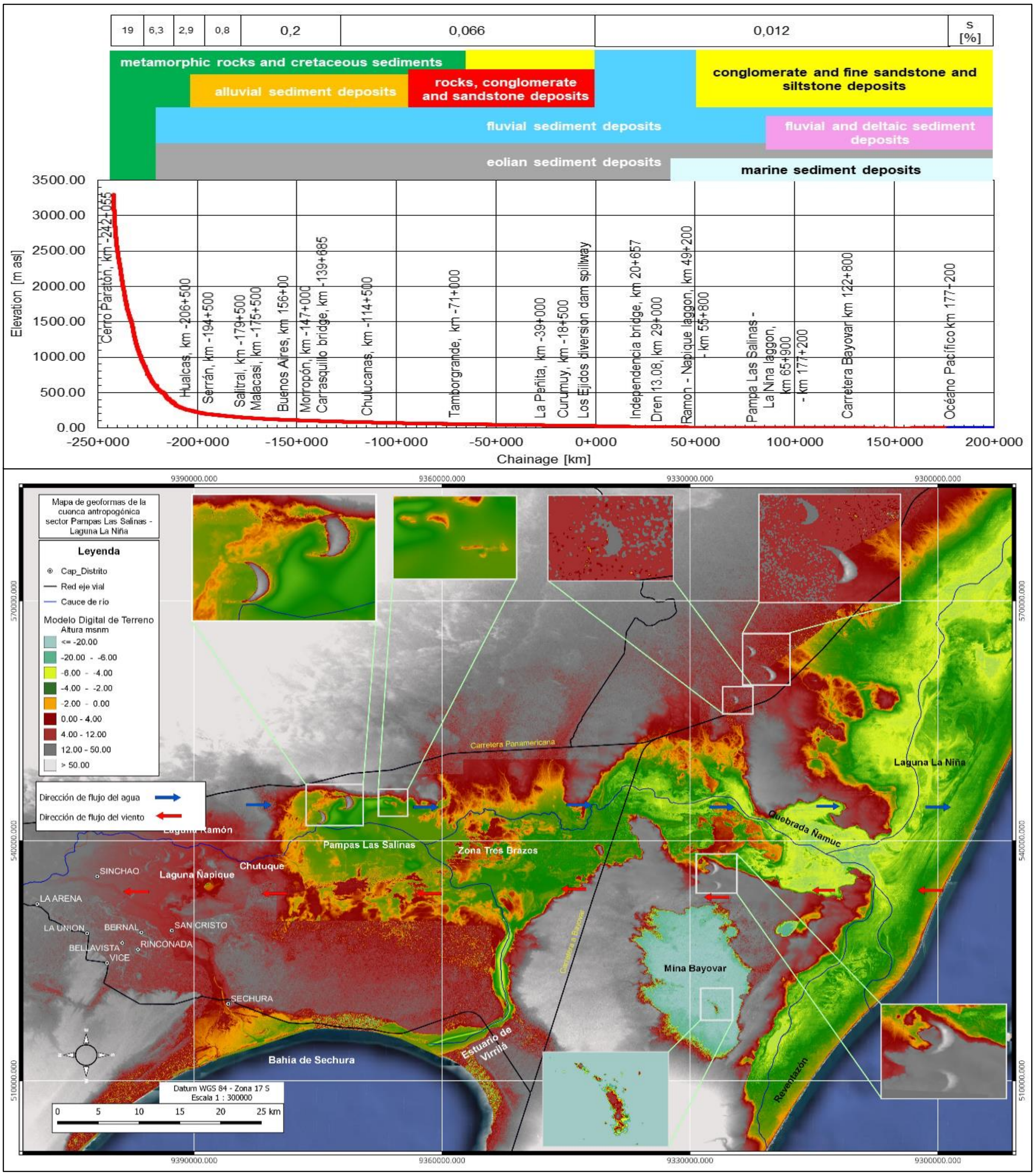

Figure 2. Top, geological profile of river Piura. Bottom, existing dunes of south-north direction using very fine sand, silts and clay material of ancient paleo-geo-planform of river Piura of north-south direction of the anthropogenic La Niña basin: Ramón-Ñapique lagoons - Pampa Las Salinas - Tres Brazos - ravine Ñamuc - La Niña lagoon - Reventazon sea outlet.

Introduction and Methodology

High sediment transport rates activated with El Niño event and anthropogenic changes after the last 50 years, causes a complex problem in the river morphology of the lower river basin, flooding Piura. The anthropogenic changes (Alvarado, 2020), with water releases to the Pacific Ocean iare forcing river Piura to release at the sea through several existing “tombolos” along the coastline after La Niña Lagoon, the delta of ravine Ñamuc. A geology, tectonic and fluvial-geomorphology study supports the identification of the ancient outlet to the sea of river Piura as the new one due to anthropogenic changes.

Results

The anthropogenic changes in the current river alignment do not only occasioned the river Piura to look for a new sea outlet, but also the geology and the tectonic tilting of the earth’s surface in the Antearc (Forearc) zone of northwestern Peru, support the new river outlet to the sea.

Piura River, origin of the sedimentation of the estuary of Virrilá due to anthropo genic changes - El Niño impact, Peru

Cesar Alvarado Ancieta[a,b,c,d]
Jhonath Mejía[e]
Aaron Alva[d]
Yoel Cordoba[d,f]
Pedro C. Zavaleta[d]

Highlights

- A historical review of the estuary evolution morphology between 1975 and 2022
- Analysing available dataset since 1925 and performing a 2D- numerical hydraulic modelling
- Sedimentation of the estuary of Virrilá due to anthropogenic changes in Piura River is being accelerated due to El Niño 1998 and 2017

Overview

The deviation of the natural course of the Piura river in the lower river basin, which discharged into the sea in the past, to a new point of discharge, with a longer river length, has resulted in a complex problem in the river morphology, thus, the process of sedimentation occurs in the lower basin, result of high suspended sediment transport rates during extreme flood events as El Niño phenomena, and this further affects the estuary of Virrilá (Alvarado, 2020). As a consequence, a high aggradation process is occurring in the last 25 years. The high suspended sediment concentration during the 1998 and 2017 extreme floods in the Piura River are transported through the new man-made river alignment, impacting the Ramón-Ñapique lagoons, Pampa Las Salinas, Tres Brazos, the estuary of Virrilá, ravine Ñamuc and La Niña lagoon.

Sedimentation processes in the estuary of Virrilá occurs due to very low flow velocities in the system, as a consequence of a very low slope of the river, the estuary channel or the system as well. The very fine suspended sediments: very fine sands, silts and clays, i.e. cohesive sediments settling at the tail of the estuary, mainly before the bend formed between the inverse L and Y shapes of the estuary, and the high tide fails to remove and eject these sediments in an appreciable quantity into the bay of Sechura. Thus the hydrodynamic tidal effect is limited up to 7 km upstream of the outlet of the estuary. In addition, these large deposits are being consolidated in a time scale. However, these suspended particles can be only removed and suspended again by erosion by high flow velocities. The aggradation, erosion, settlement and compaction process are the key phenomena to understand the estuarine sedimentation dynamics in this case.

This research is focused in the estuary of Virrilá. This requires an understanding of the morphological processes involved in the anthropogenic change of Piura river and its impact in the estuary, especially due to peak floods as El Niño phenomena (Alvarado et al., 2022), together with the physical processes occurring in estuaries.

It is important to emphasize that the changes in the natural system when they are not implemented in harmony with nature, creates a conflict with it. This “building with nature” approach requires a deep understanding of the sediment transport processes in morphological systems (Van Rijn, 2002). The estuary of Virrilá is a declared Ramsar site since June 2021, and a high biodiversity is under a potential ecological damage.

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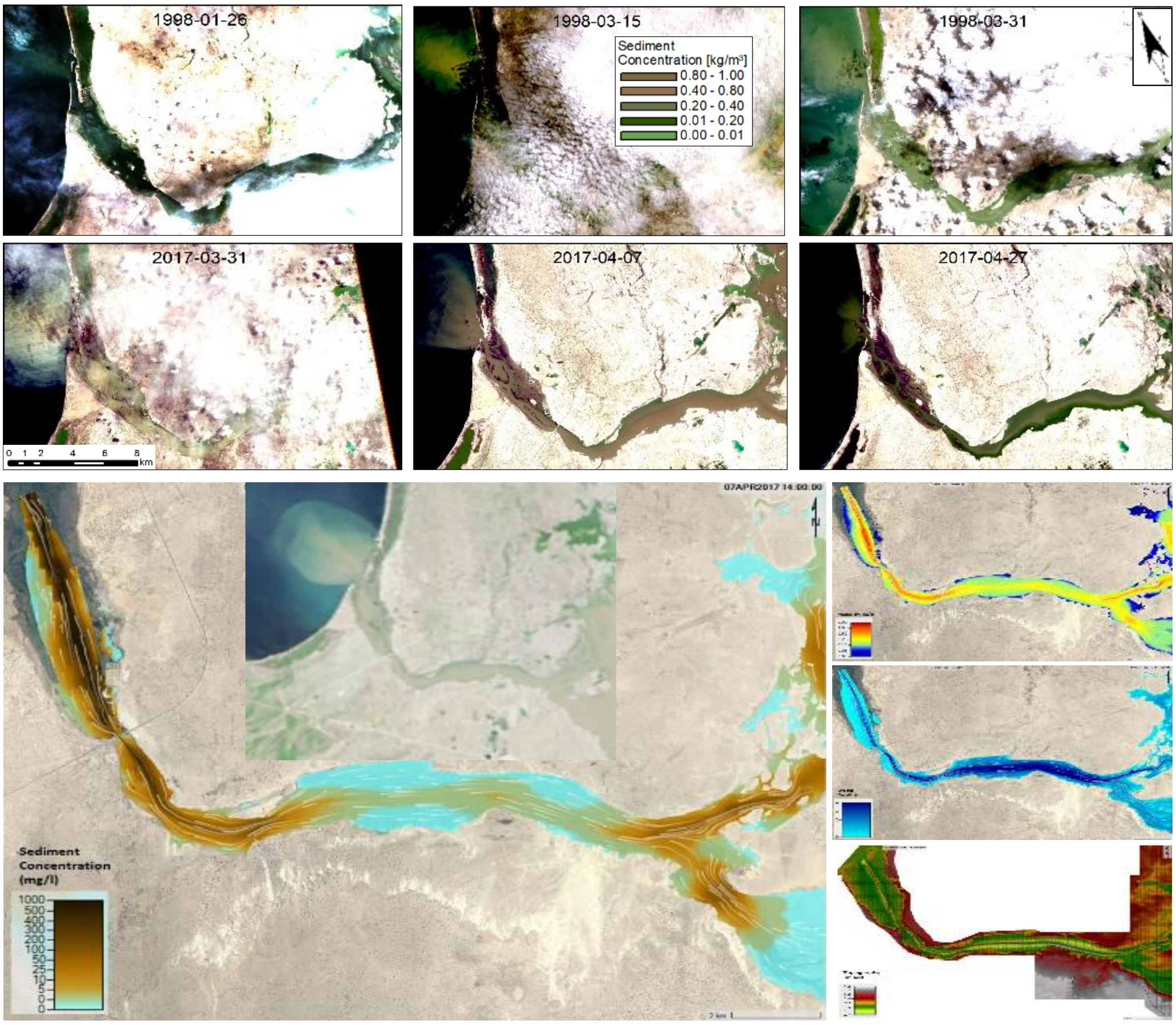

Figure 1. Morphological processes of the sedimentation of the estuary of Virrilá due to El Niño climate impact 1998 and 2017.

Introduction

Anthropogenic changes in the river Piura and El Niño Phenomena impact, produces that high suspended sediment yields and Sechura desert sandbanks to be transported up to the estuary of Virrilá producing his sedimentation which has been observed during the extreme event 1998 and 2017.

Study area

It is the estuary of Virrilá which releases into the Bay of Sechura, located at the S-W of the anthropogenic deviation of the Piura river alignment and its old river mouth in Sechura, to a new one in Ramón and Ñapique Lagoons; directly west of Cascajal River mouth, Tres Brazos and Ñamuc Ravine; and at the north-west of La Ñiña Lagoon.

Methodology

A historical review of the morphology changes between 1975 and 2022 was carried out, analysing the available topography, bathymetry, DTM 2011 & 2022 with 0,25 m res. satellite images, hydrological and sediment since 1925, geological, geotechnical, and geophysical data since 1930, and performing 1D/2D numerical hydraulic modelling, $t_{2017\ \text{flood wave}}$ = 6 months, with many simulations for different approaches.

Results

The analysis found a high suspended sediment concentration up to 1 kg/m3 of silts and clays, during the flood wave. The hydrodynamic tidal effect of the Bay of Sechura at Parachique mouth into the estuary, is limited up to 7 km upstream, at Virrilá bridge, during the flood event. The aggradation phenomena of the estuary of Virrilá is confirmed by the formation of small islets that cannot be removed by the high tide along 23 km estuary length. The site, a unique mangrove ecosystem for more than 132 species, a high biodiversity, and provide fishery to the population is under a potential ecological damage.

On the relationship between flow-field and bank erosion in rivers: insights from large-eddy simulations

Authors:
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Francesco Bregoli[a,d]
Alessandra Crosato[a,e]

Highlights

- A 3D large-eddy resolving hydrodynamic model setup in OpenFOAMv10
- High-resolution flow-field data for a large flume experiment with mobile bed
- Spatio-temporal evolution of bank accretion can dictate the progress of bank erosion

Overview

Bank erosion is perhaps one of the most notorious hydro-morphological processes in rivers with a complex and wide spectrum of implications – ranging from the spatio-temporal evolution of river behaviour to the impacts on riparian demography. While bank erosion is an intricate phenomenon resulting from multiple interacting process i.e. entrainment by flow and mass failure, there have been several endeavours to model the process especially in the context of river bends (Rinaldi, et al., 2008).

Studies have shown that the erosion of one river bank can be triggered by the accretion of the opposite bank (Bonilla-Porras, 2017, Vargas-Luna, et al., 2019). This bank accretion may occur naturally due to morphodynamic instability or be induced through human interventions such as the use of groynes. To gain a better understanding of the underlying processes, a computational fluid dynamics (CFD) numerical study was conducted. The study utilized data from previous experiments that were carried out in a large flume with a mobile bed, which observed bank erosion opposite to bar formation (Vargas-Luna et al., 2019). The CFD model was set up to replicate these experiments at a high-resolution (~6million cells with an average cell-size of 5mm in the region of interest), enabling a detailed investigation of the drivers behind the observed phenomenon.

The hydrodynamic model used in this study takes in boundary conditions and high-resolution bed topography data that were collected during the experiment at specific time intervals. The simulation runs until it reaches a steady state, providing the flow field for that particular bed topography configuration at that given time. This process is repeated for subsequent time instances with updated bed topography, resulting in a set of flow field data for each time instance. By correlating various flow field variables such as near-bank velocities, turbulent kinetic energy and turbulent dissipation, with the rate of bank erosion observed, we can determine the driving factors behind the erosion of the opposite bank. Additionally, the large eddy simulations allowed for the identification of coherent turbulent structures using the Q-criterion.

