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SEDDON II

T3.2.1 Best Practices - EN

Summary

SEDDON II (AT HU10)

BOKU – Wasserbaulabor Errichtungs- und Betriebs-Gesellschaft m.b.H.

Bundesamt für Wasserwirtschaft

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Picture front page: IWA/BOKU

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SEDDON II (AT HU10)

Sedimentforschung und –management an der Donau II

A Duna hordalékvizsgálata II

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Abstract

This report on best practice examples has been prepared as a part of the Sediment Research and -management at the Danube River II (SEDDON II) project within the ERDF funded Cross-border Cooperation Programme, Austria-Hungary 2014-2020.

The Danube River and its surrounding landscape nowadays lies in the field of various interest such as flood protection, hydropower, navigation and ecology. Due to this fact the formerly untamed and wild river system since the end of the 19th century faced a wide range of anthropogenic alterations leading to manifold hydromorphological issues. As one of the tasks in Work Package 3 (River Engineering) an analysis towards current sediment-related problems in the two project reaches was carried out aiming to improve the hydromorphological condition of the Danube River.

Based on the findings, this report attempts to present best practice examples of already implemented sediment-related river engineering measures from the entire Danube basin and beyond. The report is structured in four categories representing the main drivers for the implementation of measures, namely flood protection, ecology, navigation and hydropower.

Examples that can handle the multiple problems faced by the different stakeholders and can compensate the negative impacts of human pressures along river systems are presented. Thereby, a contribution towards the development and optimisation of river engineering measures is made. Furthermore, the presented examples build the basis for an evaluation towards their relevance and the technical applicability for the Upper and Middle Danube (Austrian and Hungarian project area) within activity 3.2.2 (Best practice evaluation document).

Contents

1 Introduction

A detailed understanding of sediment-related problems is essential for a successful and sustainable management of large rivers. The Upper Danube in Austria and Middle Danube in Hungary face several sediment-related problems. A description of the morphological characteristics, the flow and sediment regime as well as the resulting sediment-related problems were elaborated and presented in both outputs T3.1.1 (List of problems) and Output T3.1.2 (Report on the analysis of sediment-related problems along the study reach of the Danube in Austria and Hungary).

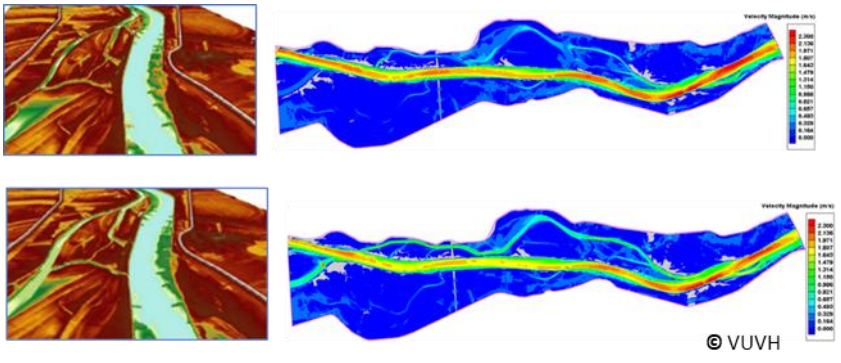
Based on the elaborated impacts concerning flood protection, ecology, navigation and hydropower, a study providing state of the art solutions for sediment-related river engineering measures was prepared. Within this report (Output T3.2.1), best practice examples from the entire Danube basin and beyond were summarized. In Output T3.2.2 these examples were compared. Furthermore, the relevance and the technical applicability of these examples for the Upper and Middle Danube (Austrian and Hungarian project area) were evaluated.

2 Best-Practice-Examples

2.1 Flood Protection

2.1.1 F1 - DuReFlood Project

DuReFlood Project	
River Basin	Danube River Basin
River	Danube
Country	Slovakia / Hungary
Main driver	Flood protection
Interrelation with	Navigation
Application	Free-flowing section
Aim and Background	DuReFlood Project was a cross-border cooperation project between Slovakia and Hungary focusing on flood protection and morphological alteration of the regulated section of the Danube influenced by the hydropower plant (HPP) Gabčíkovo. The whole project reach is between rkm 1810 to 1708. Based on the assessment of the current state, a proposal of measures for effective flood protection and lateral connectivity restoration to improve ecological status was prepared. Due to river bed erosion, groynes which were originally designed to concentrate the water in the navigation channel during low discharges, are too high at present. In addition, sediments are being deposited between the groynes, reducing the cross-sectional area of the river channel. The 'ineffective' groyne elevation and sediment deposition tend to increase the river channel's resistance to the flow of high discharges and may cause a rise in water levels during floods.
Objectives and Goals	- Assessment of the current state of flood protection in the Danube floodplain between Sap and the mouth of the Ipeľ river - Formulation of proposals for effective regulation measures to achieve a flood level reduction - Formulation of proposals for restoration measures (in the Slovak part of the river / floodplain) to improve the current ecological situation
Proposed measures	- Reconnection of side-channels

	- Groyne elevation reduction: Proposed elevation of groynes is - minimum navigational water level +1.2 m (scenario 1) or -minimum navigational water level +0.5 m (scenario 2) - Deforestation of groynes - Removal of deposits between the groynes - Partial sediment removal from branches on both the Slovak and Hungarian sides - Construction of a bypass canal around the sharp bend in the Danube (rkm 1782–1778) on the Hungarian side - Reconnection of large branches in the area of Medveďov-Kľúčovec and VeľkýLél should restore the river system and floodplain prior to human regulations of the Danube River, increase flow dynamics in reconnected branches and decrease sediment transport capacity of the river.
Assessment	1D and 2D hydrodynamic modelling incl. sediment transport model, long-term and medium-term morphological development of evaluated Danube river section (incl. changes in longitudinal profile, erosion/sedimentation), model prognosis of Danube channel morphological development, abiotic monitoring: bathymetry, LIDAR scanning, hydrological regime, water level measurements (incl. flood 2013), measurements of flow velocities and discharges, groyne surveying, river bed material sampling, grain size distribution analysis, suspended sediment sampling.
Pictures/photos	
Reference	http://www.dureflood.eu/eng/ https://www.interreg-danube.eu/approved-projects/danubesediment/outputs DanubeSediment report „Sediment Management Measures for the Danube“, factsheet codes in annex 2: E_FF_FP_D_GP03

2.1.2 F2 - Restore lateral erosion processes downstream of the reservoir

Restore lateral erosion processes downstream of the reservoir	
River Basin	Danube River Basin
River	Jiu
Country	Romania
Main driver	Flood protection
Interrelation with	Ecology
Application	River banks downstream of dams
Aim and Background	Restoration of lateral erosion processes downstream of the Isalnita reservoir under consideration of the potential risk to create a possible sedimentation area downstream of the reservoir by manoeuvring/operating the hydraulic equipment (intake dam gates, flushing container gates, sedimentation tank gates)
Objectives and Goals	- Restoring the river banks (flood protection) - Improvement of the river morphology downstream of the dam (ecology)
Proposed measures	- Sediment transit downstream of the dam by manoeuvring/operating the hydraulic equipment (intake dam gates, flushing container gates, sedimentation tank gates)
Assessment	- Before implementation: Hydrometric station upstream (Racari monitoring station) of the River Dam. Periodically assessment of the river cross-section profile, suspended sediment load and granulometry. - After implementation: Hydrometric station downstream (Podari monitoring station) of the River Dam. Periodical assessment of the river cross-section profile and granulometry.
Pictures/photos	
Reference	Investment approved by Government Decision no. 343/2015, published on Official Journal of Romania no.357/25.05.2015 (regarding the endorsement of the investment objective "Safety of the Isalniţa Dam, Dolj County", as well as of its main characteristics and the technical and economic indicators related to it). https://www.interreg-danube.eu/approved-projects/danubesediment/outputs

	DanubeSediment report „Sediment Management Measures for the Danube“, factsheet codes in annex 2: E_FF_FP_T_GP05

2.1.3 F3 - Open revetment / Open cover

Open revetment / Open cover	
River Basin	Danube River Basin
River	Wertach
Country	Germany
Main driver	Flood protection
Interrelation with	Ecology of water body (structuring elements installed; removal of embankments)
Application	Free-flowing section, gravel bed river
Aim and Background	The Wertach River was straightened and narrowed 150 years ago, which led to an increased flow velocity, riverbed deepening and problems for flood protection and nature. The project Wertach vital aims to widen the straightened river and give it more space (rkm 11.0 – 8.4). It is an integrated concept including river development, urban development, flood protection, morphology, ecology and public participation (for leisure and recreation).
Objectives and Goals	- Flood protection - Improvement of the ecology in the river - Bed stabilisation - Improvement of social functions of the water body
Proposed measures	Open cover (or revetment): large stones, which are bigger than the existing bed material, are placed onto the riverbed, covering about half of the area. The stones increase the resistance for the water flow and protect the finer, natural bed material in their shelter zones.
Assessment	- Before implementation: physical model by TU Munich (morphological study) - During implementation: qualitative monitoring - After implementation: monitoring of cross profiles

