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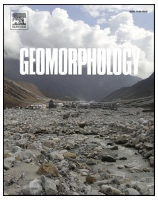

The Dutch Rhine branches in the Anthropocene – Importance of events and seizing of opportunities

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ABSTRACT

The Rhine branches in the Netherlands have been profoundly altered by human interventions in the past 2000 years. Three examples are elaborated to show that these alterations often result from specific events and the seizing of opportunities: the creation of a new Rhine bifurcation at Pannerden, the Room-for-the-River programme, and the mitigation of riverbed scour in the Rhine-Meuse estuary. This makes historical inquiry one of the keys to understanding geomorphological developments in the Anthropocene. For river restoration it holds the lesson that plans can be prepared in ordinary times and then be implemented at the right moment by seizing the opportunities offered by events.

1. Introduction

Rivers in deltas around the globe have undergone profound anthropogenic hydromorphological alterations due to modifications of the discharge hydrograph (Best, 2018), embankments (Stouthamer and Berendsen, 2000; Berendsen and Stouthamer, 2002; Hobo et al., 2014; Hobo, 2015), stabilization of bifurcations or damming of distributaries (Berendsen and Stouthamer, 2002), land-use-induced increases of sediment yield (Syvitski et al., 2009; Syvitski and Kettner, 2011; Nienhuis et al., 2020), trapping of sediment upstream (Syvitski and Kettner, 2011; Alexander et al., 2012; Best, 2018; Dunn et al., 2019), sediment mining (Brunier et al., 2014; Best, 2018), river training (Alexander et al., 2012; Havinga, 2020) and enhanced subsidence due to land drainage and extraction of groundwater, oil and gas (Syvitski et al., 2009; Bravard, 2019). The Rhine branches in the Netherlands (Fig. 1) are no exception, due to 2000 years of human interventions for military purposes, safety against flooding, protection against erosion, land reclamation, freshwater supply, navigation, and nature restoration (Appendix 1). The Romans implemented river training works and derivation canals. Dikes were constructed from the Middle Ages onwards, depriving the reclaimed land from sediment deposition and enhancing the sedimentation on floodplains within the dikes (Fig. 2). The main channel was narrowed by river training works, mainly groynes (Fig. 6), to reduce the risk of ice jams and, subsequently, to improve navigability. Sand and gravel were mined massively until implementing a partial ban on mining from the main channel only recently. The lower reaches were affected by the damming of the Zuiderzee bay and the Haringvliet estuary, as well as by the dredging of deep waterways for ocean ships through rivers around the port of Rotterdam. Sediment mining and erosion due to increased sediment transport capacity (Mosselman, 2020) caused riverbed incision that still proceeds today (Figs. 2 and 3). The general development of the Dutch Rhine branches thus complies with the global trends of change. Often, however, developments are triggered by specific events and by the seizing of opportunities offered by these events. Methods of historical inquiry are therefore relevant for a full understanding of the genesis of the earth surface. Moreover, the importance of events and the seizing of opportunities hold a lesson for river restoration too. Successful restoration calls for preparing a vision or plan for required restoration and then seizing the opportunities that often arise in a narrow time window only. This paper presents three examples of how major events and subsequent actions shaped the Rhine branches in the Netherlands. The first example has been documented widely before (Van de Ven, 1976, 1979, 2007). It regards the creation of the Pannerdens Canal as a new course for the river Rhine. The other two examples regard the Room-for-the-River programme and the formation and mitigation of scour holes in the Rhine-Meuse estuary. These have not been described before in the present form that is based on personal involvement and witnessing. The descriptions might leave room for refinements or corrections, but they do provide a more accurate picture than the rational decisions and long-term foresight generally portrayed