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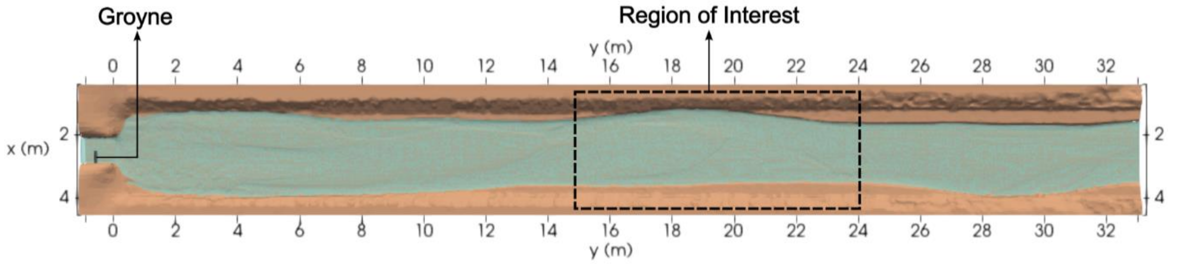

Figure 1: Model domain (shaded region indicates water)

Preliminary Results

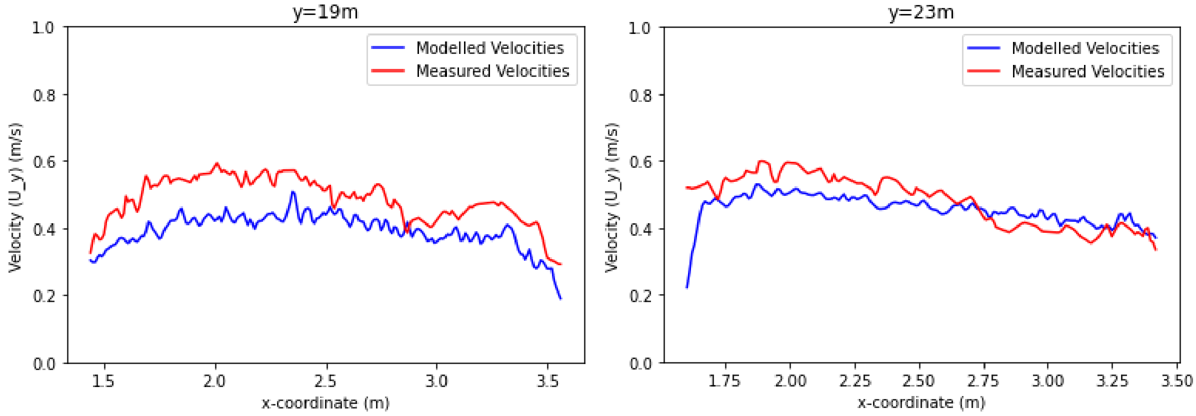

Figure 2: Modelled v/s Measured velocities

A comparison of cross-sectional velocity profiles indicates good agreement between the modelled and measured data (Vargas-Luna, et al., 2019) with the model slightly under-predicting velocities towards the upstream of the domain.

The large-eddy simulations conducted herein utilize the Wall-Adapting Local Eddy-Viscosity (WALE) sub-grid scale model. The domain is monitored so as to ensure sufficient (>80%) resolution of the turbulent kinetic energy (k).

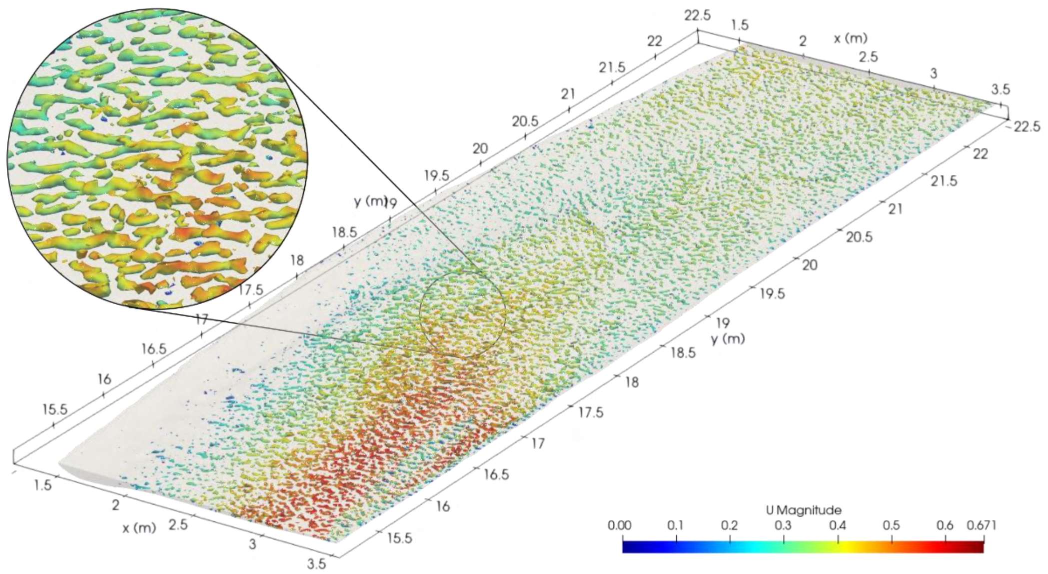

Figure 3: Contours of coherent turbulence structures identified using the Q-criterion (Coloured by velocity magnitude)

Hereafter, the rate of bank erosion is computed for all near bank points in the region of interest and Principal Component Analysis (PCA) is to be performed against a selected group of flow variables and non-dimensional quantities to identify those with highest influence on bank erosion rate.

Implementation of an implicit 1D scheme in Delft3D FM

Authors:
Victor Chavarrias[a]
Bert Jagers[a]

Highlights

- An implicit scheme for flow has been implemented in Delft3D FM for one-dimensional cases.
- Simulations are 100 times faster.
- Results are more accurate and without spurious energy losses at bends.

Overview

Delft3D FM is a tool for modelling hydrodynamic, water quality, and morphodynamic cases in 1D, 2D, and 3D. While having one tool for all cases has several advantages such as reducing maintenance costs and benefiting from shared features and knowledge, it hampers development of techniques for specific situations, as generality of the code prevails.

Due to the generic approach, even a one-dimensional model is internally treated as a (albeit very coarse) two-dimensional model with momentum equations in x- and y-direction. Furthermore, the advection term is treated explicitly, which results in a timestep restriction. This causes two problems arise when using Delft3D FM for 1D river morphodynamic applications: (1) the so-called “bend effect”, and (2) a large computational time.

As regards to the first problem, the spatial resolution usually employed in 1D river simulations is excessively coarse to properly reproduce flow in bends using the two-dimensional flow equations. Hence, the large angles between subsequent computational cells cause spurious grid-dependent physically-unrealistic energy losses.

The timestep restriction may not cause too many issues for short simulations, but when considering morphodynamic development over decadal timescales, this is a major issue. As an example, the D-Flow FM 1D model of the Rijntakken requires approximately 8 h for modelling 15 years of development. This contrasts with the same type of simulation using SOBEK-RE, developed in the 90's for the specific case of one-dimensional modelling. In this latter case, the same type of run takes approximately 90 s. This is possible thanks to the efficient and unconditionally stable implicit flow solver that it features.

For reducing the simulation time as well as for solving the “bend effect” we have implemented the flow solver of SOBEK-RE into Delft3D FM. Simulations are not only faster but also more accurate.

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References

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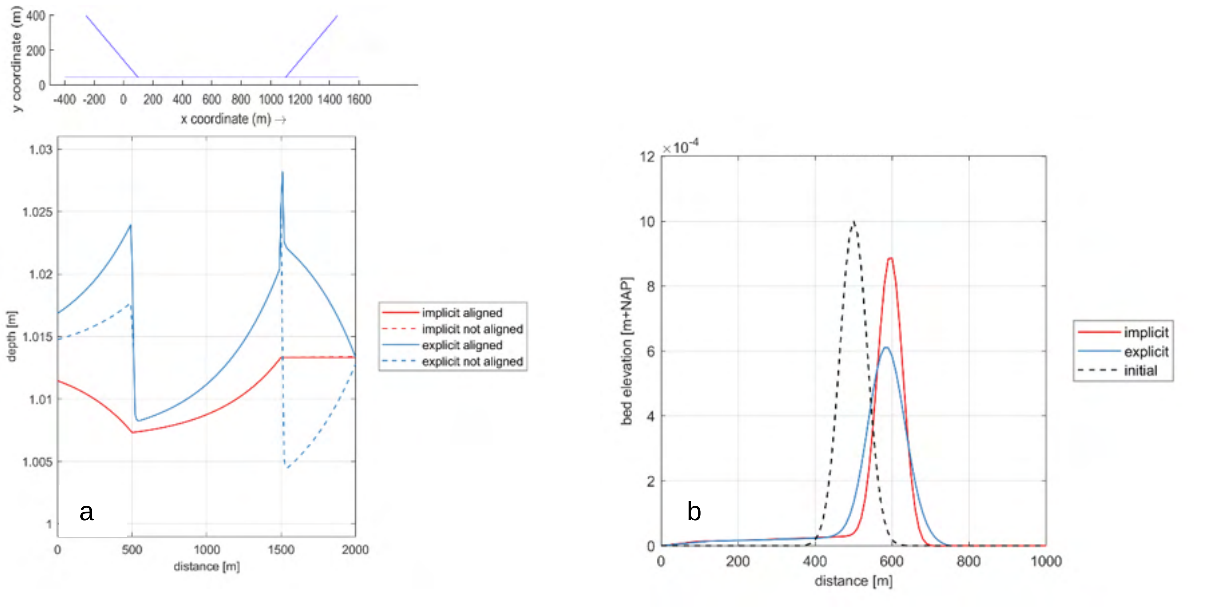

Figure 1. a: Case 1, Flow depth under steady state."aligned" refers to the track along the branches at constant y coordinate. "not aligned" refers to the track along branches at an angle. b: Case 2, Propagation of a small bed level hump.

Results

We present results of two test cases: (1) hydrodynamic distribution network, and (2) morphodynamic development of a small hump in a straight channel. In both cases we compare the explicit (default Delft3D FM) and implicit (newly implemented) schemes.

The network of Case 1 is shown at the top of Figure 1a. A constant, equal discharge is imposed at the two left boundaries and a constant, equal water level at the two right boundaries. The properties of the affluents and effluents are equal such that the solution is symmetric in a purely 1D sense while the orientation of the branches causes it not to be symmetrical in a 2D sense. The middle branch is twice as wide as the other branches. Consequently, the side wall friction is effectively halved in that reach which results in a slightly lower equilibrium water depth. As designed, the solution of the implicit purely-1D solver is the same along the parallel branches, and equal to normal flow in the most downstream reach (x=1500-2000 m). When using the explicit solver, however, the 2D approach causes more than half of the discharge to flow along the aligned branch in that reach which results in an M2 backwater curve along the aligned branch. The opposite occurs along the not-aligned branch such that there is an M1 backwater curve. Along the upstream reach (x=0-500 m), the solution tends to 1.013 m using both solvers, but while using an implicit solver we observe an M2 backwater curve, using the explicit solver we find an M1 backwater curve due to the higher water level at the confluence caused by the 2D effect.

Figure 1b shows the propagation of a small hump in bed level (height equal to 1% of the flow depth) added to a solution under equilibrium. The characteristic size of sediment is 1 mm and its transport is modelled according to Engelund and Hansen (1967). The simulation with the implicit solver shows less numerical diffusion. This is due to the larger morphodynamic CFL number achieved with a larger timestep.

In both cases, using the implicit solver was 100 times faster.

Outlook

The reduced computational time will allow new calibration methods and applications (e.g., Monte Carlo analysis) and results will be more accurate, and free from spurious 2D effects. Several processes need to be implemented still, such as structures and drying and flooding.

Assessing the ecological state of the Common Meuse and its restoration potential

Authors:
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Wilco C.E.P. Verberk [a]
Gertjan Geerling [a, b]

Highlights

- The current knowledge about the ecological state of the Common Meuse is incomplete
- We aim to fundamentally understand the drivers for aquatic species in this system
- Our ultimate goal is to propose evidence-based management options for RWS

Overview

The Common Meuse and its floodplains (Limburg) are part of a Natura 2000 area. The Common Meuse has a few traits that make it unique, especially in the Netherlands; it is a free and fast flowing river, has a gravel bed, and no shipping function. To assess the current ecological state and identify the main obstacles to achieving a sustainable favourable conservation status for the Natura 2000 species and habitat types in the Common Meuse, we will study the ecology of the Common Meuse, focussing on aquatic macroinvertebrates (e.g. insects, crustaceans, molluscs).

Our research consists of four parts:

1) Investigating the relationship between sediment composition and aquatic macroinvertebrates
2) Investigating how aquatic macroinvertebrates respond to various management measures (e.g. placement of trees, large boulders).
3) Investigating the effect of water quality on aquatic species
4) investigating the functioning and quality of the hyporheic zone

The research will be performed in close collaboration with Rijkswaterstaat (RWS) and Utrecht University (UU). Since this project has only just started (March 2023), there is plenty of opportunity to incorporate great ideas and suggestions.

Affiliations

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[b] *Deltares*

References

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Introduction

The Common Meuse and its floodplains (Limburg) are part of a Natura 2000 area, see Figure 1. In addition, the Common Meuse is the only fast flowing river with a gravel bed in the Netherlands. **T**he Common Meuse has a few traits that make it unique, especially in the Netherlands: it is a free and fast flowing river, has a gravel bed, and no shipping function. While shipping as ecological pressure is absent, many other pressures exist that may influence the local biodiversity and its abundance. The Common Meuse is morphologically modified, its riverbed is incised, and somewhat confined, upstream weirs produce an unnatural discharge regime, the sediment balance is unnatural, and the water quality fluctuates.

To assess the current ecological state and identify the main obstacles to achieving a sustainable favourable conservation status for the Natura 2000 species and habitat types in the Common Meuse, we will study the ecology of the Common Meuse, focussing on aquatic macroinvertebrates (e.g. insects, crustaceans, molluscs).

To achieve this, two sub-questions are distinguished:

1. Which factors determine the occurrence of riverine aquatic species in the Common Meuse?
2. What (optimalization of) management measures can be proposed based on knowledge of the determining factors for aquatic species, while also taking into account the conditions of the river?

The research will be performed in close collaboration with RWS and UU. RWS will aid in data collection and direct advise on the project. UU will focus on elucidating the hydro-morphological processes that affect the ecology via substrate dynamics.

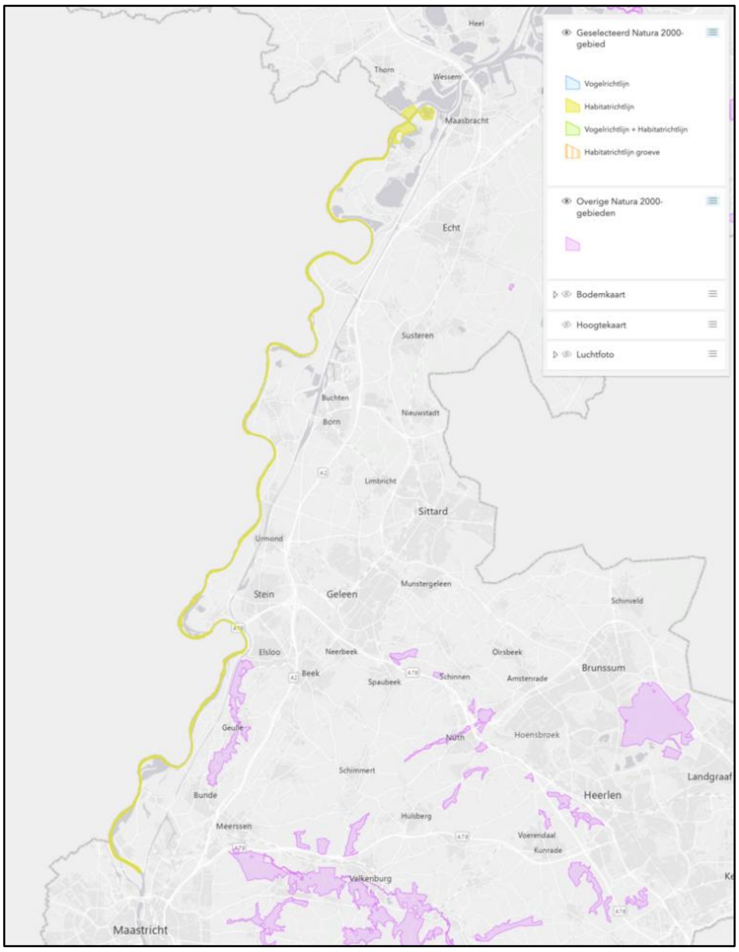

Figure 1. Map of the N2000 area in the Common Meuse (source: https://www.natura2000.nl/).

Methods

Our research consists of four parts:

1) The relationship between sediment composition and aquatic macroinvertebrates

The river contains many different sediments, which are known to impact aquatic macroinvertebrates (reciprocal feedback; sediment provides habitat and macroinvertebrates alter the sediment). The presence of aquatic macroinvertebrates and sediment composition will be mapped in detail, and the relationship between these will be analysed. Information on aquatic macroinvertebrates will be collected using net sampling, trapping, and visual surveys. Sediment mapping will be performed using side scan sonar and ADCP. This part is closely related to what UU will investigate.

2) Responses of aquatic macroinvertebrates to various management measures (e.g. placement of trees, large boulders).