	It is proven that there is a bed stabilisation after 15 years. Depending on the conditions on site, open revetment can be a suitable approach in riverbed improvement.
Pictures/photos	See website
Reference	https://www.wwa-don.bayern.de/hochwasser/hochwasserschutzprojekte/wertachvital/index.htm

2.1.4 F4 - LIFE project “Natur Wachau” (2003-2008) / Reconnection of side-channels

LIFE project "Natur Wachau" (2003-2008) / Reconnection of side-channels	
River Basin	Danube River Basin
River	Danube
Country	Austria
Main driver	Flood protection
Interrelation with	Navigation (water depth during low flow), Ecology, Infrastructure (e.g. roads, electricity cables close to side-channel), Hydropower/water abstraction (less discharge in the main stream)
Application	Free-flowing section, reconnection of side-channels
Aim and Background	The Wachau-project (rkm 2033.5 – 2009.0) was the first realized LIFE-project in the Wachau, which aimed at the preservation of endangered habitats in that region. Amongst others, the reconnection of side-channels was one important measure. The backwaters of "Grimsing", "Aggsbach Dorf" and "Rührsdorf-Rossatz" were all reconnected to the Danube. The purpose of this measure, was to ensure the long-term sustainable connection to the Danube, which has now been successfully implemented.
Objectives and Goals	- Improvement of ecological conditions - Permanent connection of side-channels at low flowing conditions - Permanent refugial areas, protection against wave influence - Increasing flood retention, lower water level at high flow - Sediment input
Proposed measures	The reconnection of side-channels primarily leads to improved ecological conditions in these river systems. This measure creates

	new aquatic habitats and refugial areas, where organisms are protected against wave influences. Due to the permanent connection to the main channel, the water level, flow velocity, shear stress and transport capacity are increased. Morphodynamical processes are enhanced in the side-channel system. By tendency, these effects are causing a higher sediment inflow from the side-channels into the main channel. Furthermore, flood retention is increased, resulting in lower water levels in the main channel at high flows. Benefits for ecology and flood protection.
Assessment	- Integrative planning process, win-win case (Improvement for ecology and flood protection), sustainable measures, stakeholder engagement and involvement - Assessment after implementation: Habitat monitoring (Fish)
Pictures/photos	 Side-channel system Grimsing 2013, Foto: ©viadonau
Reference	https://www.weltkulturerbe-wachau.at/naturschutz/life-projekte/life-wachau https://info.bmlrt.gv.at/themen/wasser/wasser-eu-international/eu-foerderprogramme/life-natur/life-projekte_abgeschl/wachau.html https://www.viadonau.org/unternehmen/projektdatenbank/aktiv/auenwildnis/renaturierungsprojekte-in-der-wachau

2.1.5 F5 - LIFE+ project “Mostviertel-Wachau” (2009-2014) / Revitalization of side-channels

LIFE+ project "Mostviertel-Wachau" (2009-2014) / Revitalization of side-channels	
River Basin	Danube River Basin
River	Danube
Country	Austria

Main driver	Flood protection
Interrelation with	Navigation (water depth during low flow), Ecology, Infrastructure (e.g. roads, electricity cables close to side-channel), Hydropower/water abstraction (less discharge in the main stream)
Application	Free-flowing section, reconnection of side-channels, creation of a biotope, redesign of a tributary mouth ("Pielach")
Aim and Background	The reconnection of side-channels primarily leads to improved ecological conditions in these river systems. This measure creates new aquatic habitats and refugial areas, where organisms are protected against wave influences. The shallow gravel banks, where water has a high velocity, serve many fish species as spawning areas; the bays with a steadier flow is primarily used by juvenile fish. The deep areas and potholes of the river are important wintering areas. Altogether, every stage in the lifetime of fish is considered.
Objectives and Goals	- Improvement of ecological conditions - Permanent connection of side-channels at low flowing conditions - Permanent refugial areas, protection against wave influence - Increasing flood retention, lower water level in main channel at high flow - Sediment input
Proposed measures	Downstream of Melk the side-channel system "Schallemmersdorf/Grimsing" with a total length of 4 km was created as well as a side-channel at "Schönbühel" with a length of 1.5 km. Upstream of "Dürnstein" the biotope "Frauengärten" was established. These backwaters are now connected year-round to the main river and provide important and wave protected habitats for the fish species of the Danube. Additionally, the "Pielach" mouth is redesigned and a new conservation area is created. Due to the permanent connection to the main channel, the water level, flow velocity, shear stress and transport capacity are increased. Morphodynamical processes are enhanced in the side-channel system. By tendency, these effects are causing a higher sediment inflow from the side-channels into the main channel. Furthermore, flood retention is increased, resulting in lower water levels in the main channel at high flows. Benefits for ecology and flood protection.

Assessment	- Integrative planning process, win-win case (Improvement for ecology and flood protection), sustainable measures, stakeholder engagement and involvement - Assessment after implementation: Habitat monitoring (fish)
Pictures/photos	 Nebenarm bei Schallemmersdorf, Foto: © Haslinger  www.life-mostviertel-wachau.at  https://www.life-mostviertel-wachau.at/pages/Schallemmersdorf.htm
Reference	https://www.life-mostviertel-wachau.at/ https://info.bmlrt.gv.at/themen/wasser/wasser-eu-international/eu-foerderprogramme/life-natur/life-projekte_abgeschl/mostviertel.html https://www.viadonau.org/unternehmen/projektdatenbank/aktiv/auenwildnis/renaturierungsprojekte-in-der-wachau

2.1.6 F6 - LIFE+ project “Auenwildnis Wachau” (2015-2020) / Revitalization of side-channels

LIFE+ project "Auenwildnis Wachau" (2015-2020) / Revitalization of side-channels	
River Basin	Danube River Basin
River	Danube
Country	Austria

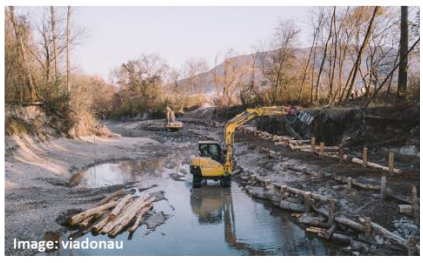
Main driver	Flood protection
Interrelation with	Navigation (water depth during low flow), ecology, infrastructure (e.g. roads, electricity cables close to side-channel), hydropower/water abstraction (less discharge in the main stream)
Application	Free-flowing section, revitalization of existing backwaters and reconnection of a side-channel
Aim and Background	The project follows two former LIFE projects in the "Wachau" region and builds on their findings. This projects primarily aims at improving the ecological conditions in the floodplains by conducting species protection measures. These measures create new aquatic habitats and refugial areas, where organisms are protected against wave influences.
Objectives and Goals	- Improvement of ecological conditions - Permanent connection of side-channels at low flowing conditions - Permanent refugial areas, protection against wave influence - Increasing flood retention, lower water level in main channel at high flow - Sediment input
Proposed measures	The revitalization of exiting backwaters and the creation of a new side-channel is planned, as are species conservation measures (amphibians, black poplar and sea eagle) and the generation of approximately 50 ha of nature conservation area with new and improved floodplain forests (rkm 2012.5 – 2010.0). Due to the permanent connection to the main channel, the water level, flow velocity, shear stress and transport capacity are increased. Morphodynamical processes are enhanced in the side-channel system. Besides, the new created side-channel (near "Schoppestatt") has positive effects on the main channel, too. By tendency, the reconnected side-channel is causing a higher sediment inflow into the main channel. Furthermore, flood retention is increased, resulting in lower water levels in the main channel at high flows. Benefits for ecology and flood protection.
Assessment	- Integrative planning process, win-win case (Improvement for ecology and flood protection), sustainable measures, stakeholder engagement and involvement - Assessment after implementation: Habitat monitoring (Fish)

Pictures/photos	
Reference	https://www.weltkulturerbe-wachau.at/naturschutz/life-projekte/life-auenwildnis-wachau https://www.viadonau.org/unternehmen/projektdatenbank/aktiv/auenwildnis/renaturierungsprojekte-in-der-wachau