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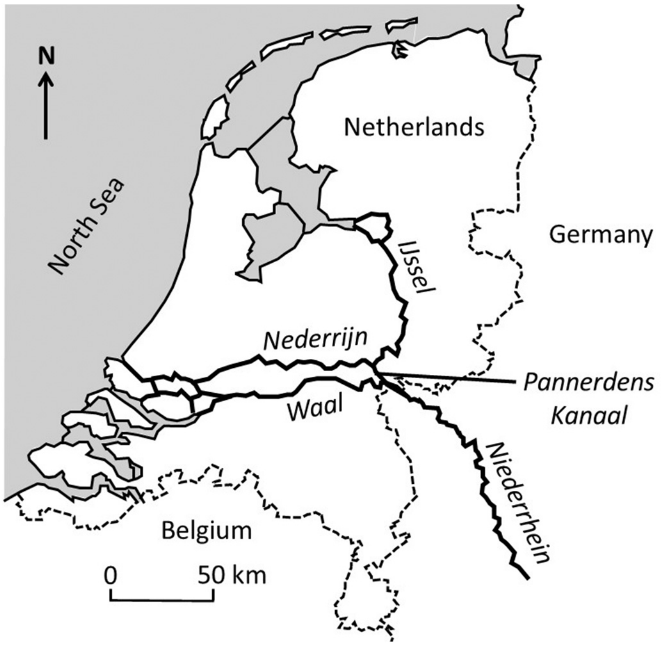

Fig. 1. Map of the Dutch Rhine branches.

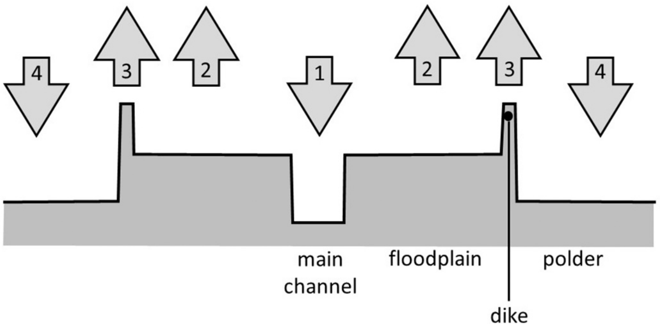

Fig. 2. Typical development of cross-sections of the Rhine branches. 1: Erosion of the main channel due to river training, sediment mining and other effects (Visser, 2000; Berkhof et al., 2018; Mosselman, 2019). 2: Accretion of floodplains (Hobo, 2015). 3: Raising of dikes in response to higher flood water levels and higher societal demands. 4: Subsidence of polders due to sediment deprivation and oxidation of peat in response to dewatering.

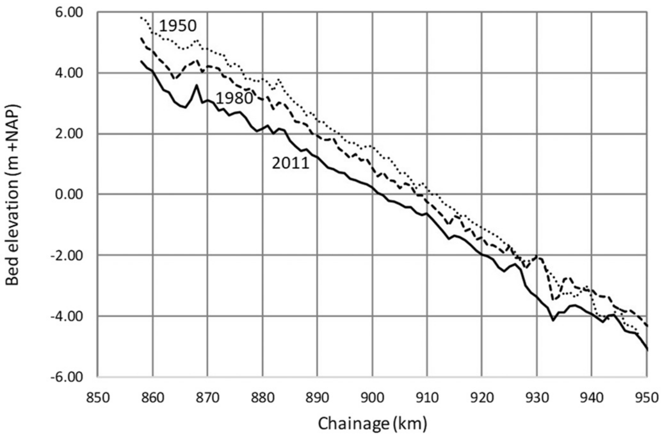

Fig. 3. Degradation of longitudinal bed profiles of the Bovenrijn and Waal branches of the river Rhine.

in brochures, presentations and documentaries on Dutch water management.

