Title:	River engineering measures to improve navigability
Author:	Sanjay Giri
Review:	Erik Mosselman
Date:	21 January 2011
Project:	Knowledge for Climate – HSRR08 "The effects of climate change on inland water transport via the Port of Rotterdam"

APPENDIX #: RIVER ENGINEERING MEASURES TO IMPROVE NAVIGABILITY

#.1 Introduction

Navigability can be improved by technical measures in the main channel, such as dredging and the construction or modification of groynes, fixed bed layers, bottom vanes, bendway weirs and longitudinal dams. This appendix presents technical measures for the Dutch Rhine branches as well as a review of these measures in the Waal Programme and the DVR project.

#.2 Overview of technical measures

#.2.1 Fixed layers

The shallow point bar developing in meander bends often leads to unfavourable conditions for navigability. By constructing a non-erodible (fixed) layer in the pool of a river bend (Figure #.1) the distribution of flow and sediment discharge can be modified such that the shallow inner bend will degrade to a certain extent (i.e. lowering of point bar). This results in a larger width for navigation. A fixed layer in the outer bend consists of a partly filled up outer bend with sand and gravel, protected by a layer of riprap. This measure raises the bed level, which initially decreases the overall flow area but then scours away the inner-bend shoal. The approach has been successfully applied in the Waal bends at Nijmegen and St Andries.

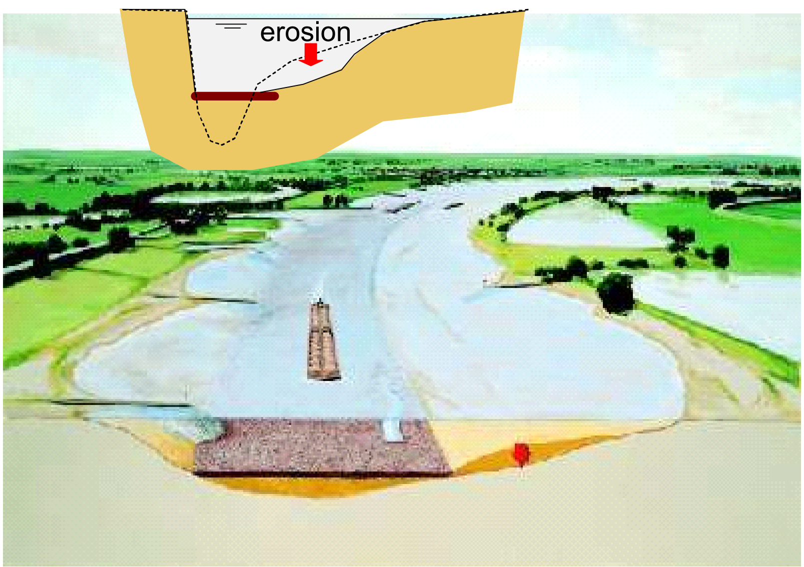

Figure #.1. Fixed layer in outer-bend pool.

#.2.2 Bendway weirs

Another solution is the use of bendway weirs in the outer bend (Figure #.2). These are in fact submerged groynes, constructed with sand, geo-textile and riprap, leading to the reduction of spiral flow close to the riverbed. They are placed with a slight inclination to reduce the spiral flow even further and to direct the sediment transport near the bed towards the outer bend. In this way, the bed in the outer bend is aggraded, whereas the bed in the inner bend is degraded, yielding a larger fairway width. Moreover, the resistance to flow exerted by the bottom groynes deflects the flow towards the inner bend, which leads to an additional eroding effect. The bendway weirs were realized in the bend at Erlecom.

Figure #.2. Bendway weirs in outer-bend pool.

#.2.3 Groyne extension

Groyne extension reduces main-channel width and hence increases navigation depth (Figure #.3). However, it increases the hydraulic resistance which leads to higher flood levels. Another disadvantage is that groynes produce shoals by generating an alternating pattern of scour holes at groyne heads and ridges in front of the beaches between the groynes. The latter ridges are called “groyne flames”.

Figure #.3. Groyne extension.

#.2.4 Longitudinal dams

Longitudinal dams have been introduced as an alternative to groyne extension, as they neither increase hydraulic roughness nor produce groyne flames (Figure #.4). They increase the navigation depth by reducing the main-channel width.