2.1.7 F7 - Pilot project Bad Deutsch-Altenburg / Reconnection of a side-channel ("Johler Arm")

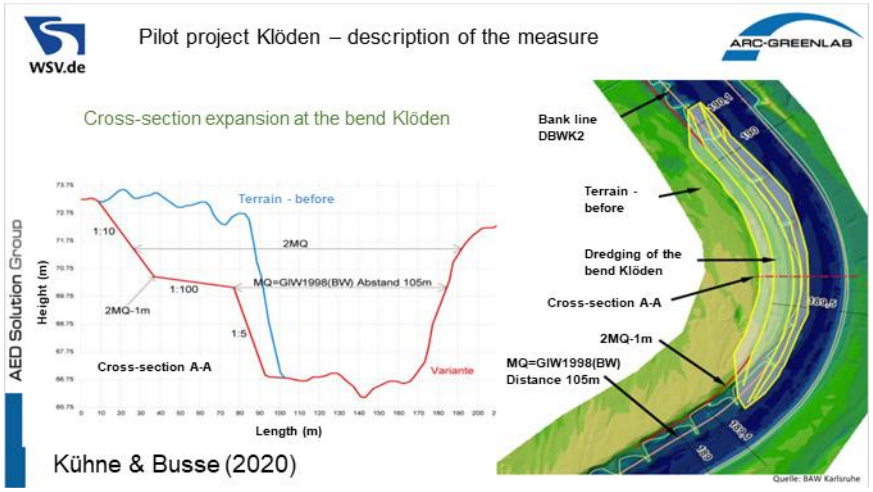
Pilot project Bad Deutsch-Altenburg / Reconnection of a side-channel ("Johler Arm")	
River Basin	Danube River Basin
River	Danube
Country	Austria
Main driver	Flood protection
Interrelation with	Navigation (water depth during low flow), ecology, infrastructure (e.g. roads, electricity cables close to side-channel), hydropower/water abstraction (less discharge in the main stream)
Application	Free-flowing section, reconnection of a side-channel
Aim and Background	The realization of the Pilot Project Bad Deutsch-Altenburg (rkm 1885.6 – 1884.3) enabled the stabilization of the riverbed in the test section. Through the reconnection of the Johler side-channel, the first side-channel in the national park where water flows through all year round has been re-established. Restoration of riverbanks has created natural shore areas. These newly created habitats were immediately embraced by the animal world of the Danube floodplains. Scientific support was responsible for the evaluation of the pilot project and the knowledge gained from it

	is an essential basis for the design of the "Catalogue of Measures".
Objectives and Goals	- Emphasizing flood retention, lowered water level at higher discharge - Sediment input - Reduced shear stress in main channel - Permanent connection of the side-channel system (at low flow) - Improvement of the ecological conditions (esp. at the river banks and side-channels) - Sustainable sediment budget in the side-channel system - Permanent refugial areas, protection against wave influence
Proposed measures	By discharging water from the Danube, the stress inflicted on the river bed in the main channel is reduced and the tendency of bed erosion decreases. The water level at high flow is also positively influenced. At larger discharges, the connected side-channels lead to lower flow velocities and water level in the main channel. In the side-channel systems morphological processes are increasing, leading to a higher habitat diversity. Due to higher shear stresses, the transport capacity is increased, resulting in sediment influx from the side-channel into the main channel. Benefits ecology and to a lesser degree the sediment regime. First side-channel in the national park "Donau-Auen", which is permanently (also during low flow conditions) connected with the main stream. Due to extended lateral erosion in the instream section a nearby small road was in danger of being eroded in the 4th year after the reconnection, therefore this part was reinforced with ecological engineering measures made of tree trunks over a length of approx. 250m.
Assessment	- Assessment before implementation: Pre-monitoring (morphology, flow velocity, discharge, suspended sediments, substrate, biota) - Assessment after implementation: Post-monitoring (morphology, flow velocity, discharge, suspended sediments, substrate, biota (esp. Fish))

Pictures/photos	     Remove fine sediments to open the side branch  Ecological Engineering to prevent lateral erosion 
Reference	http://www.viadonau.org/en/company/project-database/top-aktuell/integrated-river-engineering-project-catalogue-of-measures/

2.1.8 F8 – Floodplain excavation - Pilot project Klöden

Floodplain excavation - Pilot project Klöden	
River Basin	Elbe River Basin
River	Elbe
Country	Germany
Main driver	Flood protection
Interrelation with	Ecology (connectivity of river and floodplain)
Application	Floodplain
Aim and Background	In the area of the upper Middle Elbe, the section from El-Km 121 to 290 is characterized by high erosion of the riverbed. Since 1996, bedload feeding is performed in this eroding section. Thus, the aims here were to: - Identify causes of erosion - Establish a bed stabilization concept - Test the applicability in a pilot section - Realize and perform monitoring in the pilot section The 15 km long reach near Klöden was selected as a first pilot measure to stop/reduce erosion. Here, a set of measures was discussed, e.g. the partial lowering of the floodplain by excavation.
Objectives and Goals	- Maintaining or restoring the defined navigation conditions - Stabilization of the mean bed level while maintaining and promoting morphological dynamics - Adjustment of the bedload transport with the result of reducing the amount for sediment feeding - Consideration of the influence of the applied measures on the ground water and the flood neutrality as well as ecological requirements - Stronger structuring and dynamization of the river course and the floodplain (allowance of structure-forming processes, interconnection of river and floodplain)
Proposed measures	Bed stabilization, dynamization of the flood flow by areal and/or linear lowering of the foreland and excavation of natural levees, including reactivation of flood channel systems.
Assessment	- Physical and 2D HN models - 1D sediment transport model - Terrain model and field measurements

	- High-resolution 3D HN model of the pilot stretch - Ecological modeling with Inform (BfG) - Monitoring
Pictures/photos	
Reference	Kühne & Busse (2022); Lege (2008); BMVI & BMUB Elbe (2017)

2.1.9 F9 - Removal of natural levees

Removal of natural levees	
River Basin	Danube River Basin
River	Danube
Country	Germany
Main driver	Flood protection
Interrelation with	Navigation, Agriculture
Application	Bedload carrying, alpine river with massive embankments
Aim and Background	In the 18th/19th century, this section of the Danube was straightened, oxbows were removed and bank reinforcements were installed. These activities enabled the surrounding land to be used for agriculture. The high morphological dynamic was lost. A small portion of typical soft wood floodplain forests was maintained near Irnsing. 60 years ago, a flood protection was built that further constrained the forested area. An oxbow of 500 m length ("Pfannenstiel") was maintained but it was only connected to the Danube during flooding events.

	As a consequence of the bank reinforcements, sediment levees have grown on the river bank during the past decades by 2 cm/a. These levees protect the floodplain from flood events and thereby further reduce the floodplain dynamics. With the goal of revitalising the floodplain forest, the responsible authority held intense stakeholder consultations with the regional nature protection authorities, the local fishing association and local residents. Instead of connecting the oxbow, which would change the character of the floodplain altogether, the decision was made to enable a near-natural development by removing the levees over a stretch of 400 m and reconstructing the floodplain troughs/ditches.
Objectives and Goals	- Removing the levees improves flood protection by enabling the water more width (during average flood events). Reconnection of the floodplain (i.e. enabling a natural hydraulic floodplain dynamic) supports the protection of the soft wood forest and the remaining native black poplar population. - Reducing riverbed erosion by decreasing the shear stress and sedimentation at the river banks - Natural morphological development and sediment input from the river banks
Proposed measures	- In 2011, during the course of 4 weeks, the river bank levees (reaching between 1-2 meters height) were removed along a 400-m stretch of the Danube. - According to the natural formations in the floodplain, the inflow and outflow areas (streams/ditches) into the floodplain were reconstructed over a length of up to 150 m.
Assessment	
Pictures/photos	  Left picture: natural levee at the Danube near Irnsing (Bavaria). Right picture: same bank after removal of the natural levee. (photos: Johann Zeller – left and Ulrich Menacher – right, WWA Landshut).
Reference	https://www.interreg-danube.eu/approved-projects/danubesediment/outputs

	DanubeSediment report „Sediment Management Measures for the Danube“, factsheet codes in annex 2: E_R_H_T_GP34 https://www.wwa-la.bayern.de/fluesse_seen/massnahmen/neustadt_kelheim/index.htm https://www.wwa-la.bayern.de/fluesse_seen/gewaesserportraits/donau/index.htm