2. Stabilization of the main Rhine bifurcation

The Netherlands emerged as an independent union of autonomous provinces after signing the treaties of the Peace of Westphalia in 1648. In that time the main Rhine bifurcation was located at Schenkenschans in present-day Germany. In line with millennia of avulsions in the Rhine delta (Stouthamer and Berendsen, 2000; Berendsen and Stouthamer, 2002), this bifurcation was unstable. Discharges to the left Waal branch were increasing whereas discharges to the right Rhine branch were declining. As a result, dikes along the Waal were breached more frequently. The province of Guelders therefore proposed to dig a new river course near Pannerden, shifting the bifurcation to a more favourable location downstream (Fig. 5). Holland, the most powerful province of the union, was against this proposal as it feared that reduction of the discharges through the Waal would compromise the navigability of the waterway between the port cities of Rotterdam and Dordrecht and the Rhenian hinterland. The stalemate was broken when France invaded the union in 1672. The rivers did not pose any obstacle because the French army could simply wade through the declining Rhine immediately downstream of the bifurcation at Schenkenschans (Fig. 4). Further marching to the major cities in the west of the union was blocked by inundating lands between Muiden and Gorinchem, but the ease of crossing the rivers was nonetheless a shock. Guelders proposed the excavation of a retrenchment, not by coincidence along the alignment of the new river course proposed earlier. Holland gave in under the condition that the retrenchment would not be connected to the rivers, taking away discharge from the Waal. Guelders was happy with the agreement and with the co-funding from Holland. They reckoned that connection would become possible later once the retrenchment would be in place. The latter was completed in 1701 and, indeed, already connected to the rivers seven years later to counter the silting up of the Rhine (Nederrijn) and the IJssel. Yet instability of the new bifurcation at Pannerden and continuing siltation of the rivers to the north remained problematic throughout the 18th century. To stabilize the bifurcation in a way that served all interests, the provinces installed the first ever central government organization of the union. This became Rijkswaterstaat, the country's executive body for water management and infrastructure. It was the war with France that offered the opportunity for restoring the discharges to the Nederrijn and IJssel branches. Without that war, the river system in the Netherlands might have

Fig. 4. Invasion by French army of Louis XIV into the Netherlands by wading through the declining Rhine branch downstream of the bifurcation at Schenkenschans. Bas-relief on Porte Saint-Denis, Paris, France.

developed in a completely different way. The main bifurcation at Pannerden is now more or less stable and passes two thirds of the arriving discharge to the Waal branch and one third to the Pannerdens Canal. Its stability remains nonetheless a point of attention. Kleinhans et al. (2008) and Sloff and Mosselman (2012) therefore studied the underlying processes in detail.

3. Room for the river

The 1953 flood disaster marked a turning point in flood risk management in the Netherlands. A Delta Committee was installed to advise the government on improving safety against flooding. They based standards for the level of flood protection on an economic optimum between the investments to increase the safety against flooding and the damage avoided by these investments (Van Danzig, 1956). Furthermore, they designed the Delta Works in the Rhine-Meuse-Scheldt estuary, choosing closure dams across estuary branches rather than hundreds of kilometres of dike reinforcement along these branches, because these dams would create freshwater basins that would reduce salinity of adjacent agricultural lands. For the river branches in the deltaic plains, the standards did lead to the need of reinforcing the dikes. The population generally accepted the dike reinforcements when the memory of the flood disaster was still fresh. In the 1970s, however, this memory faded away and opposition grew against the reinforcements that degraded the historical landscape and necessitated the demolition of houses. Public acceptance became particularly problematic if reaches already completed had to be reinforced again due to new technical insights, for instance if new data altered the statistics of extreme floods (Mosselman, 2006). Meanwhile a group of ecologists had proposed the alternative Ooievaar Plan for improving the safety against flooding (De Bruin et al., 1986). Rather than raising dikes, they proposed to lower flood water levels by giving more space to the river, i.e. by increasing conveyance capacity. Despite winning a landscape architecture prize, their plan did not change the government policy for flood risk management. Even when a second-opinion review of the policy indicated that giving more space could be a feasible alternative (Wijbenga et al., 1993, 1994), changing the existing policy was considered too drastic for realization. This all changed after the 12,000 m^3/s flood on the Rhine in 1995. As part of the dike reinforcement works had not been completed yet, 250,000 people were evacuated from the area behind the corresponding dike. In the end no dikes were overtopped or breached, but the event had a huge impact on public opinion through the extensive media attention to the evacuation and the rows of people on beds in sports facilities. This created a general sense of urgency that finally opened the door for a drastic change of policy. It resulted in the 2.3 billion Room-for-the-River programme (Klijn et al., 2018a) in which floodplains were lowered, obstacles were removed, groynes were lowered or replaced by longitudinal training walls, side channels and floodways were excavated, and dikes were set back (Figs. 6 and 7). These interventions aimed not only at the reduction of flood water levels but also at improvement of "spatial quality", an amalgam of nature, landscape and cultural heritage (Klijn et al., 2013).