Figure #.4. Longitudinal dams (example in right panel: Parallelwerk Walsum-Stap, Germany).

#.2.5 Dredging

In order to maintain a fairway for navigation in alluvial rivers, dredging is one of the recurrent measures. Dredging can be a good option in situations where the execution of several river training measures is not certain, where the impact of the measures is uncertain (e.g. Room for the River), or where funding is too limited to allow for expensive structural measures.

Various methods of dredging and dumping of the dredged material were tested in the Waal River during the past ten years. New regulations stipulate that all dredged material shall be dumped into deeper parts of the river to decrease the omgoing trend of overall bed degradation. Where to dredge is usually easily determined on the basis of soundings and extrapolations of water level and bed level trends. Finding a suitable place for dumping is a larger problem. At first glance the deeper spots in the river seem obvious dumping sites. However, these spots are maintained deep by the flow of the river, and as a consequence the dumped sediment eventually will be transported further downstream and settle in locations with low flow velocities, thus increasing existing shoals. Spoil dumped in outer bends appears to stay there for more than 50% until the peak flow occurs, so, depending on the discharge hydrograph, dumping in outer bends can be considered to be an option mainly for temporary storage of dredged material. The same holds for dumping in the erosion pit immediately downstream of a fixed layer and dumping in the space between consecutive bendway weirs.

Dumping in groyne fields is an attractive alternative. Here the location of dumping (close to the low water bed or higher on the banks) defines the rate at which sediment will be supplied back to the main channel. In practice, application of this method may be hampered by legislation regarding possible contamination of the sediments (in particular regarding mixing with the sediment already present in the groyne fields as the dredged material is of good quality). It also requires study of the local flow patterns during peak flows to estimate the supply rate. Nevertheless, dumping in groyne fields is considered a sustainable sediment management solution.

In order to decrease the ongoing bed degradation, dredged material is dumped upstream of the dredging location to increase the sediment load. Logically this might mean that the volumes to be dredged are increasing too. This upstream dumping is subject to criticism and may be changed into dumping downstream in the near future after further investigation of different dumping strategies.

#.2.6 Sediment nourishment

Sediment nourishment or sediment feeding is considered to have great potential to effectively reduce riverbed degradation, while providing sufficient flexibility for adapting to changing conditions and anticipating on the high uncertainties in future morphology. It is for that reason that sediment feeding has already been successfully applied in the German Rhine, and plans are drawn to extend the nourishments to the Dutch Rhine branches.

#.3 The Waal Programme

The Waal programme was carried out in the 1990s. Considering forecasts of further traffic growth, the Toekomstvisie Hoofdtransportas Waal concluded in 1993 that safe, fast and efficient navigation in 2010 would require enlargement of the navigation channel from its present 150 m × 2.5 m to a profile of 170 m × 2.8 m at OLR, i.e. at the low water level that is exceeded during 95% of the time. The OLR criterion has been established internationally in 1947 and corresponds to a Rhine discharge of 1020 m^3/s at Lobith. Alternative strategies to achieve this enlargement of the navigation channel were elaborated in the Waal Programme. In 1996, Rijkswaterstaat Oost Nederland selected a preferred strategy, composed of groyne extensions, maintenance dredging and, above all, structural measures in river bends. The latter comprised fixed layers, bendway weirs and bottom vanes.