2.2 Ecology

2.2.1 E1 - Introducing sediment downstream of weir

Introducing sediment downstream of weir	
River Basin	Danube River Basin
River	Isar
Country	Germany
Main driver	Ecology (creating new habitats downstream of weir and restoration of river sections downstream)
Interrelation with	Flood protection, hydropower
Application	Free-flowing section (river with alpine characteristics, carrying gravel; river banks have been stabilized)
Aim and Background	Prevent erosion downstream of weir. Sediment was dredged from the weir reservoir and recouped directly downstream (rkm 142.9).
Objectives and Goals	- Compensate sediment deficit in the Isar - Prevention of erosion
Proposed measures	Deposition of sediment as parallel dams along the river for 1.200 m. This measure was conducted for the following reasons: - The water depth was too low for sediment feeding - selective addition was not possible due to the required sediment masses - Flushing was not possible due to constructional operation measures.
Assessment	- After implementation: Cross sections were measured in the year 1997,1999, and 2003 showing no significant changes of the profile. - Efficiency of the measure is still high (and saves the regular input of sediment)

Pictures/photos	 © LfU Bavarian Environment Agency)  © LfU Bavarian Environment Agency)  © LfU Bavarian Environment Agency)  © LfU Bavarian Environment Agency)  © LfU Bavarian Environment Agency)  © LfU Bavarian Environment Agency)
Reference	https://www.interreg-danube.eu/approved-projects/danubesediment/outputs DanubeSediment report „Sediment Management Measures for the Danube", factsheet codes in annex 2: E_R_H_T_GP24,

2.2.2 E2 - Re-introducing of sediment downstream of dam, removal of bank protection

LIFE project "BeeSandFish" / Re-introducing of sediment downstream of dam, removal of bank protection	
River Basin	Danube River Basin
River	Danube
Country	Slovakia
Main driver	Ecology
Interrelation with	Flood Protection, Hydropower, Navigation
Application	Free-flowing section
Aim and Background	BeeSandFish project is a LIFE project with a goal to restore steep Danube River banks for bird nesting. To reach the goal, bank

	protection removal measures were proposed and possible localities were chosen based on numerical modelling results. An integrated effect for stabilisation of river bed and decrease of sediment transport capacity in the same river reach can be reached together with re-introducing of sediments downstream of Gabčíkovo dam.
Objectives and Goals	- restore longitudinal continuity of sediments - reduction of erosion downstream of the dam - stabilisation of the river bed - lateral connectivity improvement
Proposed measures	An integrated effect for stabilisation of river bed and decrease of sediment transport capacity downstream of Gabčíkovo dam (rkm 1810 – 1708) can be reached by combination of measures: re-introducing of sediments downstream of Gabčíkovo dam, bank protection removal in selected reaches and restoration of side-channels (improvement of lateral connectivity).
Assessment	- before: 1D and 2D hydrodynamic modelling incl. sediment transport model, long-term and medium-term morphological developement of evaluated Danube river section (incl. changes in longitudinal profile, erosion/sedimentation), model prognosis of Danube channel morphological development, abiotic monitoring: bathymetry, LIDAR scanning, hydrological regime, water level measurements (incl. flood 2013), measurements of flow rates and discharges, groyne surveying, river bed material sampling, grain size distribution analysis, suspended sediment sampling
Pictures/photos	See website
Reference	https://broz.sk/en/projekty/beesandfish/

2.2.3 E3 - River bank restoration Thurnhaufen / Integrated River Engineering Project - Pilot Project Phase - LIFE project

River bank restoration Thurnhaufen / Integrated River Engineering Project - Pilot Project Phase - LIFE project	
River Basin	Danube River Basin
River	Danube
Country	Austria
Main driver	Ecology

Interrelation with	Flood protection (prevent infrastructure from being damaged by lateral erosion), Navigation (water depth in the fairway, fairway width)
Application	Free-flowing section - gravel bed river
Aim and Background	This project involved the removal of all artificial elements protecting the left bank of the Danube in the reach opposite the town Hainburg. This project was the first river bank restoration measure at a river of a dimension like the Danube. Possible conflicts with flood protection, shipping, settlement areas and technical infrastructure were taken into account.
Objectives and Goals	1. Flood protection (increase of discharge cross sections) 2. Increase of sediment input 3. Reduction of river bed incision by reducing shear stress 4. Natural morphological development of bank zones (morphodynamics) 5. Sustainable improvement of the ecological conditions (particularly at the banks) 6. Improvement of the landscape appearance
Proposed measures	Removal of the bank protection: In the entire downstream section of the project area, the complete bank protection was removed along a length of around 2.8 km. In order not to change the course of the river, the bank protection at the height of the regulated low water level remained in the upstream part of the project area.
Assessment	Premonitoring (morphology, water level) Monitoring (side erosion processes, morphology, water level) Postmonitoring (side erosion process, morphology, water levels, flow velocity)
Pictures/photos	 Pilot Project Thurnhaufen – bank armouring before construction work. Pilot Project Thurnhaufen – renaturated river bank after the construction work. The project was awarded the prize for Best Life Nature Project 2007-2008. ICPDR (2010)

Reference	https://www.viadonau.org/en/company/project-database/top-aktuell/integrated-river-engineering-project-catalogue-of-measures/

2.2.4 E4 - Removal of bank protection

Removal of bank protection	
River Basin	Elbe River Basin
River	Elbe
Country	Germany
Main driver	Ecology
Interrelation with	Navigation
Application	River banks, free-flowing section
Aim and Background	Ecological optimization of hydraulic structures: - Creation of dynamic, unsealed bank areas by allowing erosion and accretion processes, such as the formation of steep banks. These measures are an important contribution to achieving the good ecological state and a dynamic development of the river. Rivers can again form habitats such as pools, moving inner and outer bends as well as sand or gravel bars.
Objectives and Goals	Improvement of the river and bank structure: - Initiation, improvement and restoration of morphodynamic processes in the bank and submerged area, especially in groyne fields - Restoration and improvement of protected biotopes and habitats of particularly protected animal and plant species typical for waterbodies and floodplains - Increase of the structural diversity - Habitat improvement for sand martin and kingfisher by creating steep banks
Proposed measures	- Unsealing of bank areas that are no longer required - Removal of bank protection in groyne fields - Removal of revetment sections or reduction of the revetment height according to requirements.
Assessment	

Pictures/photos	 BMVI & BMUB Elbe (2017)
Reference	BMVI & BMUB Elbe (2017)

2.2.5 E5 - Groyne notch

Groyne notch	
River Basin	Elbe River Basin
River	Elbe
Country	Germany
Main driver	Ecology
Interrelation with	Navigation
Application	Main channel
Aim and Background	In the early 1990s, the Elbe River (between river-km 440 and 445) had a few groynes that were almost completely destroyed and many groynes that showed massive damage in the form of breaches. In the case of the almost completely destroyed groynes, reparation was almost equivalent to a new construction. Thus, redesigning the groyne geometry in such a way that a more favourable structure of the banks and groyne fields for site-typical plants and animals can develop was considered. In the case of groynes with breaches, diverse flow patterns were evident in the groyne fields, so that opportunities to increase structural diversity were seen here.
Objectives and Goals	The following requirements were defined: - Preventing or limiting sedimentation in groyne fields, - Increasing heterogeneity and dynamics (high variability of flow velocity and water depth), - Natural increase in the water exchange zone due to localized sedimentation or an extension of the shoreline, - Hydraulic efficiency related to bank protection and discharge in the middle of the river: it must not be significantly worse than that of regular groynes.

Proposed measures	Adaptation and modification of groynes by installing notches in the groyne crest or in the area of the bank connection
Assessment	Pre-Assessment: numerical and hydraulic modelling Post-monitoring: Biological monitoring
Pictures/photos	 Anlauf & Hentschel (2007)  BMVI & BMUB Elbe (2017)
Reference	Anlauf & Hentschel (2007), Kleinwächter et al. (2017), BMVI & BMUB Elbe (2017)

2.2.6 E6 - Change of groyne orientation

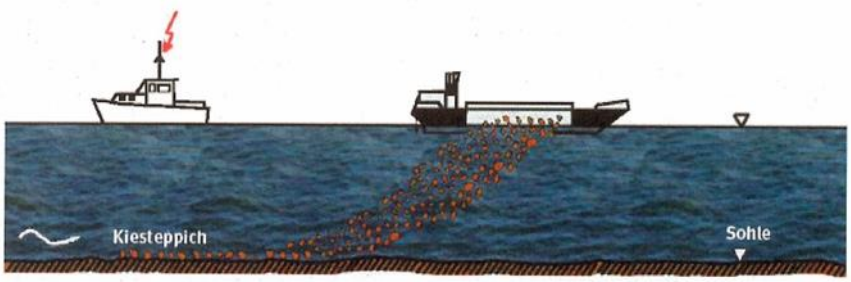
Change of groyne orientation	
River Basin	Elbe River Basin
River	Elbe
Country	Germany
Main driver	Ecology
Interrelation with	Navigation
Application	Free-flowing sections (priority given to heavily destroyed groyne fields)
Aim and Background	In the early 1990s, the Elbe River (between river-km 440 and 445) had a few groynes that were almost completely destroyed and many groynes that showed massive damage in the form of breaches. In the case of the almost completely destroyed groynes, reparation was almost equivalent to a new construction. Thus, redesigning the groyne geometry in such a way that a more favourable structure of the banks and groyne fields for site-typical plants and animals can develop was considered.
Objectives and Goals	The following requirements were defined: - Preventing or limiting sedimentation in groyne fields,