Multiple organisations have implemented measures to increase habitat quality (e.g. placement of dead wood) or ascertain hydrological safety (e.g. lowering of the winter bed). However, the effect of the measures on aquatic species has not been studied yet. We aim to investigate the effect of these interventions using a before, after, control, impact study setup (BACI) to elucidate causal relationships.

3) Effects of water quality on aquatic species

The water quality in the Common Meuse has improved strongly over the last few year, but potentially it is still limiting for certain characteristic species. The effect of water quality is arguably more severe when water discharge is low, causing pollutants to be more concentrated and temperatures to fluctuate more strongly. Species composition of the Common Meuse will be compared to reference conditions (e.g. historical records or a comparable river abroad) to gain insight in missing species. Furthermore, the effects of abiotic parameters on selected species will be tested in the lab.

4) The functioning and quality of the hyporheic zone

Potentially, the hyporheic zone is of great importance for aquatic species, and we aim to investigate its relevance and current functioning in the Common Meuse. One threat that is specific to the hyporheic zone is it filling up with mud and silt, impeding the waterflow and leading to unsuitable, anoxic conditions. To study the relevance of the hyporheic zone, we aim to map abiotic characteristics and follow the development of this zone over time.

Since we have only just started we do not have any results yet. However, I am looking forward to presenting future results and keeping you updated on our work in the Common Meuse!

Genetic-based biomonitoring in an annular flume

Authors:
Jelle A. Dercksen[a], Laura Maria Stancanelli[a], Astrid Blom[a]

Highlights

- eNA degradation experiments were performed in an annular flume.
- Flow velocity measurements were in line with previous investigations.

Overview

Biodiversity across the globe has followed trends of decline (e.g. in abundance and genetic diversity) resulting from a number of human-induced drivers, i.e. climate change, pollution, invasive alien species, land use change and overexploitation (Purvis et al., 2019). For example, the most recent Living Planet Report by WWF (2022) reported an 83% decline in abundance between 1970 and 2018 within 6,617 monitored freshwater populations of a wide variety of vertebrate species. To monitor the effects of the aforementioned drivers, as well as to track progress by conservation and restoration efforts, there is a need for monitoring methods that can record high-resolution biodiversity data across large geographic scales (Bush et al., 2017).

The analysis of environmental DNA and RNA (eDNA and eRNA; i.e. eNA) has the potential to address these monitoring needs (Taberlet et al., 2018). eNA is the genetic material released by species into their environments in various forms (such as mucous, faeces, and skin tissue). The detection of this species-specific genetic material suspended in sampled water reflects the presence of the associated species and provides a non-invasive sampling method.

In lotic systems, i.e. rivers and streams, eNAs may be deposited or transported downstream, which spatially distances the genetic signal from its host. This depends on, for instance, the characteristics of the released eNA, the rate of eNA degradation and the flow characteristics of the system (Jane et al., 2015; Deiner & Altermatt 2014). As a result, a water sample collected in lotic systems contains a genomic 'cocktail', which may indicate species presence on extensive geographic scales (Deiner et al., 2016). Yet to estimate species distributions at finer scales, knowledge of the age of sampled eNA (the time between release by the organism and capture by the practitioner) should be combined with knowledge of the hydrodynamics within a system to yield estimates of the transported distance of sampled eNA. As of this moment, no such techniques have been studied in combination.

To address this knowledge gap, the authors have conducted a set of laboratory experiments. The objective of these experiments is to assess the viability of degrading eRNA-eDNA ratios as an indicator for the age of the sampled material under conditions with flow. Four different flow velocity conditions were created in a rotating annular flume (depth = 19.7 cm; Ø = 3.7 m), which features counter-rotating bottom and top components. The tested angular velocities of the top lid ($v_{top\ lid}$) were 0.00, 0.35, 1.05, and 1.80 m/s, with velocities of the bottom in a constant ratio ($v_{top\ lid}/v_{bottom} = \mathbf{1.8}$). Each of the configurations was tested over the duration of a seven day run. As a source of eNA, water previously inhabited by wild-type zebrafish (Danio rerio) was added to the flume. Concentrations of eRNA and

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eDNA were measured over the duration of the experiments by sampling water at multiple time points. Three samples were taken per time point to account for the observed spatial heterogeneity in the distribution of eNA (Wilcox et al., 2016). eNA concentrations were subsequently quantified using ddPCR by targeting a 73 base pair fragment of the frequently used cytochrome c oxidase subunit 1 gene. To characterize the vertical velocity profile in the flume, measurements were taken using an acoustic Doppler velocimeter (ADV). Validation of these measurements was done by comparison with a previous annular flume investigation under near-identical conditions (Booij, 1994). Flow velocity measurements of both investigations were in agreement, approximating the conditions to which the eNA was subjected in the flume experiments.

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Comparison of hydrodynamic conditions with literature

As the eNA was subjected to four different rotational velocity configurations, a first step was the description of the flow velocities in the flume. A vertical flow velocity profile was therefore measured using an ADV. As to validate our measurements (see Figure 1), additional data points were extracted from a previous annular flume investigation (Booij, 1994) which used an identical rotational velocity configuration ($\boldsymbol{v_{top\ lid}} = \mathbf{1.05\ m/s}$). Concurrently, this allowed us to supplement the velocity profile with data points that could not be obtained due to limitations of our measuring equipment. The velocity profiles of both investigations are in agreement, and produced the expected s-shaped curve with velocities increasing near the bottom and the top of the flume. To further characterize the conditions within the flume, we plan to create a vertical profile of the Reynolds shear stress using the ADV data which is once more validated by, and supplemented with, data from Booij (1994).

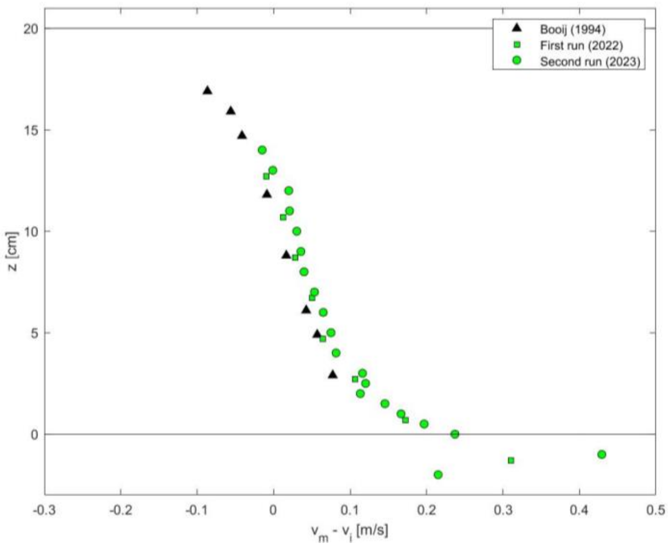

Figure 1. Comparison of the vertical velocity profile in the stream-wise direction with data from Booij (1994). $v_{top\ lid}$= 1.05 m/s; v_m = measured velocity in streamwise direction; v_i = velocity of the instrument mounted to the flume.

Preliminary observations in eNA results

Preliminary analyses of the eNA samples confirm the expected decrease of both eDNA and eRNA concentrations throughout the experiment, regardless of the imposed flow velocity. Degradation rates of both eDNA and eRNA were more rapid during the first days of each experimental run, which decreased towards the end of each run. In addition, regardless of flow velocity, concentrations of eRNA generally decreased at higher rates than eDNA.

Calibrating hydraulic models of bifurcating rivers: avoiding uncertain discharge measurements

Matthijs R.A. Gensen[a]
Ferry van Tilburg

Highlights

- We use the physics of river bifurcations to calibrate peak water levels for the 1995 flood event in the Rhine.
- The calibration on water levels in bifurcating system has multiple solutions.
- A single combination of roughness can be selected without using discharge observations at the bifurcation.

Overview

Accurate water level predictions using hydraulic models require a reliable calibration strategy. However, calibrating hydraulic models of bifurcating rivers is challenging, because of the feedback mechanism between water levels and the discharge distribution at bifurcations (Gensen et al. 2020): a change in roughness in one distributary changes the discharge partitioning and thereby affects the water levels in both distributaries.

A standard calibration strategy in which water levels are calibrated against an observed upstream discharge is unsuitable for bifurcating rivers because of equifinality. Equifinality arises when multiple parameter sets give the same output result (Savenije, 2001). In river models, a well-known case of equifinality is the simultaneous use of both the main channel and floodplain roughness as calibration parameters (Pappenberger et al., 2005). In the case of a bifurcating river, multiple combinations of main channel roughness can result in the same water level as the discharge distribution is variable too.

In current Dutch practice, this equifinality is solved by using observations of discharges at each bifurcation. However, discharge measurements are known to be uncertain (e.g. Di Baldassare et al., 2012) and this uncertainty affects the model calibration (Domeneghetti et al., 2012). Therefore, avoiding the use of discharge measurements at multiple locations may improve the accuracy of hydraulic models. In this study, we show that discharge measurements at bifurcations are not required to accurately calibrate water levels at upstream locations in the bifurcating Rhine River.

We only use water level observations and main channel roughness in the distributaries and get an accurate calibration. The calibration strategy leads to a mismatch between the modelled and observed discharge distribution at the river bifurcation. This may indicate that the observed discharges (and/or model schematization) are inaccurate, which introduces uncertainty in the current calibration strategy in Dutch practice. Such uncertainty is amplified in the extrapolation domain, i.e. for extremely high discharges.

Further steps are to verify the reliability of our calibration strategy for other flood waves. Then, the strategy is extended to include other calibration parameters, such as a spatially distributed main channel roughness. This will further increase the accuracy of the hydraulic models, which is important for flood risk management.

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Modelling approach

In this study, we use the Dutch Rhine branches as a case study. In the Netherlands, the river Rhine bifurcates into the Waal, Nederrijn and IJssel branches. We use a 1D schematization of the river Rhine branches (Iplo, 2023). We calibrate the hydraulic model for the peak water levels of the 1995 flood wave. This flood wave had the highest recorded peak discharge of the river Rhine with a peak discharge of nearly 12.000 m^3/s. Our approach requires discharge observations at a single location, namely at the upstream boundary of the model domain. For this study, we use the available discharge records provided by Rijkswaterstaat. We calibrate the peak water levels at upstream locations in the distributaries by changing the roughness of two (or three) branches simultaneously. We then select the roughness combination that gives the observed peak water levels at the chosen locations. In this abstract, we show the calibration results for the peak water levels at Nijmegen (in the river Waal) and at Doesburg (in the river IJssel) by adapting the main channel roughness of the entire river Waal and for the combined Pannerdensch Kanaal and river IJssel at the same time.

Simultaneous calibration of the water levels at locations in the *rivers* Waal and IJssel

Fig. 1 shows the modelled peak water levels at Nijmegen in the river Waal (left panel) and Doesburg in the river IJssel (middle panel) for different roughness values in the two branches (calibration parameter sets). The black lines indicate all calibration parameter combinations that results in the observed peak water level at the specified locations. At the intersection point of two lines (indicated by the arrows), the water levels at both Nijmegen and Doesburg match the observed peak water levels. This point thus gives the calibrated values of the roughness in the two branches. This shows that the calibration strategy can reproduce observed water levels without using inaccurate discharge observations at the bifurcation. To also reproduce the observed water levels at a location in the river Nederrijn, a third calibration parameter is required (e.g. the main channel roughness of the river Nederrijn).

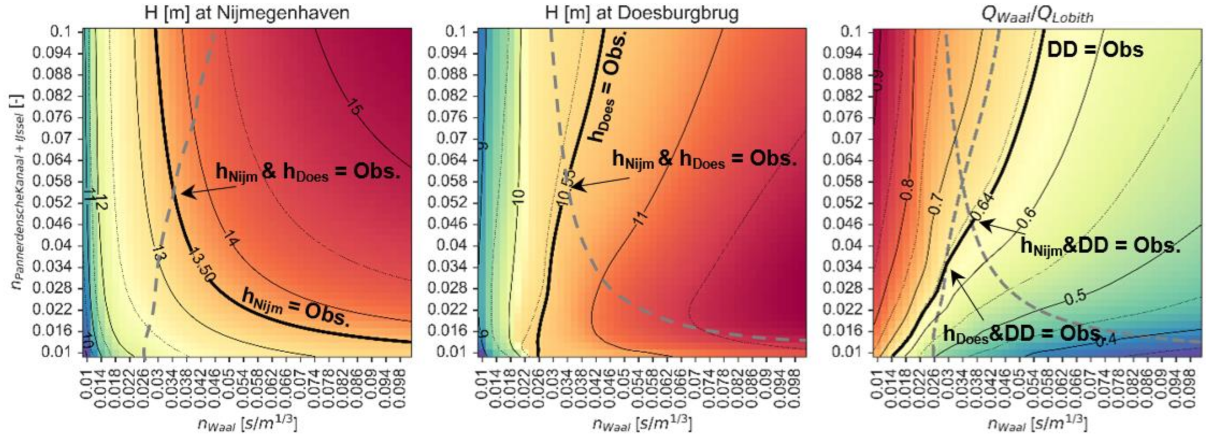

Figure 1. Modelled peak water levels at Nijmegen in the river Waal (left) and at Doesburg in the river IJssel (middle) during the 1995 flood wave. The thick black lines show the parameter sets for which the modelled water levels match the observed values. The right panel shows the modelled (color scale) and observed (thick black line) discharge distribution (DD) at the peak of the discharge wave as well as the combination of parameters for which the water levels at Nijmegen and Doesburg match the observed values (dotted gray lines).

Discharge distribution at the main bifurcation

By plotting the modelled discharge distribution (right panel of Fig. 1), we see that the observed discharge distribution does not match the modelled discharge distribution for the calibration parameter combination that reproduces the observed water levels at Nijmegen and Doesburg. This may indicate that the observed discharges during the 1995 flood wave are not accurate (or that the model schematization is inaccurate). It also means that the currently operational calibration strategy, which uses the observed discharge distribution, introduces an uncertainty in the hydraulic model. Such uncertainty is amplified in the extrapolation domain for which hydraulic models are typically used.

Conclusions and next steps

This study shows the potential of using mainly water level measurements to calibrate hydraulic models of bifurcating rivers. A significant difference between observed and modelled discharges in the distributaries is subsequently found. The next step is to also include the river Nederrijn roughness as calibration parameter, such that the observed water levels in all three distributaries can be reproduced. In addition, the accuracy of the upstream discharge boundary can be improved, by for instance using physical constraints of the bifurcating river such as the water balance (Gensen et al., 2022). Finally, we recommend to verify the general reliability of our calibration strategy in other cases.

The effect of modifications to a groyne area in the Nieuwe Waterweg

Tors Kouwenhoven

Highlights

- Two field researches have been conducted to obtain data from the groyne area.
- The largest influence on the flow is caused by the tide and waves from passing ships.
- Typical groyne flow with eddies changes to a lateral flow in the groyne area.

Overview

In the Nieuwe Waterweg an ongoing pilot takes place in one of the groyne areas. This pilot is a part of the "De Groene Poort" project. The idea for this project is to create intertidal areas by modifying and nourishing groyne areas. These artificially formed intertidal areas will create a new habitat for wildlife and attract different vegetation. For this project, several modifications have been made to the groyne area: a dam has been placed in front of the groyne area, the groynes on either side have been partially heightened and a nourishment has taken place. To better understand the effects of these modifications to the groyne area, research has been done on the effects of the tide and waves caused by shipping on the flow and sediment behaviour inside the groyne area.

Two different measurement campaigns have been carried out for this research. In the first measurement campaign six ADVs were placed in the groyne area between March 24 and April 12 ,2022. These ADVs measured the velocities and pressures with a frequency of 8 Hz. Also, sediment samples were taken during this campaign, which have been analyzed using laser diffraction. In the second campaign, ADCP measurements were carried out with a floating ADCP attached to a jet ski. With this ADCP the vertical velocity profiles have been obtained for several cross-sections at different stages of the tide.