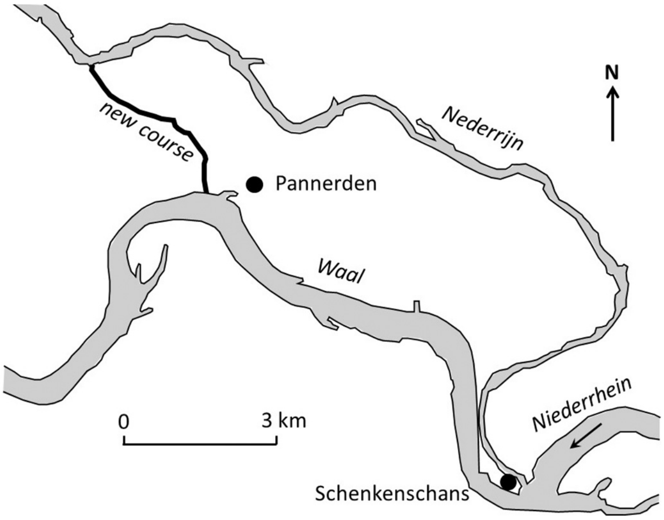

Fig. 5. Proposal of new river course in 17th century, later developed into retrenchment and Pannerdens Canal.

During implementation of the works of the programme from 2000 to 2015, the 2005 Katrina flood disaster occurred in New Orleans, and Diamond's (2005) book "Collapse" and Gore's (2006) documentary film "An inconvenient truth" appeared. These events gave another impulse to the policy of flood risk management. Flood risk professionals initially laughed about Diamond's and Gore's doom scenarios that the Netherlands were bound to disappear under the waves, as flood defences were known to offer protection for centuries to come, even considering accelerated sea level rise due to global warming. Two considerations, however, indicated that the Netherlands might be not safe enough; even more so in the face of climate change. First, experiences from Katrina showed that the damage of flooding could be much higher than accounted for in the econometric calculations for optimum safety against flooding. Destruction of chemical installations had caused pollution and permanent migration of customers out of New Orleans had affected the local economy. Second, flooding of the Netherlands was seen as a larger risk than realized before, because it would damage the reputation of a country that exports expertise on water management and hydraulic engineering. These considerations resulted in the installation of a Second Delta Committee that reviewed the consequences of future climate change for the water system in the Netherlands. For the rivers it advised to increase the space even more than already underway in the Room-for-the-River programme. However, new standards for flooding risk in 2017 turned this advice upside down. The new standards are no longer based on the statistics of extreme flood water levels but on the probabilities of flood defence failure as a result of a whole array of factors. As failure by piping, one of the most important factors, is insensitive to moderate variations in water level, reducing flood water levels by giving more space to the river is less effective than reinforcing the dike. Although room for the river has clear benefits for ecological restoration and the robustness of flood protection (Klijn et al., 2018b), it probably would not have been embraced if the new standards had already existed in 1995. Massive restoration of the river in this way thus has had only a narrow window of opportunity.