	- Increasing heterogeneity and dynamics (high variability of flow velocity and water depth), - Natural increase in the water exchange zone due to localized sedimentation or an extension of the shoreline, Hydraulic efficiency related to bank protection and discharge in the middle of the river: it must not be significantly worse than that of regular groynes.
Proposed measures	Change of building orientation: from previously aligned against the direction of flow (inclinant) to then partly aligned in the direction of flow (declinant)
Assessment	Pre-Assessment: numerical and hydraulic modelling Post-monitoring: Biological monitoring
Pictures/photos	 Anlauf & Hentschel (2007)  Anlauf & Hentschel (2007)
Reference	Anlauf & Hentschel (2007), Kleinwächter et al. (2017)

2.3 Navigation

2.3.1 N1 - Bedload management at the free-flowing section of the Rhine River

Bedload management at the free-flowing section of the Rhine River	
River Basin	Rhine River Basin
River	Rhine
Country	Germany / France
Main driver	Navigation
Interrelation with	Flood protection, hydropower
Application	Free-flowing section (rkm 334.0 - rkm 865.5)
Aim and Background	The Rhine River has been greatly altered by human use over time. Besides the diking of the floodplains, especially the regulations of the river course, the low and medium water regulation of the riverbed as well as the protection of the banks and finally the damming have seriously influenced the hydrological and morphological conditions. The prevailing bedload deficit and the heterogeneous bedload distribution lead to a constantly progressing riverbed deepening over long stretches, while other areas remain stable or are in the process of uplift. Damage to the ecosystem of the floodplain, restriction of the unloading depth for navigation and disadvantages for water management and rural culture are the consequences.
Objectives and Goals	In order to avoid the above-mentioned disadvantages, a strategy was developed to stabilize the bed by combining conventional measures with bedload management measures. The latter attempts to compensate for the deficits and surpluses in the bedload balance of the river by targeted feeding and removal of bedload. This dynamic stabilization of the riverbed is supported by local control and bed stabilization measures.
Proposed measures	- Gravel feeding: amount and grain size is selected based on transport capacity and the grain size of the natural bedload, - Optimisation of groyne elevation, - Dredging and feeding, - Bedload trap: width 160 m; depth: 1,5m - Coarse gravel feeding, - Bed stabilization measures

Assessment	Measurements of hydrological, hydraulic, sediment and morphological parameters to control the development of the river bed and the water level. Every second year a report summarizes the monitoring results.
Pictures/photos	 DWA-M 525 (2012).
Reference	DWA-M 525 (2012).

2.3.2 N2 - Sediment management in the Dutch Rhine arms

Sediment management in the Dutch Rhine arms	
River Basin	Rhine River Basin
River	Rhine
Country	Netherlands
Main driver	Navigation
Interrelation with	Coastal protection, ecology
Application	Free-flowing section
Aim and Background	Due to the regulation measures along the Lower Rhine, insufficient sediment supply from the Upper Rhine, damming of the tributaries and the interception of bedload in the area of the mountains between Duisburg and Wesel, there is a bedload deficit of 250,000 m³ per year between rkm 800 and 860. As a result of this and also because of the reduced water levels in the Rhine arms, water levels lowered in the Lower Rhine in the 20th century and the river bed deepened. Bed erosion reduced the stability of the banks and structures, and the cover of cables and pipelines in the river was reduced. Because of decreasing water levels, the performance of intake and outlet structures decreases. Groundwater levels decrease and the unloading depth for ships in river sections with stable beds becomes lower. Continuation of

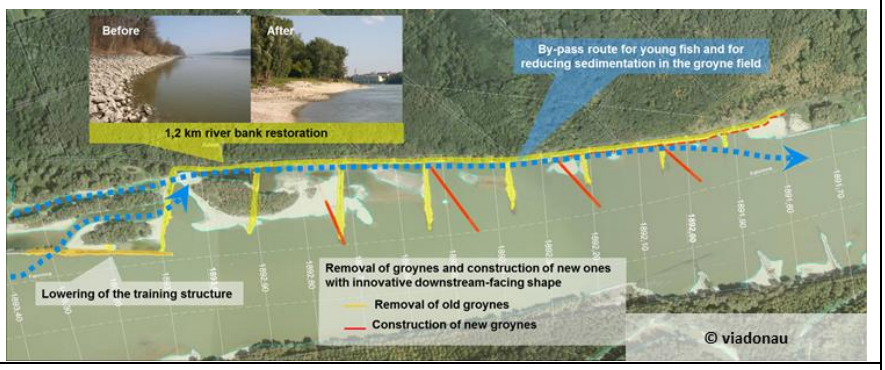
	this process will make future use of the river more difficult and will also affect the river ecology.
Objectives and Goals	The sustainable and economic management strategy of the Dutch arms of the Rhine essentially means: - the early recognition of the effects of climate change on high and low discharges and - the protection of river-related infrastructure, navigation and ecology by stabilizing the elevation of the river bed and the water level. The detailed objectives are: - Increased flow capacity to handle more severe floods. - Stabilization of the level of the river bed in sedimentation and erosion stretches - Satisfaction of freshwater demands - Maintaining navigable depths during climate change. To achieve each of these goals, a combination of river engineering measures and sediment management appears to be appropriate.
Proposed measures	Sediment Management: - Lowering of the low-water bed in the lower reaches of the feeders. - Sediment addition in erosion reaches - Optimization of dredging and dumping strategies - Restriction of sediment removal Structures/river regulation: - Lowering of groynes - Increasing the discharge capacity of the floodplains - Detour of freshwater at river forks - Operation of weirs - Constriction of the low-water bed by guiding walls - Installation of partially stabilized layers in narrow outer bends
Assessment	Monitoring of water level and flow velocities and the behaviour of tracer material Monitoring of long-term development of water level and bed elevation and composition of bed, dredging and feeding material based on multi-beam measurements Application of numerical models considering - 2D morphological processes in river bends

	- Development of the bed elevation and bed composition during flood events and over 50 years - The influence of bedforms on the navigation depth - The influence of maintenance measures on morphodynamics
Pictures/photos	
Reference	DWA-M 525 (2012).

2.3.3 N3 - Pilot project Witzelsdorf / Alternative groyne types

Pilot project Witzelsdorf / Alternative groyne types	
River Basin	Danube River Basin
River	Danube
Country	Austria
Main driver	Navigation
Interrelation with	Flood protection (no changes in flood water levels allowed), Ecology (improvement of conditions)
Application	Free-flowing section - gravel bed river
Aim and Background	The section between river kilometres 1893.4 and 1891.7 has for a long time been one of the most heavily obstructed sections along the entire Danube. In addition to the bank protection structures that reinforce the riverbanks, there was a longitudinal structure (guiding wall) and eight groynes located along less than two kilometres of the riverbank. However, this riparian section, which is not directly exposed to the current of the river, offered the ideal conditions for riverbank restoration and the testing of innovative groynes in an optimized form and arrangement. The construction was carried out between November 2007 and May 2009. An optimization of the groynes and the guiding wall was implemented in September and October 2015 to reduce / stop the dredging, which was necessary after a shallow developed. The height of the groynes and the guiding wall was increased by 40-65 cm.
Objectives and Goals	- Reducing river bed incision (reduced erosion) - Reduction of groyne field effects (less sedimentation etc.) - Restoration of banks (side erosion due to higher shear stress along the river bank) - Increased hydromorphological dynamics at the banks