The flow in the groyne area has changed due to the dam and the nourishment. Typical flow in an emerged groyne field with the eddies is unrecognizable during lower water levels in the modified groyne area. The exchange of water between the main channel and the groyne area is through the gap in the dam, which removes the mixing layer that separates the groyne and the main channel during submerged conditions. The flow in this groyne area is lateral and divided into two main flows along either side of the nourished island. Rocks and a higher entrance in the downstream groyne compared to the entrance in the other groyne, gives the groyne area different flow velocities between ebb and flood. The neap and spring tidal cycle enhances Ebb and flood differences in the groyne area even more. These velocities differences also impact the sediment transport and its absolute direction in the groyne area. The dam also helps reduce the wave influence on the groyne area, although these waves still significantly influence the velocities. Waves also propagate in a lateral motion from groyne to groyne through the groyne area. The water can move material from the nourishment, but the spreading of this material is limited to a number of locations in the groyne area. For the largest part, the nourished material is still at the location where it is deposited.

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Flow directions in the groyne area

Figure 1 shows that the directions of the velocities differ significantly from an unmodified groyne area. In a typical emerged groyne area multiple eddies form as a result of the flow in the main channel (~~B.~~ Przedwojski & Blazejewski, 1995). In the modified groyne area, a lateral flow occurs during the whole ebb and flood period at both sides of the nourishment. This lateral flow is present even during the limited time that the groynes emerge. The exchange of water between the main channel and the groyne area takes place through the gap in the dam. While the groynes are submerged, this exchange through the gap replaces the regular exchange through the mixing layer, which separates the flow between the main channel and the groyne area in an open submerged groin field.

Figure 1: Flow directions during a tide. Start of the tide is marked in blue and is at low water before flood, the end is marked in red and is at the next low water at the end of ebb.

Wave influence in the groyne area

Waves are caused by ships passing the groyne area. Depending on the location, these waves can cause average velocity increases of 0.11 to 0.23 m/s. The increase in velocity is measured as the difference between the peak velocity during the passage of a ship wave and the tidal velocity. Tidal velocities have been averaged over 30 minutes to remove the oscillations from the signal. Relations have been found for these increases in the velocity relative to the wave height and to a ratio of the wave height relative to the water depth. However, no relation has been found to the tidal velocity. The relations are shown in Fig. 2.

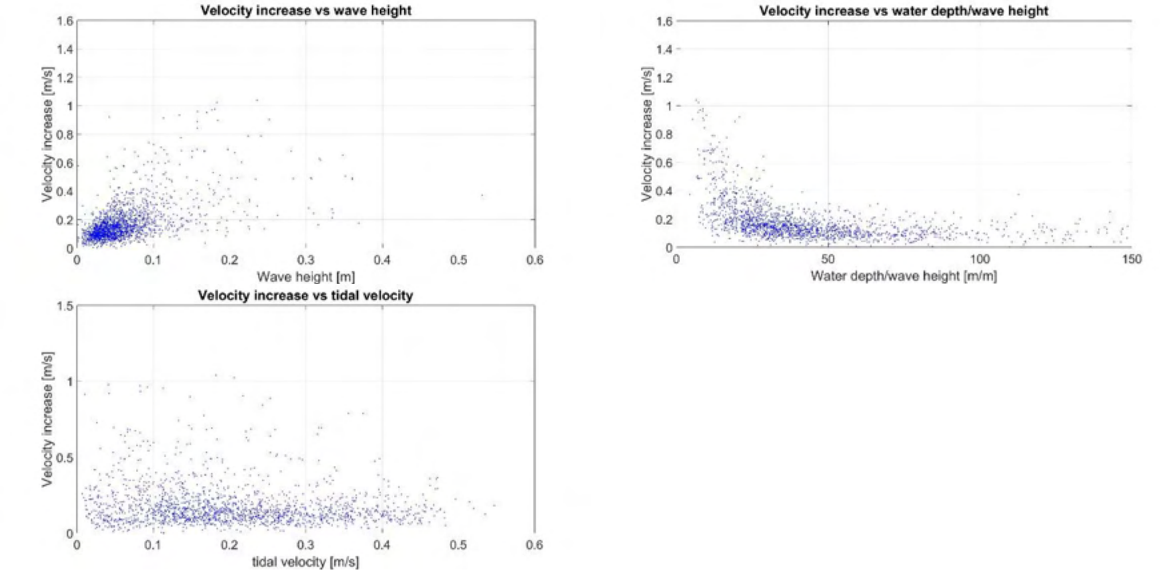

Figure 2: Relation of the waves found from 1805 passing ships. The ships have been found with AIS data.

Investigating and modelling nourishments strategies for the Midden-Waal River

Simon van Laarhoven[a],
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Highlights

- We investigated the boundary conditions for a successful sediment nourishment in the Midden-Waal River.
- We studied the sensitivity of different nourishment designs in the Midden-Waal River.
- We designed a feasible nourishment including monitoring strategy that can be executed in a large-scale field pilot.

Overview

Over the past decades, the riverbed of the Waal River has been degrading (Blom, 2016). Especially in the Boven-Waal River, this has become problematic. To accommodate a stable base downstream of the Boven-Waal River, the Midden-Waal River needs to be stable. An option for stabilization is nourishment of sediment. Studies (e.g., Becker et al., 2022) have shown that sediment nourishments have the potential to compensate bed degradation. However, experience in river nourishment is limited so far. Rijkswaterstaat has asked Arcadis to develop a sediment nourishment pilot in the Midden-Waal River and to come up with a feasible design with realization and monitoring plan.

We have assessed the hydrodynamic effect of reducing the inflow sections of the longitudinal training dams in the Midden-Waal to create a margin that allows for sediment nourishment with minimal depth reduction. Furthermore, we investigated the hydrodynamic and morphological effects of different nourishments strategies. During the analysis, challenges arose, such as restricted dredge-dump locations, lateral extractions by the Amsterdam-Rijn canal and model domains.

Our results show that reducing the inflow sections of longitudinal training dams creates around 11 cm of low-water level set up, which enables maintaining navigability while conducting nourishments. Sediment nourishment extend this low-water level set up in upstream direction with 10 cm at maximum, as larger raises of bed level encounter larger raises of flood levels. Nourishment effects diminish with time. The sediment is expected to migrate downstream including passage through non-dumping areas specified by RWS. Based on the model results and a multi-criteria analysis, a feasible, cost-efficient, and sustainable sediment nourishment strategy has been developed for a large-scale field pilot.

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Introduction – Bed degradation and the Waal River

Numerous studies have shown that the riverbed of Rhine River and its branches are degrading, with increasing impacts on river functions because of this incision. Navigation and ecology are severely impacted by bed degradation, especially during low-flow stages as bed degradation rates are not uniform at all trajects. One way to counter bed degradation is sediment nourishment. Sediment nourishments stabilize the riverbed and are considered to be a flexible, no-regret option to (partially) restore eroding river segments in an overall strategy that can include re-normalization and river-relandscaping. Sediment nourishments are however relatively new, with only a handful of recent cases available as reference material. A large amount of research questions exists about the effectivity of the available sediment, durability, risks for shipping and realization of nourishments (Becker et al., 2022). A pilot is necessary to obtain experience with river nourishments. Arcadis was asked to design this pilot. We have come up with a design of a pilot that answers the research questions by nourishment in the Midden-Waal River, including a realization and monitoring plan.

Method – Investigating opportunities to mitigate bed degradation through sediment nourishment

We have determined the possibilities for nourishments without hampering navigation. By reduction of low-flow through the side channels of the longitudinal training dams in the Waal River (rkm 910 – 921), the low-flow water levels in the Waal River are raised, creating extra depth to allow sediment nourishments. With numerical simulations using the DVR model with a detailed numerical grid, we've assessed the water level increases during stationary discharges for both low flow (1,020 m^3/s) and high flow stages (16,000 m^3/s). During low flow stages, the Amsterdam-Rijn canal extracts water from the Waal River, which lowers the water levels. This has been included manually in the model by means of a sink term of 40 m^3/s.

The margin created by the water level upset can be applied to perform nourishment. We compared the hydrodynamic and morphological effects of several types of nourishment using the standard-DVR grid for morphological effects and the refined DVR-grid for hydrodynamics. 10 simulations were run in total, accounting for four stationary hydrodynamic simulations and six dynamic (using 10 yearly hydrographs) morphological simulations. Besides nourishment thickness (25 and 50 cm) and nourishment length (2.5, 5 and 10.8 km), the nourishment style (profile-filling or spatially-uniform nourishment) and effect of grain size (coarse or fine) were varied.

Results – Effects of sediment nourishment

The water level set-up by reduction of flow through the side-channels of the longitudinal training dams is 11.9 cm during low-flow (1,020 m^3/s) and negligible during high flow stages (16,000 m^3/s). The water level set-up of the nourishment considered ranges from 6 to 13 cm at low flow (1,020 m^3/s), directly upstream of the nourishment. From the combinations analysed, the shorter nourishments with a thick layer have a larger water level set-up than longer nourishments with a thin layer. The strategies with nourishments thicker than 50 cm affect the high-flow water levels.

Upstream of the nourishment a slow backfill is formed. Downstream of nourishments a sedimentation front develops, which migrates with an average speed of 1 – 1.5 km/year, in line with Sieben (2005). Nourishments with smaller grain sizes (e.g., from the Beneden-Waal River) are morphologically more active and move faster. Eventually all sediment is transported from the nourishment site downstream. For all simulations, sediment will also be flushed towards so-called non-dumping locations (e.g., harbour entrances). The thicker the nourishment layer, the more likely minimum navigational depths can be affected. This occurs mostly in inner bends of the fairway.

Discussion – Modelling issues

Several challenges arose during the modelling of nourishments, which raises the question if and whether the models are applicable to simulate sediment nourishments. For example, simulations sediment (including nourished material) drained to deeper model layers, affecting the sediment composition of the model. The bed level after nourishment was not affected by this phenomenon. Different models had to be used, since the regular DVR model grid was too coarse for accurate hydrodynamic simulations, whereas the version with the refined grid was not validated for morphological effects and had a smaller domain. Furthermore, the WAQUA model, used for hydrodynamic simulations of the final design, could not be used to assess changes at the bifurcation point, since the model domain did not include the longitudinal training dams at the time.

Conclusions – Field pilot recommendations

Sediment nourishments are no definitive way to reduce bed degradation, although nourishments do create time to implement an overall strategy that can include re-normalization and river-relandscaping. The low-flow water level set up (12 cm) at the longitudinal dams can be extended upstream by the nourishments. The effects of nourishment diminish over time. Longer spatially uniform nourishments with a small layer thickness (e.g., 25 cm) are recommended. The dredged material from the Beneden-Waal River can suffice to execute nourishments. Since sediments can migrate towards no-dredging areas and non-dumping areas within the fairway, depths should be monitored.

Our modelling efforts have led to a feasible design of the pilot including the identification of important knowledge-gaps. In addition, we've pointed out key factors that need to be considered when designing sediment nourishments in rivers.

Sediment nourishments in the River Waal to mitigate bed degradation

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Saskia van Vuren[c]
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Highlights

- We modelled sediment nourishments to investigate their effects on the morphology of the River Waal
- By adapting the characteristics of a nourishment, their effect is influenced in a non-linear way
- A distributed coarse nourishment, placed upstream mitigates bed degradation most effectively

Overview

Over the past century, the bed level of the Waal has degraded by 1 to 2 metres (Blom, 2016). The high rate of degradation and its spatial non-uniformity places the various functions of the river under stress. Rijkswaterstaat (RWS) therefore seeks solutions in their Integral River Management (IRM) programme to stop the degradational trend of eroding river sections and to elevate the bed level where needed (Klijn et al., 2022). Previous studies have shown that solely implementing measures in the current floodplains of the river, that reduce the erosivity of the flow, such as side channels, is not enough and that other measures like sediment nourishments are required to fully counterbalance bed degradation (Barneveld et al., 2019; Welsch, 2021; Barneveld et al., 2022). This study (De Lange, 2022) investigates the effect of sediment nourishments of various characteristics on the bed of the Waal. This is done by modelling sediment nourishments in a 1D-model of the Rhine branches developed by Deltares for RWS (Chavarrias et al., 2020).

The results show that individual nourishments can reduce bed degradation in the Boven- and Midden-Waal by orders of centimetres. Varying the characteristics of a nourishment influences its behaviour. Coarsening the composition causes a reduction in dispersion rate. This also leads to additional erosion downstream of the nourishment, which can be prevented by dividing the nourishment into multiple parts. By placing the nourishment further upstream, the period in which the nourishment affects the degrading section of the Waal increases. Finally, the relative effect increases with larger volumes. It is found that a coarse nourishment that is distributed into multiple parts and that is placed as far upstream as possible mitigates bed degradation most effectively.

It is shown that nourishments can mitigate bed degradation, although this requires large volumes and repeated nourishments. It is expected that in reality, the optimal characteristics of the nourishment are not leading in the design of a nourishment. Instead, practical aspects like the availability of sediment will largely determine the possibilities. The insights gained in this study can be used in the early stages of designing a nourishment strategy. Moreover, the non-linear effect of changes in volume that is found implies that performing nourishment pilots with small volumes of sediment may lead to an underestimation of the effect of large-scale nourishments. In a successive research project, the effect of nourishments with a finer composition than the bed will be investigated.

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Modelling the behaviour of sediment nourishments in the Waal

It is found that nourishments can counterbalance the impact of erosion over a section of the river larger than the original extent of the nourishment. Figure 1 shows the propagation of the investigated nourishments through the system. Upstream of a nourishment, degradation is reduced through the backwater effects of the nourishment. Downstream of a nourishment, degradation is reduced by downstream transport of the nourished sediment. In the first years after implementation, the height of a nourishment decreases exponentially. Singular nourishments can only reduce bed degradation by orders of centimetres over 50 years. It is concluded that repeated nourishments are necessary to stop bed degradation.

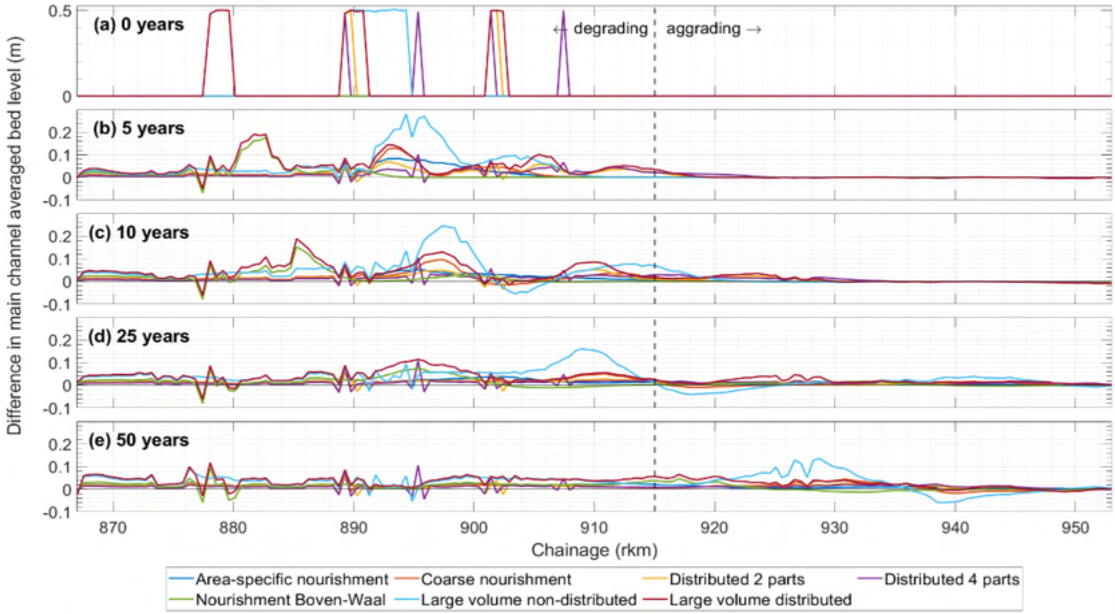

Figure 1. Difference in main channel averaged bed level in the Boven-Rijn and Waal for all studied nourishments compared to the reference simulation at various moments in time. The sediment composition of the area-specific nourishment is equal to that of the bed. All other nourishments are coarser than the bed.

The influence of varying nourishment characteristics

The behaviour of a nourishment can be influenced by altering its characteristics. By selecting a composition that is coarser than the composition of the bed, the dispersion rate of the nourishment decreases. Additionally, the reduced mobility of the bed at the location of the nourishment causes additional erosion downstream of the nourishment. It is shown that dividing the nourishments over multiple parts spaced several kilometres apart prevents this. This also holds when the size of the individual nourishment parts does not decrease, implying that it is not only a change in size that causes the difference in behaviour. The nourishment parts influence each other: sedimentation caused by one part of the nourishment counters erosion caused by another. Choosing the nourishment distribution smartly can thus prevent additional downstream erosion when nourishing with coarse sediment.