4. Riverbed scour in Rhine-Meuse estuary

Around the year 2010, mysterious bank erosion along tidal rivers in the Rhine-Meuse estuary posed increasingly problems to the regional river management office of Rijkswaterstaat. The engineers of the office were aware that flow velocities had increased in the rivers Oude Maas, Spui and Dordtse Kil after closure of the Haringvliet estuary in 1971, but these velocities could not explain the 25 m deep scour holes that developed along the banks. The engineers tried to attract attention and funds from the ministry to analyze and solve the problems, but this was in vain because funds of the central government had been earmarked for climate change and the erosion could not be ascribed to that. Some relief was expected from plans to slightly reopen the Haringvliet dam during flood tide with the purposes of restoring the ecosystem of the former estuary and improving the conditions for salmon migration in the Rhine. These plans were blocked, however, after electing a state secretary who had promised farmers in the area to keep out salinity. River engineer and fluvial geomorphologist Kees Sloff analyzed data from the rivers and discovered the mechanism behind the accelerated appearance and subsequent horizontal expansion of deep scour holes. The riverbeds in the area are composed of layers of erosion-resistant clay on top of layers of sand. High flow velocities erode the clay layers at most slowly. As

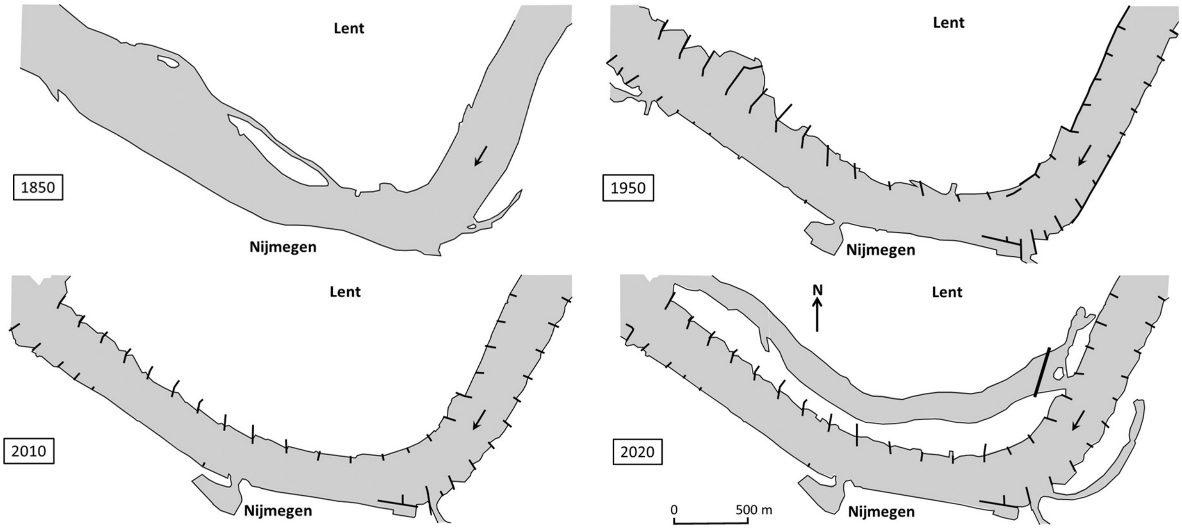

Fig. 6. Changes in the Waal River at Nijmegen. Untrained river in 1850. River trained with groynes in 1950. Accreted and more exposed groyne fields in 2010. Floodway of the Room-for-the-River programme in 2020.

Fig. 7. Excavation of floodway at Nijmegen (July 2015).

soon as such a layer has been eroded away, however, the sand is exposed and scoured to large depths (Sloff et al., 2013) (Fig. 8). The slow erosion of clay layers seemed to have been accelerated by the increase of flow velocities after construction of the Haringvliet dam. This insight helped in finally attracting broader attention to the scour (De Persdienst, 2013). For deeper investigation, Kees Sloff set up a multidisciplinary team of river engineering, geology and soil mechanics. He brought Rijkswaterstaat, responsible for river management, and the local waterboard, responsible for dikes, together to develop joint solutions. Subsequent analysis of historical data by Huismans et al. (2021) revealed a wider set of causes. Some scour holes had already formed naturally in this way before 1971, and other scour holes had formed after excessive dredging to make part of the rivers accessible to ocean ships. Meanwhile the accelerated appearance and growth of the scour holes posed threats such as breaching of the dike at Hoogvliet (Van Heel, 2013), riverbank erosion along apartments in Nieuw-Beijerland (Sloff, 2015) and collapse of the bridge at Spijkenisse (Rubio, 2018). These local threats necessitated immediate emergency interventions, but the understanding of the overall processes allows more structural mitigation. Without this timely understanding, the rivers might have become even more difficult to manage. Similar heterogeneous beds with consolidated paleo-sediments and deep scour in sand have been found in other deltas around the world such as the deltas of the Mississippi (Nittrauer et al., 2011), the Petit Rhône (Ginger-Burgeap et al., 2020) and the Mekong (personal communication Kees Sloff).