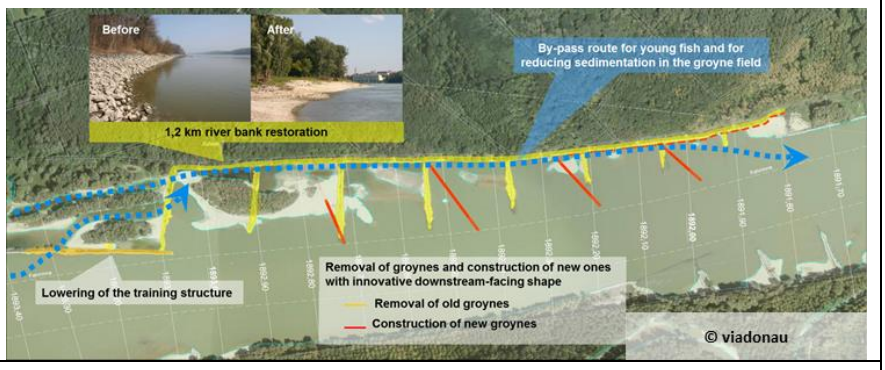
	- Improvement of ecological conditions (improvement of aquatic habitat diversity by near bank flow)
Proposed measures	The project involves an optimization of the actual groyne structures, by lowering the groyne level, increasing the distance between the groynes and changing the shape to declinant groynes. As a consequence of this measure, the narrowing effect is reduced, resulting in lower shear stresses and flow velocities in the main channel. Further, the sediment transport capacity is reduced, which leads to less erosion. The opposite effects are occurring along the river banks and in the groyne fields. Flow velocity and shear stresses are increasing and thus, leading to enhanced morphodynamics at the banks. Groyne field effects (sedimentation, etc.) are decreased which further raises the sediment transport capacity. Due to different flow velocities and water depths near the bank zone, meso and micro habitat diversity is improved. Benefit for sediment regime and river ecology. The impact of the reconstructed groynes is mainly influenced by length, spacing and height of the groyne layout. After the completion of the initial groyne reconstruction / modification, too much sedimentation occurred leading to a new shallow section for navigation, resulting in high maintenance (dredging) efforts. Therefore, in a second modification step, the groynes and the guiding wall were elevated, keeping the height of the structures still below the old level. At the present there is no dredging necessary and the bed levels are higher than prior to the initial groyne modification.
Assessment	- Reshaping of the existing groynes, reduction of the groyne height, lowering of the groyne root, removal of bank protection - Before implementation: Hydrodynamic-numerical modelling, Pre-monitoring (flow velocity, sediment transport, morphology and side erosion) - During implementation: Monitoring (flow velocity, sediment transport, morphology and side erosion) - After implementation: Post-monitoring (flow velocity, sediment transport, morphology and side erosion) - Integrative planning process - win-win case (Improvement for ecology and navigation) - sustainable measure - stakeholder engagement and involvement; monitoring / assessment before, during and after implementation

Pictures/photos	 ICPDR (2010) 
Reference	http://www.viadonau.org/en/company/project-database/top-aktuell/integrated-river-engineering-project-catalogue-of-measures/

2.3.4 N4 - Pilot project Witzelsdorf / Lowering of the guiding wall

Pilot project Witzelsdorf / Lowering of the guiding wall	
River Basin	Danube River Basin
River	Danube
Country	Austria
Main driver	Navigation
Interrelation with	Flood protection (no changes in flood water levels allowed)
Application	Free-flowing section - gravel bed river
Aim and Background	The section between river kilometres 1893.4 and 1891.7 has for a long time been one of the most heavily obstructed sections along the entire Danube. In addition to the bank protection structures that reinforce the riverbanks, there was a longitudinal structure

	(guiding wall) and eight groynes located along less than two kilometres of the riverbank. However, this riparian section, which is not directly exposed to the current of the river, offered the ideal conditions for the restoration of the guiding wall. The measures involved the lowering of the longitudinal structure at a level of 0.5 m above the low navigation and regulation level (LNRL). The construction was carried out between November 2007 and May 2009.
Objectives and Goals	- Reducing river bed incision (reduced erosion)
Proposed measures	The project involved an optimization of the existing longitudinal structure, by lowering the height. As a consequence of this measure, the narrowing effect is reduced, resulting in lower shear stresses and flow velocities in the main channel. Further, the sediment transport capacity is reduced, which leads to less erosion processes. Benefit for sediment regime. The impact is mainly influenced by the height, length and the position with respect to the main channel. After the completion of the initial reconstruction / modification, too much sedimentation occurred leading to a new shallow section for navigation, resulting in high maintenance (dredging) efforts. Therefor in a second modification step the guiding wall was elevated, keeping the height of the structures still below the old level. At the present there is no dredging necessary and the bed levels are higher than prior to the initial groyne modification.
Assessment	- Before implementation: Hydrodynamic-numerical modelling, Pre-monitoring (flow velocity, sediment transport, morphology and side erosion) - During implementation: Monitoring (flow velocity, sediment transport, morphology and side erosion) - After implementation: Post-monitoring (flow velocity, sediment transport, morphology and side erosion) - Integrative planning process - win-win case (Improvement for ecology and navigation) - sustainable measure - stakeholder engagement and involvement

Pictures/photos	
Reference	http://www.viadonau.org/en/company/project-database/top-aktuell/integrated-river-engineering-project-catalogue-of-measures/

2.3.5 N5 - Temporary gravel islands

Temporary gravel islands	
River Basin	Elbe River Basin
River	Elbe
Country	Germany
Main driver	Navigation
Interrelation with	Flood protection, ecology
Application	Free-flowing section
Aim and Background	Implementation of hydraulic structures to improve the fairway requirements and hydraulic conditions by equalizing the flow and transport behaviour. Initiation and maintenance of structure-building processes. Restoration and improvement of protected biotopes and habitats of particularly protected animal and plant species; resting and nesting areas and breeding habitats are created by the island.
Objectives and Goals	- Optimization of low water regulation - Improvement of the water and bank structure - Improvement of the river morphology and therefore habitats
Proposed measures	- Installation of temporary gravel islands
Assessment	

Pictures/photos	
Reference	BMVI & BMUB Elbe (2017)

2.3.6 N6 – Construction of guiding walls and replacement of existing structures

Construction of guiding walls and replacement of existing structures	
River Basin	Elbe River Basin
River	Elbe
Country	Germany
Main driver	Navigation
Interrelation with	Flood protection, ecology
Application	Free-flowing section
Aim and Background	With this measure, the protection of valuable bank areas is aimed. The structure is intended to create, maintain and develop areas of shallow water. Initiation, improvement and restoration of morphological processes in the bank area and waterbody are likely. Restoration and improvement of protected biotopes and habitats of particularly protected animal and plant species, that are typical for the floodplain and waterbody is aimed.
Objectives and Goals	- Optimization of low water regulation - More even bedload transport - Prevention of siltation - Reduction of sedimentation in the fairway
Proposed measures	Dismantling of existing structures / parts of structures (groynes, revetments) and construction of parallel structures according to navigation requirements and ecological aspects to optimize the traffic regulation, to balance sediment transport and to avoid structural interventions in ecologically valuable bank areas.
Assessment	

Pictures/photos	 BMVI & BMUB Elbe (2017)
Reference	BMVI & BMUB Elbe (2017)

2.3.7 N7 - Groyne extension

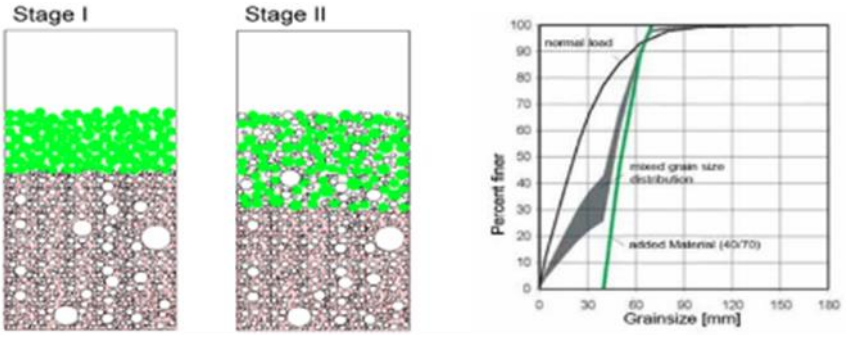
Groyne extension	
River Basin	Elbe River Basin
River	Elbe
Country	Germany
Main driver	Navigation
Interrelation with	Ecology
Application	Free-flowing section
Aim and Background	Local depositions in the fairway shall be reduced by improving the hydraulic conditions induced by groyne extensions improving the flow and transport behaviour. This measure can reinforce the uncoupling of the floodplain and harbours and bears the additional risk of stronger bed erosion. Furthermore, there are possible conflicts, as homogenizing the transport behaviour can reduce the depth variance and decrease morphological heterogeneity.
Objectives and Goals	Optimization of low water regulation to minimize sedimentation
Proposed measures	- Extension of the groynes to adjust the width of the fairway - Eventually, combination of the measure with the installation of a notch in the groyne for disconnection from the bank, allowing flow near the bank and promote island formation.
Assessment	