All investigated sediment nourishments eventually travel into the aggrading section of the Waal, after which they contribute to additional sedimentation rather than reducing degradation. The period after which this happens mainly depends on the initial location. To extend the period in which a nourishment reduces degradation, it is advised to place the nourishment(s) as far upstream as possible. However, this also increases its effect on the discharge distribution at the bifurcations.

Additionally, it is shown that increasing the volume of the nourishment by a factor 2.7, from $2{,}5 \cdot 10^5$ m^3 to $6{,}9 \cdot 10^5$ m^3, increases the effect of the nourishment by a larger factor. The maximum increase in bed level that the nourishment induces multiplies by up to a factor 3, while the length over which the nourishment increases the bed level by more than 5 cm multiplies by more than a factor 4 (Figure 2).

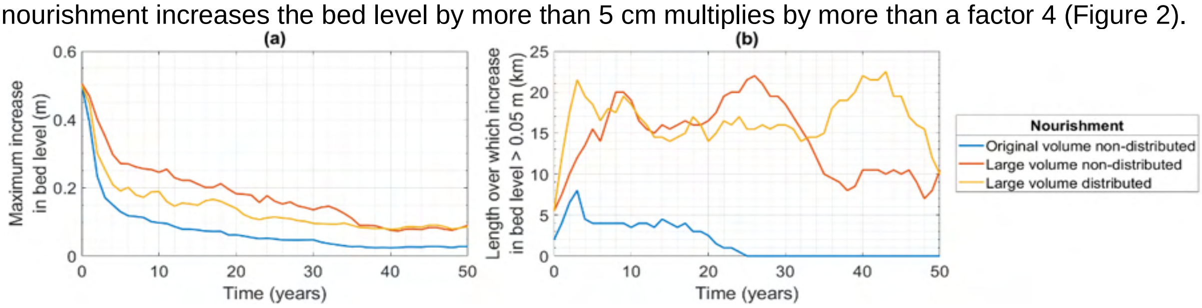

Figure 2. The maximum increase in bed level with respect to the reference simulation (a); and the length over which the increase in bed level exceeds 0.05 m (b) over time for the degrading reach of the Waal, from rkm 868 until 915.

Investigating the effect of streamlining groynes with experimental research. (work in progress)

Authors:
Langeveld, B[a].

Highlights — Experimental research in the 5 x 40 m flume in the Hydraulic Engineering laboratory of the Delft University of Technology aims to give more insight in the flow processes over and around submerged groynes for various hydraulic conditions.

Problem statement

In principle it is well known that decreasing the resistance of groynes will have a positive effect on reducing flood risk by increasing the overall discharge capacity of the river (e.g. Yossef, 2004).

The problem that arises when investigating groyne adjustments, is the inaccuracy that follows from the numerical models due to the lack of experimental data and limited theoretical knowledge regarding flow over and around groynes. Due to this lack of data, groynes are often schematized as weirs or applied as an additional resistance parameter in a subgrid model (Ambagts, 2019). For example, WAQUA adds additional resistance as a result of flow separation when the bed slope is steeper than 1:7, (Sieben, 2007). This makes it difficult to accurately quantify the effect the adjustments have on the flow resistance.

Research objective

The objective of this research is to gather experimental data on the effect that streamlining of groynes has on the reduction of the overall resistance of the river. In this thesis, the gathered data is used to get better insight in the flow processes over and around groynes and the horizontal mass and momentum exchange in the mixing layer between the main channel and the groyne field in this physical model set-up and to explain how these model results will represent real world scenarios. The following research goals were formulated:

- Quantify the change in overall water level slope over the river section and display the results in such a way that it is possible to draw clear and objective conclusions regarding the effectiveness of streamlining groynes.
- Compile flow velocity data from the scaled river section, and more specifically from around the groyne tip, to get better insight in, and to analyse the flow over and around groynes and to draw conclusion on how this flow differs from the theoretical assumptions made in numerical models.

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Experimental model set-up

The experiment is carried out in a flume with dimensions of 5 x 40 m where a river section is constructed with geometric scaling of 1:30. This river section represents a part of a cross-section comparable to the river Waal, containing part of the main channel, six groynes, five groyne fields and a part of the floodplains.

Measurements were carried out across various combinations of hydraulic conditions. Varying the hydraulic conditions for each measurement run allows for a better data coverage, and subsequently, a better understanding regarding the flow around the groyne tip. The Froude number in the main channel varied between 0.15 and 0.22. This is purposefully higher than usual for the Dutch river system. Reason being that Harms (2021) found that, especially regarding the water level measurements, the differences in water level over the length of the flume were small when comparing a situation without groynes to a situation with groynes. The higher Froude numbers would mean more extreme flow conditions while still ensuring sub-critical flow conditions in the entire flume.

Initial results

This thesis is still work in progress. In January, the measurements were finished and a start is made in the data analysis. Below, a couple of figures give a visual representation on the data.

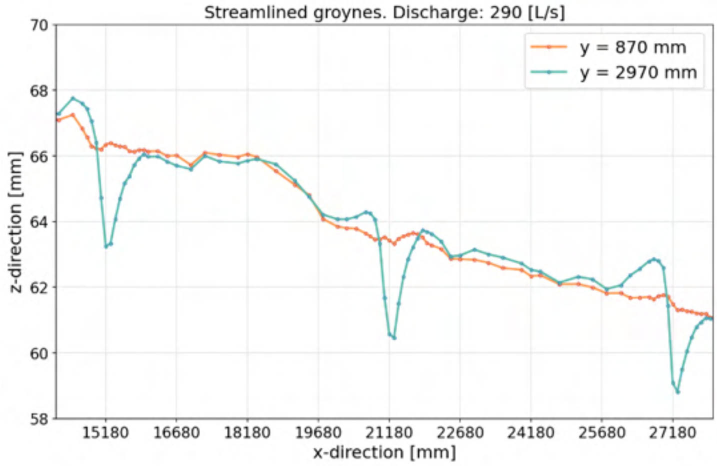

Figure 1. Water level measurements over the length of the flume. The blue line represents the water level in the groyne field and the red line represents the main channel. This plot shows the result of only one hydraulic conditions. Note that the values on the y-axis do not show the actual water depth, but the scale is correct.

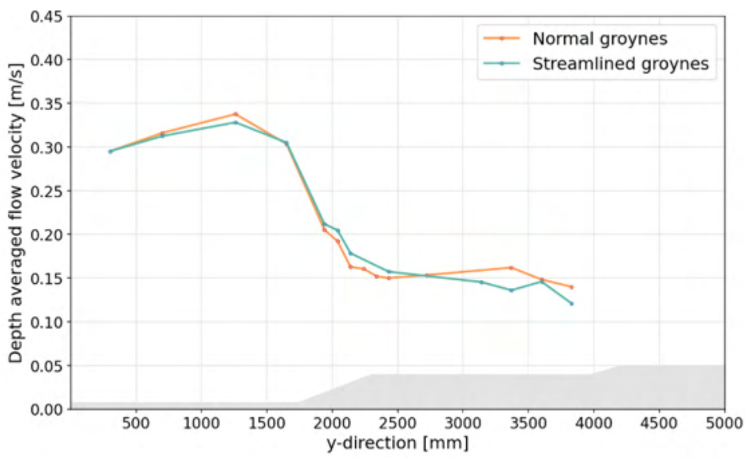

Figure 2. Plot of the depth averaged flow velocity over the width of the flume. This transact is located at the crest of the fourth groyne. This figure shows only the result of one transact for one hydraulic condition.

Is riverbank vegetation important for the estimation of flood water levels?

Anna M. Łoboda [a]
Anouk Bomers [a]
Trang Minh Duong [a, b, c]

- Simulating river flow hydrodynamics and vegetation roughness effects using Delft3D FM
- Investigating the effect of riverbank vegetation on the flood water levels
- Comparing the effect of seasonal varying riverbank roughness on flood? Water levels

Overview

Freshwater plants are one of the main components of the aquatic ecosystem and significantly influence river processes at different scales, and they are also affected by the river flow (Nikora, 2010; Nepf, 2012). Thus, a proper flood risk management requires to include understanding the processes of mutual interactions (flow-biota), which are still challenging (Nikora, 2010; Nepf, 2012). It is essential to know that such vegetation is a crucial component of the environment, which provides important tool for nature-based solutions for river engineering and management. Considering appropriate placement of plants along the stream, various possibilities for using vegetation as a nature-based solution may include facilitate sediment transport in the channel, control to direct overbank flows, and the reduction of scour and river channel erosion processes (Shields Jr. et al., 2017). However, a proper prediction of processes occurring in rivers with vegetated bank? (e.g., vegetation-induced turbulence) needs sufficient studies of vegetation seasonality due to its dynamic nature.

Past approach to the subject of river management (e.g., Ree 1949) did not include the ecological meaning (wildlife habitat) of riverine vegetation and thus, all the actions were focused only on reducing the source of flow resistance by cutting the vegetation to reduce flooding (Nepf, 2012). Hence, current methods should be developed in such a way as to comply with the assumptions of finding the balance in predicting the channel resistance in the presence of vegetation between ecological management and flood control (Nilsson et al. 2005; Nepf, 2012). Flow-biota-sediment interactions, due to continuous vegetation development, are vulnerable to extensive knowledge gaps in the investigation linking the fluid mechanics, biomechanics, ecology and transport processes that prevent a full understanding of these phenomena (Nikora, 2010; Łoboda et al., 2018).

To expand knowledge in this research field, the aim of this study is to investigate the effect of riverbank vegetation on the flood water levels, considering various riverbank vegetation coverage due to its variation throughout the annual seasons. For that purpose, the hydrodynamic model Delft3D Flexible Mesh will be used to simulate river flow hydrodynamics on the part of the Meuse river as a case study. This study will investigate various static vegetation scenarios considering seasonal changes in vegetation roughness and their life cycle, e.g., due to leaf loss or plant dying. The main focus will be drawn to short periods including before, during and after the flood event (i.e., period of approximately two weeks; starting two days before the flood event). As Nepf (2012) highlighted, vegetation is not distributed uniformly, which plays an important role in the reach-scale flow resistance. Thus, the proposed study will consider the density of plant coverage on the riverbanks as well as species variety.

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Case study

The study will be carried out on the Meuse river, the Netherlands, which is a dynamic river reshaping its channel by the processes of erosion and sedimentation due to variable discharge regime. The Meuse is 935 kilometres long and enters the Netherlands at Eijsden (Fig. 1). Its' course through the Netherlands is approximately 250 kilometres. The average flow is approximately 230 m^3/s near the Dutch-Belgian border, where the upper Dutch part of the river, characterized by gravel bed and a relatively steep slope of 40 cm per km as well as the occurrence of meanders, is the main focus in this study (Middelkoop and de Boo, 1999). The studied river reach starts from Eijsden grens to Maaseik gauging station (Fig. 1).

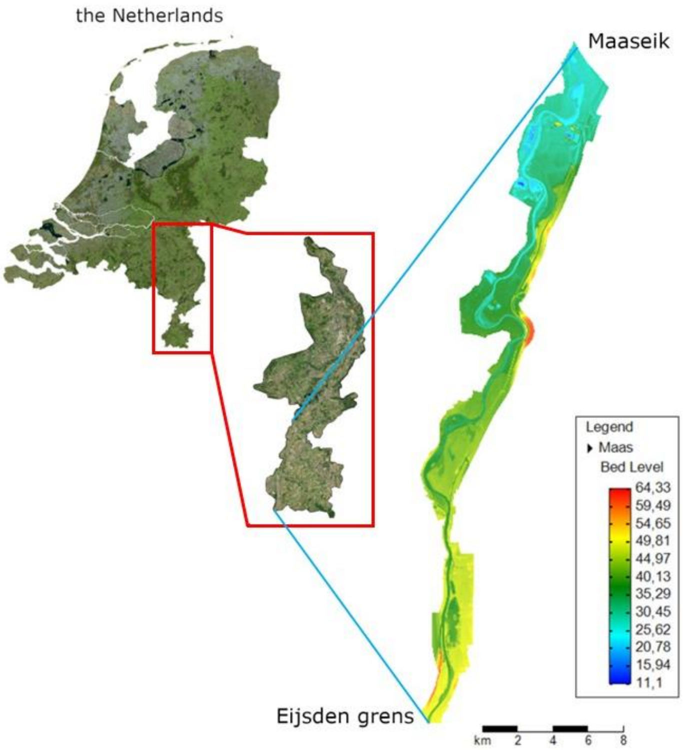

Figure 1. Bed level of the study area in the Meuse river and its location in the Netherlands.

Methods

The hydrodynamic model Delft3D Flexible Mesh (Deltares) will be used to simulate river flow hydrodynamics. The locations of the Eijsden grens (upstream) and Maaseik (downstream) gauging stations (Fig. 1) create boundary conditions for the model of the Meuse river reach, providing discharge and water level time series as input data, respectively. One of the model inputs is also the initial water level of the Meuse river based on real conditions from July 2021. As regards the occurrence of the vegetation, it is well known that the vegetation roughness varies throughout the year, which is commonly neglected in modelled predictions of river processes. The assumption of the proposed study is that it will contain various static vegetation scenarios, which means that during model time frame there will be no changes in vegetation (e.g. plant growth or senescence). In the scenarios, static representation of vegetation will be given by Manning coefficient and Baptist formula. However, seasonal changes in vegetation roughness will be considered, i.e., planned scenarios will vary in plant density and coverage, for example, during summer season, the vegetation will be characterised by the highest spatial coverage as well as density, whereas during the winter season it will drop to approximately 40 % of the total amount.

Expected results

The analysis will focus on the comparison of water levels and flow velocities model outputs. Water level modelled outputs from different scenarios will be compared and the differences will show the influence of the vegetation on rising water levels in the channel due to caused drag forces as well as plant volume. The presented approach will allow us to show the effect of riverbank vegetation diversity on rising water levels due to riverbank vegetation within the channel shortly before, during and after flood event. Moreover, the outcomes will allow for comparison of the effect of seasonal varying riverbank roughness on water levels, which could have added value on advancing river modelling.

Effect of increasing channel depth by sea level rise and active deepening on peak water levels in deep estuarine channels

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Highlights — maximum of three sentences (maximum 85 characters, including spaces). No abstract is required.

- A 3D-numerical model was deployed to systematically study the effect of increasing water depth on peak water levels in the Rhine-Meuse Estuary.
- Tidal amplification is reduced by decreasing depth convergence in case of sea level rise.
- Peak water levels rise less than mean sea level.

Overview

Many deltas are under pressure from changing boundary conditions, including climate-induced changes such as sea level rise (SLR) and human-induced changes such as land reclamation and dredging. Many estuarine channels, especially in deltas which are heavily influenced by human activities, are at the risk becoming deeper when SLR accelerates and sedimentation cannot keep pace with rising sea levels. At the same time, channels are artificially deepened for navigation purposes. These factors potentially favour amplification of the tides through reduced friction, and thereby increase flood risk. The extent of this effect however is largely unknown, and other mechanisms affecting tidal amplification may be relevant. Here, we investigate the tidal response to increasing channel depths by both SLR and artificial deepening in the Rhine-Meuse Estuary (RME).

We introduce and use a validated 3D-numerical model in Delft3D, to get a mechanistic understanding of tidal response to increasing water depths in the RME. We calculate tidal ranges along the Northern and Southern branches for varying model geometries and boundary conditions. The model geometries include a reference, deepened and shallowed bathymetry. Varying boundary conditions include average conditions with and without wind setup, a storm scenario and a SLR-scenario.

Results show that, when the current bed level in the estuary is maintained, the tidal range decreases in case of SLR. Thus, peak water levels rise less than mean sea level. The expected tidal amplification due to friction reduction is compensated by a decrease in channel depth convergence after SLR. In contrast, deepening of the mouth area leads to tidal amplification through increasing depth convergence. As a result, inland peak water levels increase. Nevertheless, deepened channels are less vulnerable to tidal amplification due to future SLR.