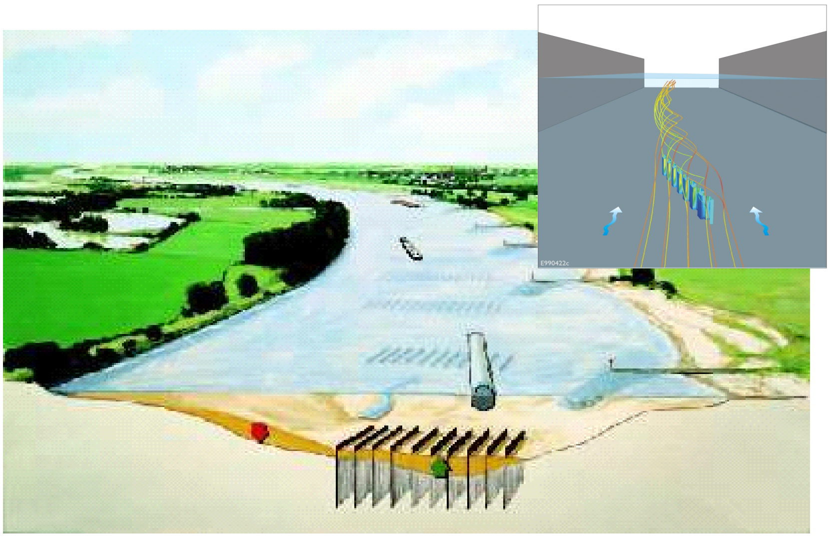
Figure #.5. Bottom vanes.

However, hesitation arose for the implementation of bottom vanes (Figure #.5) in the bends at Hulhuizen and Haalderen, because a pilot field application in the bend of the river IJssel at Fortmond had not been successful, despite extensive testing of bottom vanes in the laboratory. The precise causes of the lack of success were the object of debate. The principle of bottom vanes is that they generate spiral flows that transport bed sediments from the inner to the outer bend. A good functioning requires that the angle between the approaching flow and the vanes is about 15^{0} to 20^{0}. On the one hand, measurements revealed that the vanes had not been placed in the proper direction. On the other hand, navigation and vortex shedding at nearby groynes disturb the design flow direction and the effect of these disturbances on the functioning of bottom vanes had never been tested in the laboratory. Hesitation arose also because the shipping sector feared that ships touching the bottom vanes might be cut open by the sheet piles of these vanes. Considering all these uncertainties, Rijkswaterstaat abandoned the plans to implement bottom vanes in the Waal bends at Hulhuizen and Haalderen.

#.4 The DVR project

Another issue in navigability had gained importance around the turn of the century. The original time horizon of the Waal programme was the year 2010. As this year was coming near, Rijkswaterstaat intended to extend the horizon by 50 years for reasons of fairway sustainability. The ongoing overall bed degradation of the river Waal then arose as a problem, because the fixed layers in the outer-bend pools will not follow the degradation and hence become high obstacles that represent nautical bottlenecks in the coming years. In order to meet demands for navigation in the future too, the Directorate for Public Works and Water Management launched the DVR project, which stands for Duurzame Vaardiepte Rijndelta (Sustainable Navigation Channel Depth in the Rhine Delta). The DVR project aims at defining and evaluating river interventions to keep the Rhine navigable.

One of the key elements of the DVR project is the development of an advanced 2D morphodynamic model of the Dutch Rhine branches, enabling river managers (i) to investigate the impact of climate change and long-term morphology on river navigability, and (ii) to evaluate the effects of river intervention measures to keep the Rhine navigable. The DVR model can be used to assess the long-term large-scale evolution of the Rhine system. As the model incorporates also complex time-dependent multi-dimensional phenomena, such as curvature-induced patterns of point bars and pools in bends, assessment is also possible at the small and intermediate spatial scales. As far as the navigability of the Rhine branches is concerned, the interest ranges from micro-scale and meso-scale, on which sand bars develop and where responses to dredging activities are an issue, to the large scale where changes in the longitudinal profile of the river affect navigability. The development of this model is reported by Mosselman et al (2004, 2005, 2007), Sieben et al (2005), Ottevanger & Yossef (2006), Van Vuren et al (2006, 2008), Yossef et al (2006, 2008a, 2008b, 2010) and Sloff et al (2009).

The model contains all kinds of innovative, recently developed aspects such as domain decomposition, parallel computation, a simulation management tool to accelerate morphological computations, functionality for sediment transport over non-erodible layers and sediment management functionality to assess and optimize dredging, dumping and nourishment strategies.

Studies using the model have gained deeper insights in the effectiveness of various river engineering measures to improve navigability. It is difficult, however, to translate these insights into simple relationships between costs and benefits. Cost-benefit analyses for these measures are fraught with pitfalls (e.g. Van der Most et al, 2005). Nonetheless, the MIT Exploration Report by HKV Lijn in Water (2007) and its summary by Havinga & Barneveld (2009) do provide estimates of costs and benefits along with a multi-criteria analysis of different directions for solutions.