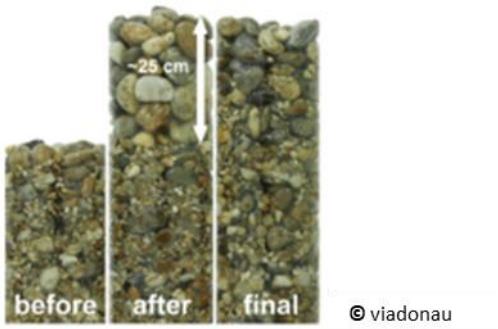
Pictures/photos	 BMVI & BMUB Elbe (2017)
Reference	BMVI & BMUB Elbe (2017)

2.4 Hydropower

2.4.1 H1 - Pilot project Bad Deutsch-Altenburg / Granulometric bed improvement

Pilot project Bad Deutsch-Altenburg / Granulometric bed improvement	
River Basin	Danube River Basin
River	Danube
Country	Austria
Main driver	Hydropower
Interrelation with	Ecology and groundwater (clogging, reduced habitat availability if stones are too big and are never transported), Navigation (water depth in the fairway, impact on ship propellers - size of the gravel and distance between ship propeller and river bed), Flood protection (dykes - flood water level should not be increased when adding the material)
Application	Free-flowing section - gravel bed river
Aim and Background	The Pilot Project Bad Deutsch-Altenburg (PP BDA) was the sixth pilot project implemented in the national park "Donau-Auen". The objective was to test river engineering measures which are to be implemented along the entire stretch of the Danube between the Freudenau power plant and the Austrian national border. All types of measures were implemented on-site for the first time in the three-kilometre-long project section (river kilometres 1887.5 - 1884.5) including the granulometric improvement to stabilize the riverbed. The behaviour of the added material was monitored during and after the implementation.
Objectives and Goals	- Sustainable river bed stabilization (stop river bed erosion)

	- Reduce maintenance (less ford dredging) - Increase of low water level - Dynamic equilibrium
Proposed measures	120.000 m^3 of coarse gravel (40/70, 40/90 and 32/120 mm) were added in the navigation channel of the 2.5 km long river reach. By adding coarser material within the natural grain size distribution, the mean grain diameter is increased. Furthermore, the increase of critical shear stresses results in a lower sediment transport capacity. This measure leads to the sustainable stabilization of the river bed (stop of river bed erosion). In addition, maintenance works, such as ford dredging are reduced. The goal was a dynamic equilibrium, regarding river morphological processes, with reduced river bed erosion. Benefits for the sediment regime.
Assessment	- Before implementation: Hydrodynamic-numerical modelling (including sediment transport), physical model tests, Abiotic monitoring: Sediment transport, grain size composition (volumetric samples, freeze cores, freeze panes), shear stress, initiation of motion via radio-tracer, underwater pictures of the river bed, connectivity to the groundwater, clogging, bathymetry; Biotic monitoring: fish and aquatic macroinvertebrates - During implementation: Abiotic: sediment transport measurements, freeze core and volumetric sampling, radio-tracer, bathymetry - After implementation: Hydrodynamic-numerical modelling (including sediment transport), Abiotic monitoring: sediment transport, grain size composition (volumetric samples, freeze cores, freeze panes), shear stress, initiation of motion via radio-tracer, underwater pictures of the river bed, connectivity to the groundwater, bathymetry; Biotic monitoring: fish and aquatic macroinvertebrates
Pictures/photos	 viadonau & IREP Planning Consortium (2009) in ICPDR (2010)

	
Reference	https://www.viadonau.org/en/company/project-database/top-aktuell/integrated-river-engineering-project-catalogue-of-measures/

2.4.2 H2 - Granulometric improvement (study)

Granulometric improvement (study)	
River Basin	Danube River Basin
River	Danube
Country	Germany
Main driver	Hydropower
Interrelation with	Navigation
Application	Free-flowing section - gravel bed river
Aim and Background	Located downstream of the hydropower plant Straubing (rkm 2308.8 – 2307.8), this free-slowing section is subject to erosion. To increase the water levels and to ensure navigation during low-flow periods, regular feeding of sediment is undertaken in this Danube stretch. To reduce the cost of feeding, a pilot study "sediment management concept for the Danube" was launched in 2009 with the goal of analysing which gravel sizes are optimal for establishing a sustainable sediment balance. The study analysed grain sizes between 4 - 63 mm to avoid negative impacts on ship propellers.
Objectives and Goals	- Sustainable river bed stabilisation (stop river bed erosion) - Reduce maintenance (less feeding) - Increase of low water level - Dynamic equilibrium

Proposed measures	- Over 1 kilometre, 2 stretches (each 500 m) were tested, which each received 5250 m³ of coarse gravel. The gravel was placed on a 70-m-wide stretch of the riverbed that lies within the fairway. The layer width should not be larger than 0.15 m (+/- 0.1 m) to avoid impacts on the ship propellers. - The 1st stretch received larger grain sizes (16/32 mm and 31.5/63 mm; 50% each) to enable the stabilisation of the riverbed. - The 2nd stretch received smaller grain sizes to imitate the near-natural grain size (15,9-20,9 mm) - Grain sizes below 4 mm are not efficient, as they are too easily eroded and grain sizes above 63 mm can cause problems for ship propellers. Due to a (low) rest dynamic in the sediment transport, the results of the first case study (larger material) can be rated as having a positive effect for ecology (habitat), which require natural dynamics of the riverbed. The costs for the field study were very high due to the use of special tracer material but using regular bedload material would be much less costly.
Assessment	- During implementation: Over three years, the two stretches were monitored via cross-section analysis, tracer-method with regular grab sampling along the cross-sections, freeze cores and freeze planes to analyse the layers of the riverbed, as well as measurements of flow velocity, sediment transport rates/velocities and riverbed stability. - Results from the first stretch showed that the added material led to a reduction in riverbed dynamics, i.e. erosion was reduced, especially in area upstream of the study site. Since the riverbed is not completely stabilised and low sediment transport still occurred, the need for further gravel feeding on this stretch is expected in the long-run. The grain size did not impact ship propellers. - In the second stretch (smaller grain size), the material was too small/light and was eroded. - The riverbed was more stable than expected and according to BAW, monitoring will continue within the next one to two years (recommended on a two-year basis). - WIN-WIN: For grain sizes tested in the first study site, the riverbed shows a long-term stability (while low sediment transport still occurs); the gravel size is small enough to not impact ship propellers.

Pictures/photos	
Reference	https://www.interreg-danube.eu/approved-projects/danubesediment/outputs DanubeSediment report „Sediment Management Measures for the Danube“, factsheet codes in annex 2: E_FF_N/H_D_GP23

2.4.3 H3 - Introducing sediment downstream of weir

Introducing sediment downstream of weir	
River Basin	Danube River Basin
River	Isar
Country	Germany
Main driver	Hydropower
Interrelation with	Ecology
Application	Free-flowing section (alpine, gravel-carrying river)
Aim and Background	The Sylvenstein dam was built for flood protection of towns and cities along the Isar (until Munich). Sediment is deposited in auxiliary dams upstream of the Sylvenstein dam. Due to strong erosion in the downstream Isar river, bedload is episodically dredged out of the auxiliary dams and fed into the Isar downstream of the dam. As of 2017, bedload will be dredged and fed yearly.
Objectives and Goals	- Stabilisation of riverbed and groundwater level - By raising the riverbed, the ecological connection to side-channels / floodplains is improved
Proposed measures	Natural development (improvement) of river structure Until 2017, 3000 m³/a were transferred; since 2017 yearly amounts of 20 000 m³ were planned. In 2018, due to drought and lack of transport capacity, no bedload was transferred. The reason was a change in the water law, enabling the transfer of bedload as a "maintenance measure for reservoirs". Previously, each transfer required approval by relevant authorities.
Assessment	- Before implementation: Cross-section surveys - During implementation: feeding locations were determined with representatives from fishery and nature protection

	- After implementation: Cross-section surveys; results from WFD surveys (ecological status)
Pictures/photos	 (© WWA Weilheim)
Reference	https://www.interreg-danube.eu/approved-projects/danubesediment/outputs DanubeSediment report „Sediment Management Measures for the Danube“, factsheet codes in annex 2: E_R_H_T_GP25

2.4.4 H4 - Removal of river embankments / widening (Acheringer Schwelle)

Removal of river embankments / widening (Acheringer Schwelle)	
River Basin	Danube River Basin
River	Isar
Country	Germany
Main driver	Hydropower
Interrelation with	Flood protection, ecology, habitat diversity (improvement of structure)
Application	bedload carrying, alpine river with massive embankments
Aim and Background	Since the 1920s, the originally meandering and multi-branched Isar has been straightened and embanked. As a consequence, the bed deepened about 5-6 metres with local bed break-downs and scours up to 7 metres. The groundwater level in the floodplain dropped drastically. Since a major hotspot occurred at the "Acheringer Schwelle", river embankments were removed, allowing the river to widen and access a natural bedload source, which reduced the deficit.