5. Conclusions

Three examples have been presented of anthropogenic changes in the Dutch Rhine branches that show the role of events in explaining those changes and the importance of seizing opportunities for restoring rivers. The main Rhine bifurcation could be stabilized thanks to a preceding plan and the shock of an invasion by the French army. The Room-for-the-River programme could be realized thanks to preceding feasibility studies and the impact of a preventive evacuation of 250,000 people during the flood of 1995. A structural approach to mitigating riverbed scour in the Rhine-Meuse estuary has become possible thanks to skillful analysis, followed by media attention and setting up collaboration

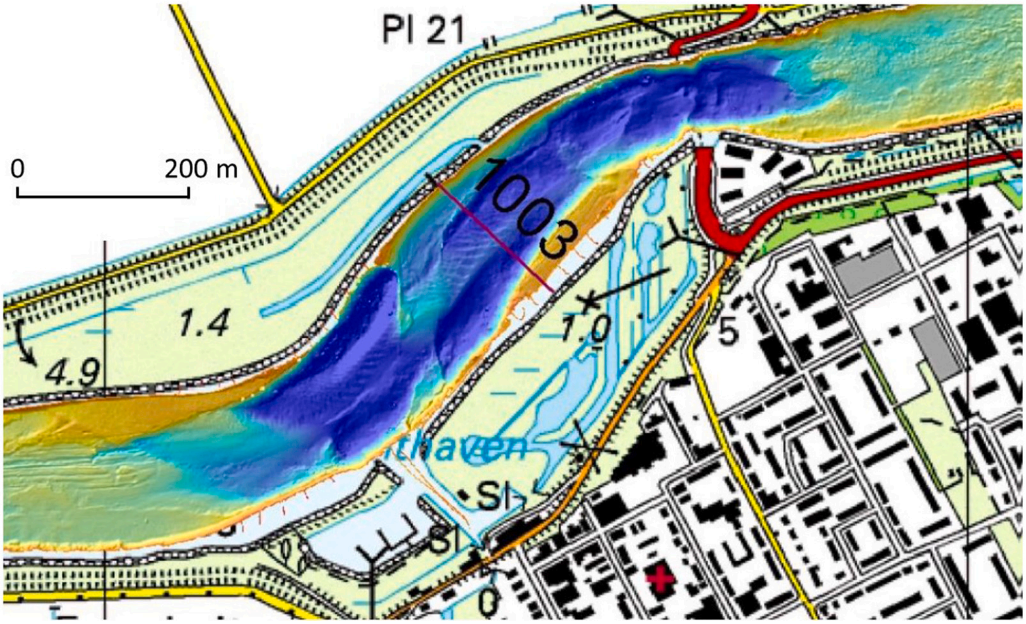

Fig. 8. Multibeam bed topography of 25 m deep scour hole in river Spui at Nieuw-Beijerland. Blue areas represent a deep sandy riverbed with dunes. Turquoise and yellow areas represent a shallower bed of erosion-resistant clay.

between different stakeholders. That major changes in rivers and associated policies in the past have been obtained by seizing opportunities holds a lesson for successful river restoration in the future too.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1. History of the Rhine branches in the Netherlands