Studies for DVR express the benefits in terms of reduction of dredging, which is not only a matter of reduction of annual maintenance costs but also a matter of traffic safety, because dredging hinders traffic on the river and increases the risk of accidents. The benefits are not expressed in terms of gains in navigation depth or load factor, because the required navigation profile at OLR is taken as a prescribed condition. This means that the costs and benefits of river engineering measures cannot be compared easily with other adaptation measures for making sure that the position of inland shipping continues on the same level in the future.

#.5 References

Havinga, H. & H.J. Barneveld (2009), Stoppen bodemdaling moet duurzame vaarweg verzekeren. Land+Water, Nr.10, October 2009.

HKV Lijn in Water (2007), MIT-Verkenningennota Duurzame Vaardiepte Rijndelta. Report PR1151.10, HKV Lijn in Water, Lelystad, November 2007.

Mosselman, E., P. Kerssens, F. van der Knaap, D. Schwanenberg & K. Sloff (2004), Sustainable river fairway maintenance and improvement. Report Q3757.00, WL | Delft Hydraulics, Delft.

Mosselman, E., C.J. Sloff & H.R.A. Jagers (2005), Voorspelinstrument duurzame vaarweg; Voorbereiding. Report Q3963.00, WL | Delft Hydraulics, Delft.

Mosselman, E., S. van Vuren, M. Yossef, W. Ottevanger & K. Sloff (2007), Case studies Duurzame Vaardiepte Rijndelta. Report Q4245, WL | Delft Hydraulics, Delft.

Most, H. van der, P. Baan, E. Mosselman & J. Dijkman (2005), Evaluatie van MKBA-Waterbodems. Report Q3866, WL | Delft Hydraulics, Delft.

Ottevanger, W. & M. Yossef (2006), Voorspelinstrument duurzame vaarweg; Roosteruitbreiding met Beneden Merwede en Nieuwe Merwede. Rapport Q4186.00, WL | Delft Hydraulics, Delft.

Sieben, J., M.H.I. Schropp & E.H. van Velzen (2005), Voorspelinstrument duurzame vaarweg; Functioneel ontwerp. Werkdocument 2005.085x, Rijkswaterstaat RIZA, Arnhem.

Sloff, C.J., S. Giri, W. Ottevanger & M. Zagonjolli (2009), Voorspelinstrument Duurzame Vaardiepte Rijndelta; Improving physical model concepts. Report 1002017-000 ZWS, Deltares, Delft.

Vuren, S. van, E. Mosselman, K. Sloff & B. Vermeulen (2006), Voorspelinstrument duurzame vaarweg; Initiële modelbouw en demonstratieberekeningen. Rapport Q4082.00, WL | Delft Hydraulics, Delft.

Vuren, S. van, A. Hauschild, W. Ottevanger, J. Crebas & M. Yossef (2008), Voorspelinstrument duurzame vaarweg; Reducing computation time. Report Q4357.10, WL | Delft Hydraulics, Delft.

Yossef, M.F.M., E. Mosselman, H.R.A. Jagers, C.J. Sloff, S. van Vuren & B. Vermeulen (2006), Voorspelinstrument duurzame vaarweg; Innovatieve aspecten. Report Q4082.00, WL | Delft Hydraulics, Delft.

Yossef, M.F.M., C. Stolker, S. Giri, A. Hauschild & S. van Vuren (2008a), Voorspelinstrument duurzame vaarweg; Calibration of the multi-domain model. Report Q4357.20, WL | Delft Hydraulics, Delft.

Yossef, M.F.M., M. Zagonjolli & C.J. Sloff (2008b), Voorspelinstrument duurzame vaarweg; Case study fixed layer and sediment nourishment in the Bovenrijn. Report Q4357.30, Delft Hydraulics, Delft.

Yossef, M.F.M., S. Giri & C.F. van der Mark (2010), Voorspelinstrument Duurzame Vaardiepte Rijndelta; DVR-model update 2010 (DVR-2010). Report 1202433-000 ZWS, Deltares, Delft.