Objectives and Goals	- Stabilisation of river bed - Increasing river bed resistance - Increasing of water and groundwater level
Proposed measures	Removing of embankments (riprap) on the right side of the river (rkm 117-119 near Freising). The removed riprap were used as current-controlling elements. A very good measure to prevent river bed incision
Assessment	
Pictures/photos	 Bank erosion at Achering (© WWA Munich)
Reference	https://www.wwa-m.bayern.de/fluesse_seen/massnahmen/gek_mittlere_isar/ufer_achering_freising/index.htm

2.4.5 H5 - Feeding / gravel supply downstream of HPP Freudenau

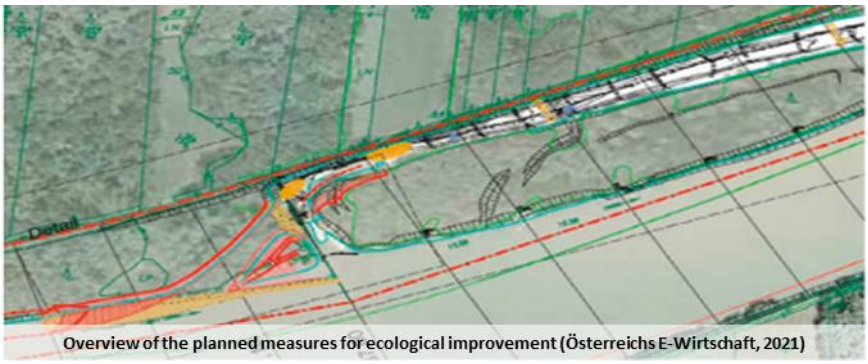
Feeding / gravel supply downstream of HPP Freudenau	
River Basin	Danube River Basin
River	Danube
Country	Austria
Main driver	Hydropower
Interrelation with	Navigation, flood protection, ecology

Application	Free-flowing section - downstream of HPP Freudenau (river-km 1921.0 - 1910.0)
Aim and Background	Due to the HPP Freudenau, the sediment continuity is interrupted. Because of the sediment deficit downstream of the HPP, deepening of the river bed can be observed. In order to maintain a stable river bed level and prevent it from further erosion processes, the hydropower plant operator VHP has to add about 235.000 m^3/a (Acheringer Schwelle) material to the Danube downstream of HPP Freudenau.
Objectives and Goals	- 1. Stabilize bed level (reduced erosion) - 2. Sediment supply / continuity
Proposed measures	- Artificial gravel supply (feeding) - As a result of this measure, a more stable river bed level is reached. Gravel is added in order to enhance this effect. The main target is to keep the mean bed level in the maintenance reach on the level of 1995 (last river bed survey before the HPP Freudenau was partially filled). Benefits for sediment regime (continuity).
Assessment	Bathymetric monitoring (before, during, after implementation)
Pictures/photos	 https://vreund.verbund.at/de-at/artikel/2012/04/23/bagger-donau-schiff
Reference	BMNT (2018)

2.4.6 H6 - “Eizendorfer Haufen” renaturation project / Reconnection of side-channel system, riverbank restoration

"Eizendorfer Haufen" renaturation project / Reconnection of side-channel system, riverbank restoration	
River Basin	Danube River Basin

River	Danube
Country	Austria
Main driver	Hydropower
Interrelation with	Navigation (water depth during low flow), infrastructure (e.g. roads, electricity cables close to the side-channel), ecology, flood protection (increased flood retention)
Application	floodplains, river bank, impounded section - gravel bed river
Aim and Background	As the operator of the Danube hydropower plants in Upper Austria, VHP has completed the "Eizendorfer Haufen" renaturation project in the backwater area in Ybbs-Persenbeug in the municipality of Saxen (Upper Austria). The "Eizendorfer Haufen", also called "Reischelau", is situated on the left river bank of the Danube (near Ardagger Markt rkm 2087.2 – 2086.2). This is an almost completely disused element, which is typical of the landscape on the left bank of the Danube and was greatly affected by the construction of a training structure at the start of the 20th Century. Due to gravel deposits, a floodplain plateau was created, which in the course of the years separated itself from the Danube. As part of a special renaturation project, this silted up side-channel has once again been reconnected to the Danube. Through specifically designed new, diverse riverbank structures, fish and bird species of the Danube should once more gain an additional habitat. The landscape elements of the original island and land surface along the Danube are typical to the landscape. It re-emerged thanks to the reconnection to the Danube and stretches out in total for 1.7km and is 200m wide. The newly created natural area will in future serve once more as a winter residence for cormorants and as a breeding ground for different species of birds. One can also find different types of floodplain, which in terms of vegetation are particularly worth protecting.
Objectives and Goals	- Sustainable improvement of ecological conditions (permanent refugial habitats for fish and fauna, protection from wave effects, ...) - Improved sediment balance - Increasing flood retention, lower water level in main channel at high flow
Proposed measures	Reconnection of a side-channel, river bank restoration: The reconnection of the side-channel primarily leads to improved ecological conditions in this river system. This measure creates new aquatic habitats and refugial areas, where organisms are

	protected against wave influences. Due to the permanent connection to the main channel, the water level, flow velocity, shear stress and transport capacity are increased. Morphodynamical processes are enhanced both in the side-channel and in the main channel, due to river bank restoration. This affects the sediment balance in the main channel by causing higher sediment input from the side-channel and the river banks. Furthermore, flood retention is increased, resulting in lower water levels in the main channel at high flows. Primarily benefits ecology and in a lesser degree sediment balance and flood protection.
Assessment	
Pictures/photos	 Overview of the planned measures for ecological improvement (Österreichs E-Wirtschaft, 2021)  Overview of the planned measures for ecological improvement (Österreichs E-Wirtschaft, 2021)
Reference	Österreichs E-Wirtschaft (2021)

3 Summary

Within this report various relevant river engineering projects were listed and described. The projects were presented towards their main drivers in 4 categories – flood protection, ecology, navigation and hydropower. Figure 1 contains a radar chart of gathered river engineering projects in the Danube River basin and beyond showing the suitability for the project reaches in AT & HU. In Output T3.2.2 (Evaluation document) these examples were compared towards their suitability for the Upper and Middle Danube (Austrian and Hungarian project reach).

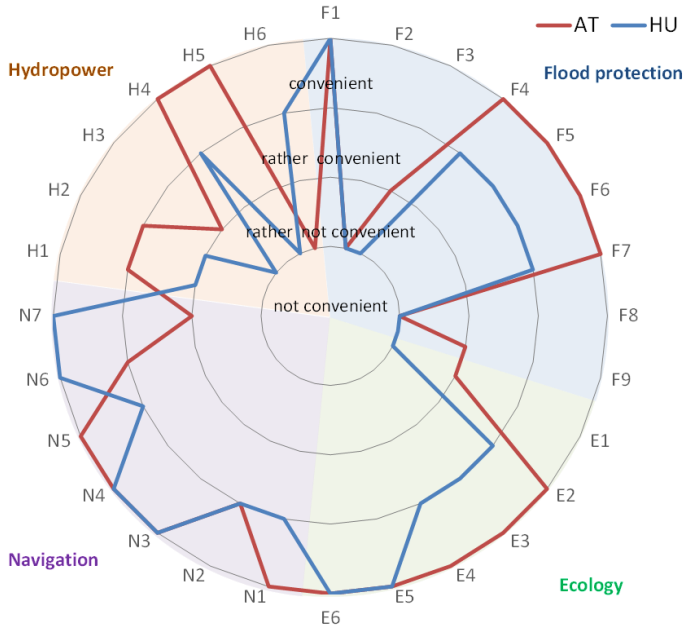


Figure 1: Radar chart of gathered river engineering projects in the Danube River basin and beyond showing the suitability for the project reaches in AT & HU

The presented sediment-related river engineering projects gathered in this report build an important basis towards a sustainable river engineering approach for the Upper and Middle Danube represented by the two Seddon°II study reaches at the Danube in Austria and Hungary. Based on the report it is aimed to improve and optimise engineering measures that can handle the multiple problems the different stakeholders face and compensate the negative impacts of human pressures along river systems.

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