Around 0	Roman river training works and canals
Around 800	Renovation and extension of river works that had deteriorated after the fall of the Roman Empire
Around 1000	Local dikes
Around 1100	Longer dikes to connect settlements on higher grounds, predecessors of later dikes around polders
1122	Dam to close entrance to Kromme Rijn distributary
1285	Dam to close Hollandsche IJssel distributary
1421	Flooding of the Grote or Zuidhollandse Waard after the Saint Elizabeth Flood, creating the Biesbosch tidal basin and increasing discharges to the Waal branch of the Rhine
Around 1450	Dike rings around polders largely closed
1500–1580	Shift of main Rhine bifurcation from Lobith to Schenkenschans
1586	Construction of Fort Schenkenschans
1602	Prohibition for private landowners in the province of Guelders to construct groynes in the river
1648	Peace of Westphalia, including an international treaty on Rhine navigation
1672	Wading of French army through Rhine at Tolhuis near Lobith
1588–1677	Bend cut-offs at Emmerich (1588, 1644), Ooy (1649), Rees (1654, 1677) and Hurwenen (1655)
1701	Implementation of retrenchment between Waal and Nederrijn near Pannerden
1708	Connection of the retrenchment to Waal and Nederrijn, thus creating a new river course and shifting the main Rhine bifurcation from Schenkenschans to Pannerden
1733	Dam in connection between Waal and Meuse at Heerewaarden, maintaining a 150 m wide connection
1750–1780	Connection of 19 out of 25 islands to the banks of the Niederrhein by damming secondary channels
1775	Digging of a new channel for the upper course of the river IJssel
1775–1776	Bend cut-off at Herwen by digging the Bijlands Canal
1780	Construction of a weir at the entrance of the old Rhine course in Het Spijk near Schenkenschans
1780–1820	Bend cut-offs at Büderich (1784), Bislich (1788) and Grieth (1819)
1799, 1809	Dike breaches and flooding due to ice jams near Pannerden and Malburgen
1820	Dike breaches and flooding due to ice jams in Pannerdens Canal, in the Waal at Loenen, in the Nederrijn downstream of Arnhem and at the entrance of the IJssel. This flood was the reason for preparing the “First Normalization” river training
1850–1876	Damming of channels in the Biesbosch and digging of the Nieuwe Merwede. Bend cut-off at Wijk bij Duurstede

(*continued on next page*)

(*continued*)

1850–1880	First Normalization of Rhine branches: river training for safe discharge of ice, water and sediment
1869	Digging of Nieuwe Waterweg between Rotterdam and the North Sea
1875	Closure of connection between Waal and Meuse at Heerewaarden
1880–1893	Second Normalization of the Waal: reduction of main-channel width from 360 to 310 m to improve navigability
1904	Dike to fully separate Waal and Meuse at Heerewaarden
1910–1916	Third normalization of the Waal: reduction of main-channel width from 310 to 260 m to improve navigability
1920–1940	Further normalization of other Rhine branches
1932	Closure of Zuiderzee bay, removing tidal effects from the lower course of the IJssel
1953	Widening of Pannerdens Canal at Candia
1953	Flood disaster in southwestern part of the Netherlands
1954	Bend cut-off in IJssel at Doesburg
1954–1971	Canalization of the Nederrijn by weirs at Driel, Amerongen and Hagestein
1958	Delta Law, setting the flood protection standards proposed by the Delta Committee
around 1970	Bend cut-offs in the IJssel at De Steeg and Doesburg
1971	Closure of Haringvliet estuary
1986	Ooievaar Plan for giving more space to the river in the area of the main Rhine bifurcations
1986–1988	Fixed layer in Waal bend at Nijmegen to improve navigability
1989	First nature development project in Duursche Waarden along river IJssel
1990	Agreement between Germany and Netherlands to stop ongoing riverbed degradation (Fig. 3). Start of resupplying dredged material to the river
1992–1993	Second-opinion review of dike reinforcement policy for Boertien Committee
1994–1996	Bendway weirs in Waal bend at Erlecom to improve navigability
1995	Flood in February with peak discharge above 12,000 m^3/s at Lobith. Preventive evacuation of 250,000 people
1998–1999	Fixed layer in Waal bend at Sint Andries to improve navigability
2000–2015	Implementation of Room-for-the-River programme
2013	Threat of dike at Hoogvliet by deep scour
2017	Risk-based standards for safety against flooding
2018	Threat of bridge at Spijkenisse by deep scour

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