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Modelling tidal response to increased channel depth

We make use of a validated 3D-numerical model in Delft3D to systematically study the response of tidal range to increased water depth. We define six sets of boundary conditions based on historical timeseries, and one set of boundary conditions which represents storm conditions with a return time of 1/100 years. The historical boundary conditions differ in terms of wind setup and upstream river discharge, and represent the current natural variability of the system. All periods are simulated with and without 1 m sea level rise, based on the RCP8.5 climate scenario (Haasnoot et al., 2018; Portner et al., 2022). Furthermore, we define three different model geometries: a reference geometry, representing the RME bathymetry of 2019, a deep geometry in which the mouth area (including the New Waterway between Maasmond and the confluence with the Old Meuse, a distance of 15 km) is deepened with 1 m, and a shallow geometry in which the mouth area is shallowed with 1 m. We thus study the tidal response to changing channel depth by both SLR and by active dredging or shallowing.

Tidal amplification mechanisms

The mechanisms that cause a tidal wave to amplify or dampen as it travels through an estuary, are described in Van Rijn (2011) and is summarized by:

$$\frac{\partial A_t}{\partial x} = -0.5\frac{\partial B \partial x}{B}A_t - 0.5\frac{\partial H \partial x}{H}A_t - \frac{fu^2}{3\pi g H \cos\phi} \tag{1}$$

in which A_t is the tidal range, x is the along-channel distance, B is the channel width, H is the channel depth, u is the peak tidal velocity, g is the gravitational acceleration and ϕ is the phase difference between the horizontal and vertical tide. The friction factor f is defined as $f = 8g/C^2$ with C the Chézy coefficient. The change of tidal amplitude along the estuary thus depends on respectively the width convergence, depth convergence and energy dissipation by bed friction.

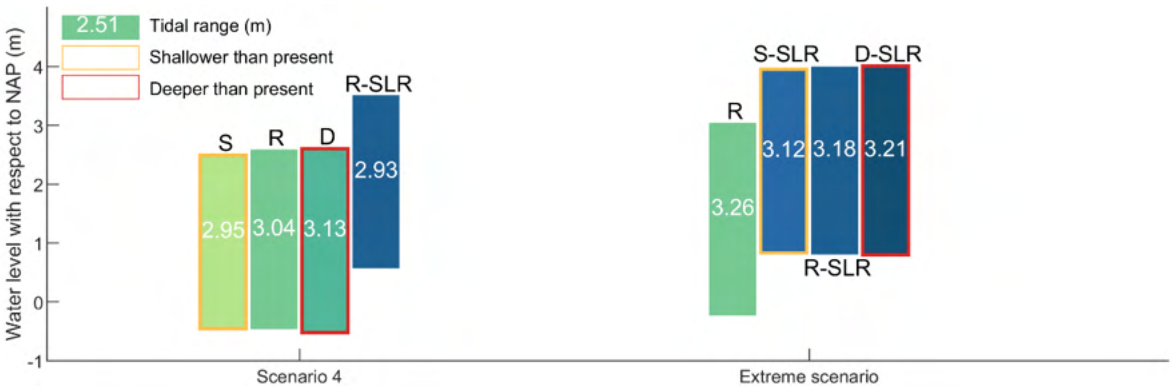

Figure 1. Modelled tidal range at Rotterdam (located along the Northern branch of the Rhine-Meuse Estuary) for a period of historical boundary forcing (Scenario 4) including medium river discharge and high wind setup, and the extreme scenario with high wind setup (Extreme scenario). Annotations indicate shallowed bathymetry (S), reference bathymetry (R), deepened bathymetry (D) and boundary forcing including sea level rise (SLR).

Tidal response to SLR and dredging in the RME

The model results show that SLR reduces tidal amplification along the New Waterway – New Meuse, but that channel deepening increases tidal ranges. Figure 1 shows the result for one of the stations along the northern branch of the RME. Although the increased channel depth leads to less energy dissipation by bed friction (3rd rhs-term in Equation 1), this effect is small compared to the decreased depth convergence (2nd rhs-term in Equation 1). In contrast, channel deepening leads to amplification of the tidal range. Whereas SLR results in a depth increase along the full channel length, dredging is a local measure which increases depth at the downstream stretch only. Hence, local channel deepening increases energy convergence through the second rhs-term in Equation 1.

Implications

The results lead us to conclude that tidal range does not increase with rising mean sea level for the considered case. Thus, peak water levels rise less than mean sea level. This effect is relevant for deep, engineered shipping channels as present in urban deltas worldwide. In contrast, shallow channels in more pristine delta areas are typically friction-dominated. There, SLR leads to a large friction reduction and amplification of the tide, which is in line with the findings of Leuven et al. (2019). Paradoxically, channel deepening has an amplifying effect on the tides on the short term, but deepened channels are less sensitive to sea-level rise.

The influence of precipitation spatial variability on mesoscale catchment hydrology: A study on the impact of rainfall distribution patterns

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Schalk Jan van Andel[a]
Ioana Popescu[a]

Highlights

- This research investigates the hydrological effects of different spatial representations of precipitation data in a physically based distributed hydrological model of a mesoscale catchment.
- Results showed that overall there was no considerable impact on the stream flows by varying the spatial resolution of precipitation, but groundwater heads were locally affected throughout the catchment.
- The overall hydrology of the mesoscale catchment was not affected much by increasing the spatial resolution of the precipitation data due to the relatively homogenous distribution of the precipitation over the entire catchment.

Overview

Precipitation is a crucial input for hydrological models, and it's essential to accurately represent it in both space and time for reliable predictions of hydrological responses. However, this can be challenging due to large spatial and temporal variations that occur within a catchment. Standard gauge measurements may not adequately capture the spatial structure, leading to significant uncertainty in hydrological modeling.

Over the years, there have been various research studies exploring the impact of precipitation on runoff response. Notable examples include the works of Obled et al. (1994), Bell and Moore (2000), Berne et al. (2004), Segond et al. (2007) and Huang and Bardossy (2019). These studies have focused on analysing the effect of rain gauge spatial density on runoff mechanisms, and most have found that reducing the density of the gauge network leads to a deterioration in the quality of model simulations.

Runoff response is also sensitive to the type of precipitation. Bell and Moore (2000) in their research compared the sensitivity of the basin runoff with two types of rainfall events and found greater variation with convective rainfall as compared to a stratiform rainfall event. While Fu, et al. (2011) in their research analyzed the effect of spatial resolution of precipitation on runoff, recharge, and groundwater head using the MIKE SHE model in the Alergaarde catchment in Denmark. The resolution of precipitation input had no apparent effect on the annual water balance and runoff discharge hydrograph.

This study examines the impact of precipitation spatial variability in the Aa of Weerijs catchment, which is a transboundary catchment between the Netherlands and Belgium. A fully distributed physical hydrological model, MIKE SHE coupled with MIKE 11 was used for the testing of three different precipitation representation scenarios. The first scenario utilized the Theisen polygon method with three rain gauge stations (Ginneken, Zundert, and Leonhout), while the second scenario used the Inverse distance weighting (IDW) interpolation technique based on daily time series from the rain gauge stations. The third scenario involved the use of radar data for the Dutch part of the catchment and interpolated data for Belgium. The interpolated data was developed by considering the three locations in the Netherlands radar data set and Leonhout rain gauge station data located in Belgium. The representation of the above-mentioned scenarios is shown in (Fig.1). The evaluation of these scenarios is done at multisite using the Nash-Sutcliffe Efficiency (NSE).

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References

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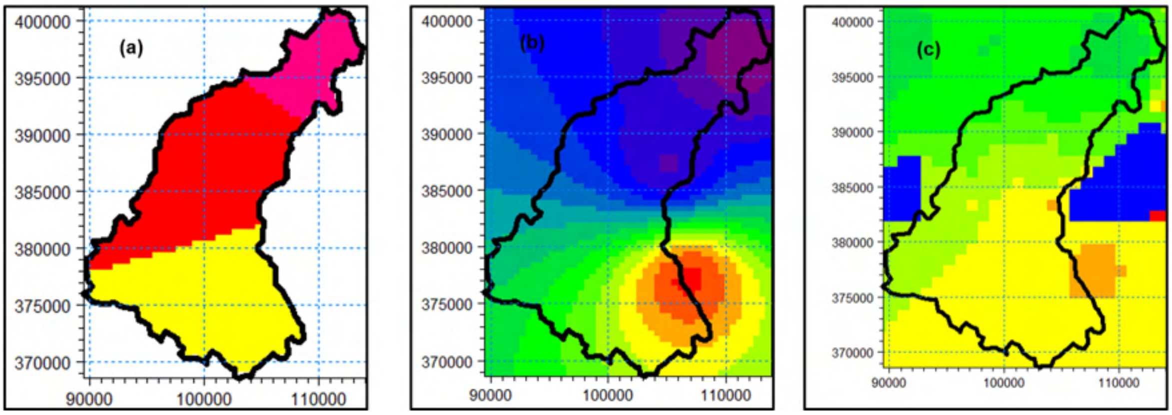

Figure 1: Precipitation representation (a) Theisen Polygon (b) IDW Interpolation (c) Radar data

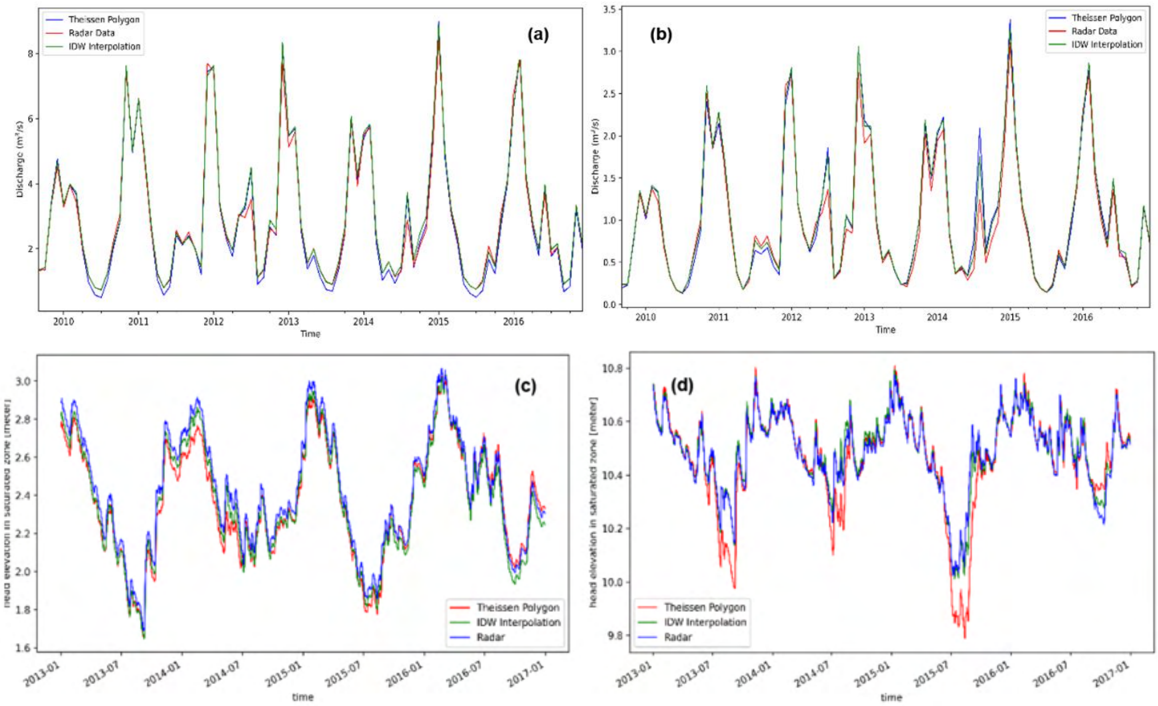

Figure 2: Stream Flows and Groundwater head elevation at different locations (a) Q at Outlet (b) Q at mid point of river (c) GW head elevation at Outlet (d) GW head elevation at mid point of catchment

The research findings suggested that changes in the spatial variability of precipitation data have a minimal impact on streamflow. The average NSE coefficient, computed for three discharge points, exhibited slight variations ranging from 0.68% to 4% when the spatial variability of precipitation data was tested. However, modifications to the spatial resolution of precipitation data did yield local fluctuations in groundwater levels, as evidenced by a maximum NSE increase of 162% and a decrease of 20%.
These observations can be attributed to the characteristics of the catchment. Aa of Weerijs catchment is relatively flat, and frontal precipitation dominates the region, resulting in a relatively uniform distribution of precipitation across the catchment. Consequently, changing the resolution of precipitation data leads to less variation in stream flows. However, the spatial variability of precipitation data within the catchment affects local recharge and, consequently, groundwater head variations. The variation in stream flow and groundwater heads at three different locations of the catchment are shown in (Fig.2).

These findings have significant implications for hydrological modeling, particularly in terms of understanding the influence of precipitation data on the surface (streamflow) and subsurface (groundwater levels) hydrological interactions.

Large-scale bank restoration in the Overijsselse Vecht River

Authors:
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Leon de Jongste[a].

Highlights

- The development of 50 km of fully restored banks along the Overijsselse Vecht in the past 10 years is analysed.
- High erosion rates are observed in certain outer bends; most banks display relatively little retreat.
- Flow currents are identified as main driver of bank erosion, and soil composition as main resistance.

Introduction

The water boards Vechtstromen (WVS) and Drents Overijsselse Delta (WDOD) are transforming the river Overijsselse Vecht into a safe and more natural river (Renner et al, 2009). To reach this goal, more dynamics through re-meandering, new side channels, and processes of erosion and sedimentation are enabled. Removing existing bank protections contributes to this. Since 2009, authorities and partners, including both water boards, have been working on the river Vecht to shape the transformation. Several projects and measures have now been implemented. The present study aims to evaluate the morphological evolution of the restored banks, identify the driving factors of erosion, and estimate long-term profiles with their uncertainty bandwidth, in order to support the update of the framework by the water boards. In total, 50 km of restored banks were analysed, including continuous stretches of multiple kilometres. This study was performed as part of a system analysis, including an analysis of the longitudinal adjustment of the river profile to interventions (Witteveen+Bos, 2022).

Methodology

We studied the driving forces of bank erosion by analyzing banklines, using bathymetric survey data (2013, 2016, 2019, 2022), applying structure-from-motion photogrammetry with stereo photos, numerically modelling hydrodynamics (D-HYDRO), carrying out field observations (July 2022), and analysing time series of discharges, water levels and ship passages at sluices (Thorne and Tovey, 1981).

The banklines were delineated along the river using aerial photos of 2013, 2019 and 2021. Three locations were studied in more detail, herein named hotspots, as they showed significant erosion and had sufficient data to investigate dominant erosion factors. After these analyses, long-term bank profiles were estimated from bankline shifts.

Results

All unprotected banks were classified into five categories based on bankline retreat. Most banks showed a shift smaller than 2 m in the period 2013-2021. Some outer bends displayed more erosion, with more than 5 m of retreat (e.g. Varsen bend, Fig. 2).

Flow currents were identified as the dominant driver for bank erosion, and the soil composition as the governing resistance against erosion. Patterns of bank erosion match with the distribution of flow velocity. Secondary factors were cattle trampling (local bank collapse and upper slope reworking) and vegetation. Vessels had a negligible contribution to erosion, opposite to observations at other Dutch rivers (e.g. Duró et al., 2021).

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A bar-mode analysis (Crosato and Mosselman, 2009) and long-term changes in longitudinal profile indicate that the development of alternate bars is not likely in the Vecht. The axis of the main channel is expected to remain in place. Bends with forced bars and large outer-bank erosion may represent local exceptions to that behaviour.

Floods with a lower probability of exceedance of 1/year took place in the past 2 years. Banks that displayed low to none erosion possibly reached a stable position under regular flood events. At these banks only limited erosion (< 5 m) is expected in the long term. Banks that did show significant erosion in recent years are expected to continue to erode at a similar pace in the short term. Their long-term behaviour is more uncertain, especially at newly restored banks where no soil composition data nor evidence of their morphological response to currents are available.

At mild and sharp bends, accretion of the inner bank can increase the erosion of the outer bank, which could lead to local meandering in the long term. Accretion of inner bends is currently not observed. However, the necessary steps for this process (point bar accretion, colonization by vegetation, sediment trapping and soil consolidation) are each observed at separate locations along the river, which indicates that the complete process of bank accretion could take place in the long term. The current regulation of water levels could limit this process.

Discussion and Recommendations

The occurrence of flood events and the bank composition are the most relevant factors that determine bank erosion and in turn contribute to a significant uncertainty in future bank erosion. Soil composition was identified as the main resisting force, but no specific data were available to include this factor in the prediction. A more accurate retreat estimate could be made if soil cores at restored banks would be made and compared to cores at locations where future bank protection removal is planned.

Monitoring of the progress of both bank erosion and bank accretion at sharp inner bends is recommended given the current uncertainties in future morphological developments. The progression of banklines can be followed using aerial photographs and direct measurements. If a bankline reaches a point where erosion is no longer desirable, measures can be taken to (partly) fix the bank (Mosselman et al., 2021) or impede accretion on the inner bank.

Acknowledgements

We would like to express sincere gratitude to the staff of water boards Vechtstromen and Drents Overijsselse Delta for their input and helpful feedback during the study.

Figure 1. Nature-friendly bank near Varsen on 12-7-2022

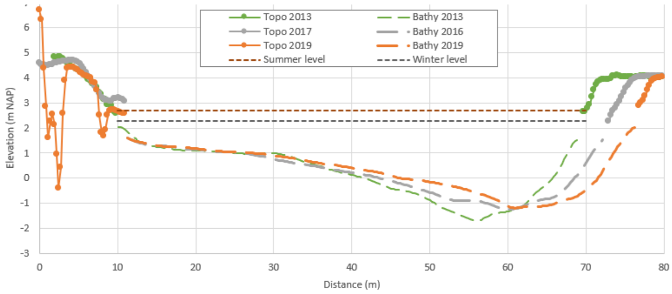

Figure 2. Cross section at one of the hotspot locations near Varsen (rkm 37.3-37.9). The topography above the water level is derived from stereophotographs, the bathymetry with echo-sounder surveys.

Invited versus claimed spaces for citizen participation in river governance

Author:
Jeroen Vos[a]

Highlights

- A literature study was done on citizen initiatives and environmental movements in river governance
- Academic attention shifted last decades from anti-dam movements to citizen science and right of rivers
- Claimed spaces for participation in river governance are increasingly acknowledged as valuable

Overview

The aim of the literature review was to make an inventory of citizens' initiatives to recover polluted rivers, oppose planned interventions in rivers, or propose alternative designs for proposed infrastructure projects in rivers.

Citizen participation in river governance can take many different forms. One can distinguish between invited versus claimed spaces. Invited spaces refer to processes of citizen involvement on invitation of a government organisation that plans a certain intervention is a river system. Citizen participation in an invited space can range from being informed, to discussion of the design, to co-design and to co-decision taking. However, the boundaries of involvement and the agenda for participation are set by the planned project. Claimed spaces for participation are created when citizens take their own initiative and organise to advocate for their own ideas on their own terms. Cornwall and Coehlo (2006) describe claimed spaces as new democratic arenas.

The main question of the literature review was to identify the different types of claimed spaces for river governance covered in academic studies and how the academic coverage of the different type of citizen initiatives has changed over the past four decades.

Results:
Relatively much attention was initially given to anti-dam movements (Fox and Sneddon, 2019). Alongside, the attention shifted to the active contribution of irrigation water users' associations and their federations (Hoogesteger and Verzijl, 2015) and local watershed governance (Kauffman, 2017). Subsequently, new water culture movements (e.g. in Spain, see Hernandez-Mora et al., 2015) are studied. This goes hand in hand with attention for the worldviews and value-systems of riverine communities and their political implications as expressed in the Riverhood concept (Boelens et al. 2022; Wilson, 2019; Yeophantong, 2017). More recent citizen science for river water quality monitoring and right for the river litigation (Kinkaid, 2019) draw academic attention.

Conclusion:
Claimed spaces for participation in river governance are increasingly acknowledged in academic literature as crucial arenas for democratic river governance.

Affiliation

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Different types of citizen river initiatives

Since the 1980s scholars have documented major protest movements against building of large dams such as the Sardar Sarovar dam in India, the Chixoy dam in Guatemala, and the Belo Monte dam in Brazil. These movements mainly consisted of communities affected by displacement and loss of livelihood without proper compensation. Less attention was paid to community action and environmental movements that promoted the restoration of canalized, diverted, depleted and polluted rivers. Since the turn of the century more attention is paid in academic literature to communities and social movements that propose to remove dams, stop pollution of rivers, restore fish ecosystems, rewild rivers, oppose top-down urban river front development and advocate for granting rivers legal personhood, or oppose dams because they want to protect free flowing rivers for fish migration or tourism. A systematic literature review of the diverse community river defence and river restoration movements was done to show trends over time and analyse the academic coverage of different types of action undertaken by the river defence and restoration movements, including protests, advocacy, citizen science monitoring and litigation (right of the river) in different parts of the world. The shifts in academic coverage reflect changing strategies of the river movements as well as paradigm shifts in interest of scholars.

Outcome of the literature review: topics and trends

The Scopus search string: (TITLE-ABS-KEY (river AND grassroots) OR TITLE-ABS-KEY (river AND activism)) AND (LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "ARTS") OR LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "EART") OR LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "DECI") OR LIMIT-TO (SUBJAREA , "MULT")) resulted in a total of 309 publication. See Fig. 1 for the trend in number of publications over time.

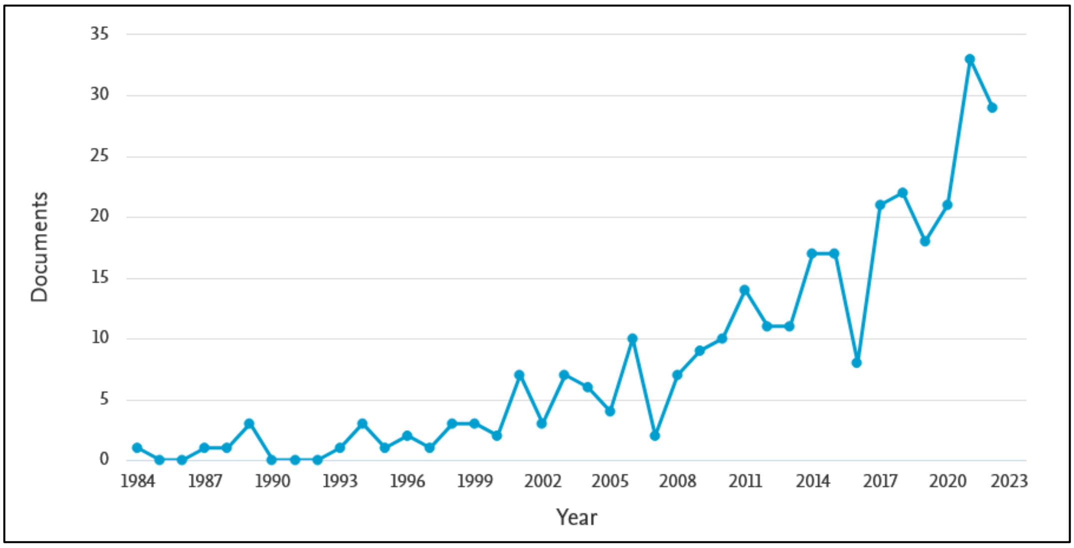

Fig. 1 Number of publications on citizen initiatives in river governance (source: Scopus search)

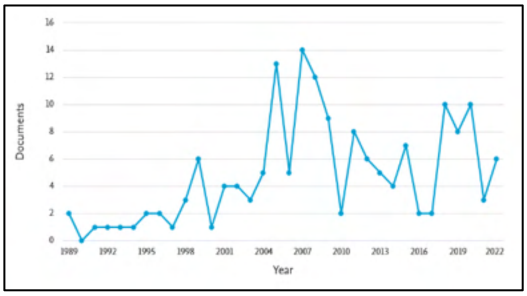

Fig.2 Number of publications on "public participation" and river projects (163 total)

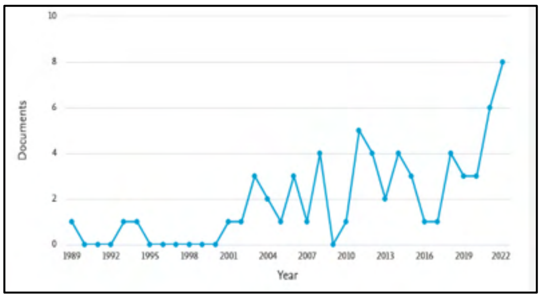

Fig. 3 Number of publications on "right of rivers" (64 total)

Fig. 2 shows the decline of attention of scientific studies on public participation through invited spaces in river projects. The Scopus search string was: (TITLE-ABS-KEY ("public participation") AND TITLE-ABS-KEY (river) AND TITLE-ABS-KEY (project)). Fig 3. shows the increased attention paid to advocacy for "right of rivers" by citizen groups. For this query the Scopus search string was: the same as for Fig. 1 plus: AND TITLE-ABS-KEY (right AND of AND rivers))

The Meandering Meuse Project, an example project for integrated River Management

Project Meanderende Maas [a]
Wiebe de Jong, Danny Booij [b]
Robbert de Koning [c]
Gijs Kurstjens [d]

Highlights

- In the Meanderende Maas project (Meandering Meuse) flood protection is achieved by realizing a dike reinforcement in combination with river widening. This combination provides an optimal implementation of high water safety, nature development, improvement of water quality, recreation and spatial quality, in a way that contributes to a more sustainable project.
- The Meanderende Maas Project contributes to the ambitions that the Integral River Management program is pursuing over the coming decades for the entire Dutch River system.

Overview

The Meandering Maas project improves the flood protection by strengthen the dike along the Maas from Ravenstein to Lith, a 26 km stretch, and by floodplain lowering on both the Gelderland and Brabant sides. Another important goal is the transition of more than 6 km^2 agricultural land into a natural floodplain and in this way to improve the touristic and economic value of the area . The project leads to an successful integration of water safety, nature development, improvement of water quality, recreational development and spatial quality. The Meanderende Maas project is therefore an example project for the ambitions which stand to be completed in the coming decades by means of the Integral River Management program (IRM). This program intends to develop a future-proof, well-functioning, multifunctional, sustainable river system. The IRM program looks for an optimal balance between the various functions of the river area.

In the exploratory phase (MIRT2 phase, ended April 2021) of the project, a preferred alternative for the redevelopment of the floodplains was made. The preferred alternative was the basis for the final design in the elaboration phase (MIRT3 phase, May 2021 – February 2023). In this phase, this plan has been optimized through a number of targeted improvements by the combination of Royal HaskoningDHV and Boskalis. One of the improvements was the increase in area of hardwood alluvial forest and reed marshes because these ecotopes match perfectly with the limited river dynamics of this river stretch. Despite the increase in vegetation roughness, the objective of water level decline for flood safety has been maintained and the side effects on navigation (like morphological impact) have been further reduced. The spatial quality has been improved by establishing a strong relationship between the geomorphological patterns and the layout of the design. The readability of the special cultural history of the landscape is thus improved. Besides this the floodplain is made accessible and more attractive for recreational users. The final design of the Meanderende Maas project gives substance to this optimal balance between high water safety, nature development and water quality, recreational accessibility and spatial quality. The combination of dike reinforcement and river widening contributes to the sustainability ambitions of the project; the use of local clay, whereby short transport distances between the floodplains and the dike reinforcement are the rule, as well as the potential for the new forests to fixate CO2.

Affiliations

[a] The Meandering Maas project is an initiative of ten project partners: the Aa en Maas water board (projectlead), the province of North Brabant, the municipality of Oss, the Ministry of Infrastructure and Water Management, Rijkswaterstaat, the province of Gelderland, the municipality of West Maas en Waal, the municipality of Wijchen, water board Rivierenland and Natuurmonumenten.
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[c] Robbert de Koning Landschapsarchitect BNT, Drielsedijk 4, 6842AB Arnhem
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http://www.meanderendemaas.nl/ Last accessed March. 2023.

The project Meanderende Maas

The main design goals for the redevelopment of the floodplains within the project are:

- Achieving a substantial water level decline through floodplain lowering (14cm decline during flood);
- Achieving the objectives of Nature Network Brabant (NNB) to develop a river and marsh landscape;
- Achieve the objectives of the Waterframe Work Directive (WFD) and PAGW targets regarding good water quality and river nature of high quality;
- Contribute to recreational opportunities, economic development and spatial quality.
- Achieve major sustainability gains by using the released soil flows in the dike reinforcement.

Approach

In an iterative design process of several steps and phases (MIRT2 and MIRT3) a final design has been made for the six different floodplains in the project area. The design was based on using the geomorphological characteristics of the subsoil, by using the behaviour of the river system during high and low discharges and the relation between inundation frequency and vegetation habitat. These three characteristics combined lead to the pattern of new side branches, the vegetation pattern and recreational services. As an example the Diedensche Uiterdijk is presented, the largest floodplain of the project area (2,5 km^2). Fig. 1 shows the geomorphological pattern of the substrate. Fig. 2 shows the final spatial design. The subsoil contour of the young meander has been used as the new layout for the side branch with surrounding reed marshes. The older geomorphological layers have been used for the contours of moist grassland, dry alluvial grassland and alluvial forest. By doing so, the values of the subsoil and the geomorphological history of the area, are made visible in the layout of the surface. The hardwood alluvial forest and reed marshes are located in the areas where river flow during high discharges is low, this gives the opportunity to achieve the biodiversity goals without affecting the high water safety goals. The area is also archaeologically and cultural-historically very rich, by retaining and emphasizing these values, the recreational value of the area is improved as well.

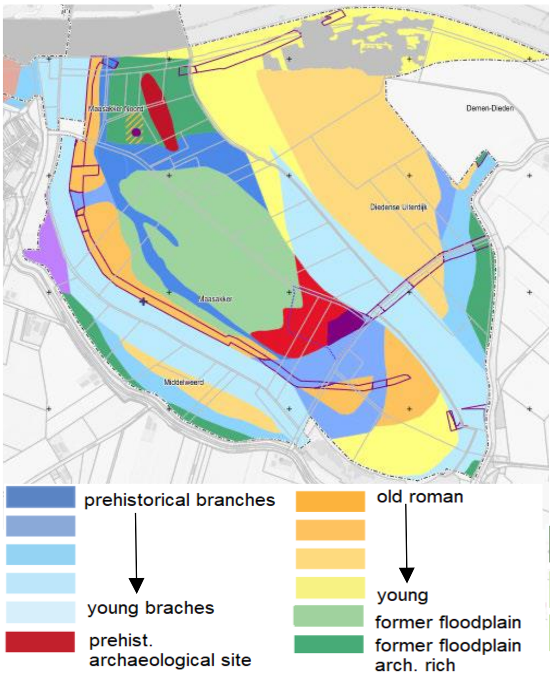

Figure 1: Geomorphological patterns in Diedensche Uiterdijk (RAAP, 2022)

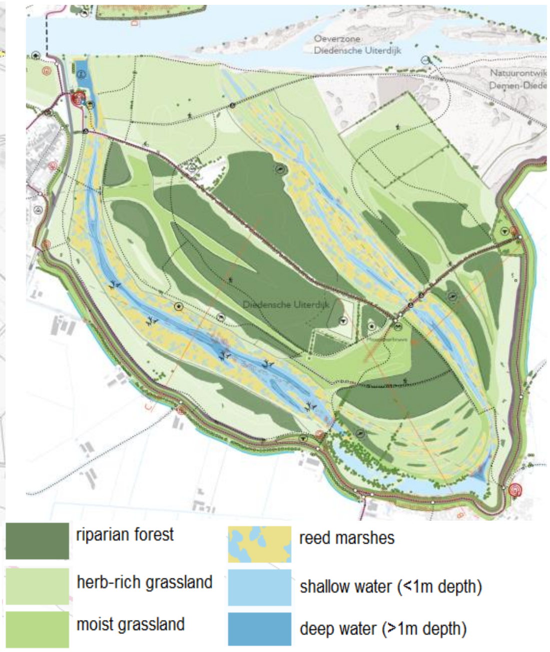

Figure 2: Spatial design of the Diedensche Uiterdijk, final design Meandering Maas project (Boskalis/Royal HaskoningDHV/Robbert de Koning, 7 October 2022)

The achieved results in the final design

The final design of the floodplains in the Meanderende Maas project (Fig. 3) has resulted in 90 hectares (16% of total area) of alluvial forest, 46 (8%) hectares reed marshes and 53 hectares (10%) open water within 9,5 km length of new side branches and meanders. This is a huge improvement in biodiversity, river nature and water quality. The project also meets the objective for high water safety as the project still results in a water level reduction of 14 cm during flood levels. The floodplain forests and reed marshes have a combined potential for the fixation of 31,000 tons of CO_2 The project achieves an optimal balance between the various functions of the river area (flood safety, navigability, biodiversity, water quality and economical and recreational value and spatial quality).

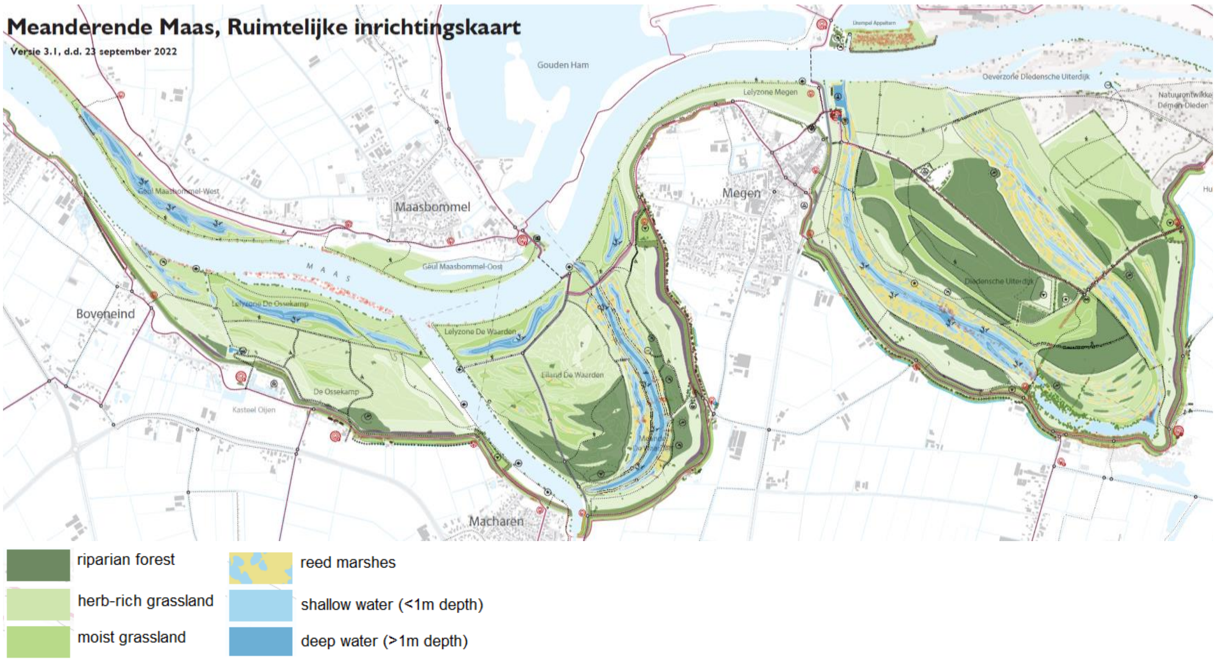

Figure 3. Spatial design of the Meandering Maas project, Diedensche Uiterdijk (Boskalis/Royal HaskoningDHV / Robbert de Koning, 7 October 2022)

Learning Spaces in river management: Innovating in the quadruple helix

Heleen Vreugdenhil[a]
Astrid Bout[b]
Joyce Zuijdam[b]
Julia Bleser[a]

Highlights

- In 2022 two new Learning Spaces have started on river stretches in the Waal and IJssel-Twentekanalen
- Rijkswaterstaat, the contractor and a knowledge institute aim to work on a basis of equivalence
- Learning Spaces have become an established instrument in river management

Overview

Learning Spaces are a novel way of working between Rijkswaterstaat, a contractor of river stretches and a knowledge partner with the objective to innovate in river maintenance and management. Unlike in most other projects, the different organisations work as partners in a triple or even quadruple helix when also a societal organisation participates. The idea is that the partners are intrinsically motivated to innovate and yet need one-another to bring the innovation to the next level, both technically and socially. Working together, daring to share and meeting each other's' interests are key philosophies of the collaboration between the partners. In 2014, a first Learning Space has been initiated, and after its termination in 2022, two new Learning Spaces in river maintenance have been launched: one focussing on the rivers Bovenrijn, Waal and Maas-Waal canal, the other on the rivers IJssel, Twente canals and Nederrijn-Lek.

The aim of this study is to discuss how Learning Spaces function as innovation instruments. The study shows that Learning Spaces provide a new, both promising and challenging way of working. In the first Learning space, up to 8 innovations have been tested or supported in multiple ways, leaving space for initiatives from different partners. They have increased both their technological and social readiness levels. Despite this promising first experience, the start of the expansion to the new Learning Spaces is slow. They need time to find their own working mode. Inspiration and hands-on work are needed to stimulate the cooperation.

The take-home message from this study is that the most successful innovation is maybe the instrument itself: Learning Spaces are now an approved and established instrument in Rijkswaterstaat. At this point in time at least 8 Learning Spaces have been launched and more will follow when new maintenance contracts start, both in river and road management. This paper is also an invitation for innovative ideas to be submitted to the Learning Spaces.

Affiliations

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References

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Vreugdenhil, A Bout, K Olde Monnikhof (2019). Het Leerteam: Samen Innoveren in het Beheer en Onderhoud van Rivieren en Kanalen H2O: tijdschrift voor watervoorziening en waterbeheer

Introduction

In 2014, Rijkswaterstaat took the initiative to start a so-called Learning Space in the river IJssel and the Twente canals (Bout and Vreugdenhil, 2018; Vreugdenhil et al. 2019). The objective of a Learning Space is to accelerate innovation in operation and maintenance and to improve river maintenance in terms of efficiency, river conditions and climate mitigation. So far, innovation in operation and maintenance gained relatively little attention. A Learning Spaces is a partnership between Rijkswaterstaat, the contractor and a knowledge partner and is directly coupled to the perennial maintenance contract of a river stretch (Figure 1). The first Learning Space (2014-2021) has facilitated 8 innovations, including flexible groynes, removing plastic from the river with a bubble screen, vegetation maintenance with sheep herding, and monitoring with an aquatic drone.

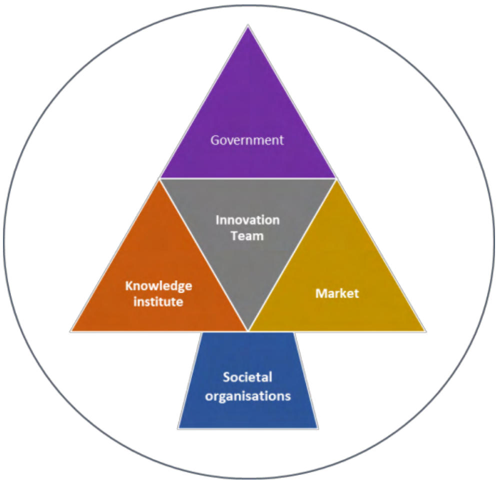
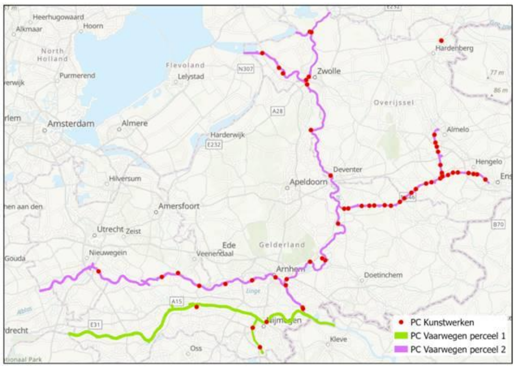


Figure 1: Design of the Learning Spaces: A partnership between the market, knowledge institutes, government and societal actors. In the middle the Innovation Team.



Since 2022, 8 new Learning Spaces have been initiated, 2 of which related to the new maintenance contracts of the river IJssel and Twente canals, and Bovenrijn, MaasWaal canal (Figure 2). In this paper, we present these two new Learning Spaces: who are in there, how do they operate and in particular, what do they focus on and how does that contribute to innovation?

Figure 2 Map of the working areas for performance contract 1 (Upper Rhine, Waal, Maas-Waal canal) and performance contract 2 (Twente canals, Lower Rhine, Lek, IJssel).

Method

This paper is the result of action research. All authors participate in the Learning Space, either in the operational teams (the 'Innovation Teams') or as coordinators. As a participant they join or organize meetings, contribute to the plan of action, and introduce or collect potentially interesting innovations. As a coordinator, support is provided to the Innovation Teams, knowledge plans are developed and more strategic issues are addressed. For this paper, we draw on our experiences in or with the Learning Spaces and on documents developed by the Innovation Teams, complemented with interviews with other participants.

Results

The new Learning Spaces have started a year ago, with partly the same and partly new partners. In terms of personnel there is also partly continuation, partly renewal. During the first year, the focus was getting to know each other and finding out how to cooperate. For that purpose, a plan of action has been made. The first pitches with new ideas have been held and one idea has been studied in more detail. In the upcoming months, the focus is on collecting ideas deriving from both practical experience and strategic research questions. The topics include sustainable sediment management, digitalization (e.g., digital twin), water quality issues, enhancing biodiversity and climate resilient networks and sustainable management of energy and resources (e.g., more sustainable working practices or energy sources, such as aquathermal energy). The current explorative period is an invitation to other organizations and people to align their research questions and innovations and explore cooperation with the Innovation Team.

From an innovation management perspective, the widespread use of Learning Spaces is interesting. It is now an approved instrument, included in any new maintenance contract. The perseverance of people in Rijkswaterstaat to institutionalize it has contributed to this. It is now a contractually accepted instrument.

River governance out of bounds – untaming the transboundary, trans-formative, transgressive river Meuse?

Jeroen F. Warner [a], Jeroen Vos [a], Heleen Vreugdenhil[b, c] Jill Slinger [b], Sumit Vij [a], Art Dewulf [a]

Highlights —

- Given its complexity, diversity and dynamics, existing models of governance may fall short on the transboundary Maas
- We propose a 'Mode 4' river governance model complementing existing models.

Overview

The transboundary Maas/Meuse is analysed as an exemplar for rivers that do not only cross boundaries, but also at times transgress its banks, and are candidates to transform their legal identity from passive recipient of regulation to legal personhood. As such it is a candidate for an as yet incomplete 'Mode 4' of river governance, which better takes into account the impacts of uncertainty, complexity, dynamics and diversity as first explored by Kooiman (1993).

While the transboundary stretch is highly dynamic and interconnected, infrastructurally but also culturally and politically (Warner 2016), it tends to be governed according to centralised control priorities, especially in crisis contexts. We analyse how river Maas governance may go beyond the three river management modes of river and problem domestication (Lach *et al.* 2005), to see if it provides pointers for an emerging fourth mode which may make space beyond control to accommodating more 'untamed' expressions of a shared river, its people and ecosystem. While older paradigms have assumed the formal control and linear rationality of governance, more recent developments have increasingly recognised notions of complexity, diversity and dynamics (Kooiman 1993) including spaces of informality (including the 'dark side', Wegerich *et al.* 2014) and plurality. This trend welcomes the exploration of how notions such as legal pluralism (Dupret 2007) and designs for the pluriverse (Escobar 2020) which have inspired analysts of river management in the global South, may also be useful for Western European contexts.

Not only is the Maas a border river for 48 km; since the federalisation of Belgium, the Flemish and Walloon authorities can conduct their own foreign policies and, uniquely, sign treaties independently. Due to this political change,.the river Meuse and its tributaries now cross sovereign borders multiple times, making its exceedingly complex.

It raises the issues of responsibility and coordination in a river prone to destructive flooding and intense pollution. While a transboundary river Maas Commission is in place, actual transboundary cooperation on quality and quantity, especially between Dutch and French and German speaking territories, has been patchy, and after the 1993 and 1995 flash floods, the river riparians originally went their own way in implementing emergency flood protection and, in places, river restoration works. The security imperative initially promoted a focus on hard infrastructure and dominance of national priorities, backgrounding the peculiarities of geography, shared history and culture.

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When in 2021 the transboundary Maas region flooded after prolonged intense precipitation, Wallonian operation of hydropower has been blamed for having exaggerated flooding in Liege and across borders. This led to increased diplomatic action at high levels to clear the way for better information exchange. But the system of weirs may also inadvertently amplify flood peaks.

The complexity continues in the normative/legal field now that environmentalists push for giving the Maas river rights and legal personhood, analogous to developments in Australia, Canada, South America and South Asia reflecting hybrids of western and non-western spiritual water traditions. They are finding resonance with Meuse water authorities eager to clean up and conserve the river's quality and natural values. Legal personhood for rivers in a transboundary context has been explored elsewhere (e.g. the rivers Vjosa and Brahmaputra), but not at this level of complexity – not to mention the issue if rivers are liable for flood damage when they are transgressive, moving out of bounds causing damage and mass evacuation.

We analyse the complexity, diversity and dynamics of river Maas governance and explore the implications for complex, dynamic and diverse governance of the river Meuse and elsewhere.

About NCR

Objective of NCR

NCR was founded as a formal cooperation between several Dutch institutions. On October 4, 2012, the partners of the 'Netherlands Centre for River studies' (NCR, Dutch: 'Nederlands Centrum voor Rivierkunde (NCR)') formally renewed their cooperation within NCR.

The objective of NCR is:

> Doelstelling van het NCR is een samenwerking tot stand te brengen tussen de belangrijkste kennisgebruikers en kennisontwikkelaars in Nederland op het gebied van rivieren met als uiteindelijk resultaat een versterking van het kennispotentieel, de profilering van de (inter)nationale positie van het Nederlands rivieronderzoek en het versterken van het onderwijs en het wetenschappelijk onderzoek aan de Nederlandse Universiteiten ten behoeve van een betere inrichting en beheer van de Nederlandse rivieren.

This translates to:

> The objective of the NCR is to establish cooperation between the major knowledge suppliers and knowledge users in Netherlands in the field of river studies, with the ultimate aim of reinforcing the knowledge potential, promoting the international position of Dutch river research and strengthen the education & scientific research at Dutch universities, to better design and manage Dutch rivers.

Domains

NCR encompasses all disciplines relevant to river studies as practices by its institutional partners. They include:

- Hydrodynamics
- Sediment transport and morphology
- Fluvial geomorphology and sedimentology
- River ecology, restoration and water quality
- Governance and spatial planning
- Modelling, serious gaming and digital twins

NCR Organisation

NCR has four main bodies. The mandates for all except Young NCR (YNCR) are documented in the *"Overeenkomst Nederlands Centrum voor Rivierkunde 2012"*.

- **Programme Secretary (Dutch: Programmasecretaris)**
  Safeguards the continuity of NCR activities, secretary to SB and PC; monitors of agreed actions by the SB and PC; reports of NCR finances; management of all NCR communications.

- **Supervisory Board (Dutch: Commissie van Toezicht)**
  Supervises the implementation of the cooperation agreement, settles disputes and approves the scientific programme.

- **Program Committee (Dutch: Programmacommissie)**
  Determines the scientific programme, stimulates and initiates proposals for activities and integration of knowledge, ideas, experiences and results.

- **Young NCR (Dutch: Jong NCR)**
  Established in December 2020, YNCR strives to strengthen the network of young/early-career scientists within NCR.

Institutional partners

The partners of NCR are: Rijkswaterstaat (RWS), Universiteit Twente (UT), Radboud Universiteit Nijmegen (RUN), Deltares, Universiteit Utrecht (UU), Technische Universiteit (TUD), Wageningen University & Research (WUR), Leiden

University Collega (LUC) and Vrije Universiteit Amsterdam (VU).

Each partner contributes in-kind and/or in-cash to realise the annual programme.

Accountability

NCR activities are annually documented in an annual programme, annual report and annual budget. The annual programme and budget are approved by the Supervisory board.

Table 1: The composition of NCR Boards in 2023. Persons marked with * are chair persons.

Person	Partner institution	Email
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Table 1: The composition of NCR Boards in 2023. Persons marked with * are chair persons.

Person	Partner institution	Email
Vacant	Vrije Universiteit Amsterdam	
Vacant	Leiden University College	

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Radboud University Nijmegen

Delft University of Technology

University of Twente

Rijkswaterstaat

Utrecht University

Vrije University Amsterdam

Wageningen University & Research

Deltares

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