Tension between navigation, maintenance and safety calls for an integrated planning of flood protection measures

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ABSTRACT:

Along the Dutch Rhine branches a vast flood protection scheme according to the Room for the River principle is planned. Execution of some 40 projects has to be completed in 2015, costing € 2.1 billion, and taking into account increase of landscape quality (by constructing side channels and natural vegetation). The responsible Dutch Ministry of Public Works, Transport and Watermanagement has handed over the preparation of many projects to local authorities to obtain the necessary public support and to facilitate combinations with local developments. The preliminary designs of many flood level reduction plans show that the inland navigation interests and future maintenance (governmental interest) did get too little attention. To prevent a serious conflict of interests between flood protection, inland navigation and ecology the side effects of increased flood conveyance which may cause serious shoaling in the low water channel must be dealt with. Introduction of natural vegetation and alluvial elements in the floodplain (side channels) intensify maintenance efforts. A system of vegetation and morphological monitoring and regular intervention to set back vegetation succession and morphological developments is demanded to guarantee the targeted design flood levels. 2D morphological computations can adequately calculate effects of the flood protection plans to inland navigation. If proper morphological analyses will not be carried out from the very beginning sub-optimal designs in the final project phase may be the result.

1 INTRODUCTION

Nowadays, enormous pressure is exerted on the Dutch river area, coming from numerous sides. Not only a vast flood protection scheme (about 40 large scale floodplain projects in the framework of Room for the River; see www.ruimtevoorderivier.nl) is executed, also floodplain rehabilitation projects are carried out. Furthermore housing projects in the floodplains (under very strict conditions) are developed and the European Framework Directive is responsible for many small scale projects in order to achieve what is called ‘a good ecological condition of the system’ (see for instance http://ec.europa.eu/environment/water/water-framework/index_en.html). European directives are also responsible for large scale nature conservation (Nature 2000), and within this directive all the floodplains along the Rhine branches are designated as Nature 2000 area. This means that when measures in the floodplains are planned, habitat often needs to be compensated or mitigated. Finally, an important Dutch state committee (Delta Committee 2008) has recently indicated that in view of climate change effects the Netherlands should prepare for large (water related) works in order to keep the Netherlands endurable for future habitation. This puts extra claims on the scarce and precious space for flood conveyance and storage in floodplains and large water bodies like Lake IJssel and the south western part of the Rhine-Meuse delta. Meanwhile, the interest of inland navigation is threatened by these developments, as this sector does not want to be confronted with negative effects of the aforementioned initiatives. So, the question is how to manage all this to prevent a large conflict of interests, leading to more tension and frustrations.

In this paper, we focus on the possible tension between flood protection measures in a broad sense and inland navigation. This can act as a guideline to solve other conflicts in the river area, as many measures one way or another have an effect on the low water bed, and thus on the navigation channel (fairway). The message that we want to transmit is that *early integration* between the different stakeholders is needed to minimise impacts for navigation due to floodplain plans and to ensure that projects will be sustainable (from management and flood safety point of view) in the long run. Early integration may seem obvious, but our experience shows that projects often are carried out in successive multiple stages: first the floodplain plan is developed to cope with reduction of flood levels, then the morphological impact on the low water bed is assessed, and next the floodplain plan is optimised to minimise this impact. Finally, when all possibilities in the floodplain are exhausted in order to minimise the morphological effects, a final solution in the low water bed is investigated. This awkward process can be explained by the different responsibilities of stakeholders, as well as the definition of the project area (often restricted to the floodplain, excluding explicitly the low water bed).

In order to assess morphological effects, 2D-tools now become available. In earlier days, computations were too time-consuming to carry out for river projects on the large spatial scale that is considered here. Hence, only rough rules-of-thumb could be used, or less detailed 1D-morphological models. This methodology is considered to be insufficient when it comes to evaluating the impact of the large number of measures proposed within the Room for the River program (Van Vuren, 2005) on the morphologic development (and vice versa) needed for design of bed stabilization measures ensuring a sustainable fairway.

With the intention to design measures for the main channel, as well as to review the effects of the combined flood protection and navigation measures a large 2D morphologic model of almost the complete Dutch Rhine branches has been built. With this tool, it becomes feasible to accompany every (larger) initiative in the floodplain by thorough morphological analyses to reveal possible tensions. These analyses enable the river manager to adequately judge proposed flood management and navigation measures. This broadens his view considerably, adding an important indicator for a proper assessment.

The 2D-model is now available (implemented in the software package Delft3D, see Lesser et al, 2004) and will presumably be used in all Room for the River projects (whenever necessary). In the development, an ambitious list of requirements has been studied and implemented (Yossef et al, 2008), Havinga et al, 2005). This numerical process-based morphodynamic package has become a commonly used tool in river engineering practice, such as evaluation and optimization of strategies to improve navigability. Main limitations at this moment are the inability to allow for sediment exchange between the floodplain and low water bed, and correct simulation of the near bank region.

2 NAVIGATION AND SAFETY: A POSSIBLE TENSION

The major rivers in the Netherlands play a vital role in navigation. Navigation is immense (170,000 ships a year pass Dutch-German border, carrying 160 million tons, see also Havinga et al, 2006) and economic consequences are immediate whenever sailing depth decreases. To a certain extent depth reduction due to natural causes (e.g. the severe drought in 2003) can be dealt with. However, occurrence of depth reduction and bottle necks due to dynamic morphological changes, inflicted by autonomous processes (as a result of river regulation) or local floodplain projects can be mitigated to a large extent, as is shown in (Havinga et al, 2005).

Besides the important role of inland navigation, flood protection is of utmost importance. The Dutch Flood Defense Act indicates how and when the flood levels for areas prone to flooding by Rhine and Meuse river are to be calculated, as well as the method to determine the associated design discharge. This Act also states that this procedure has to be repeated every five years and in case of new results, action has to be taken. This led in 2001 (after the 1993 and 1995 periods of very high discharges) to an increase in the design flood discharge and hence an increase in design flood levels.

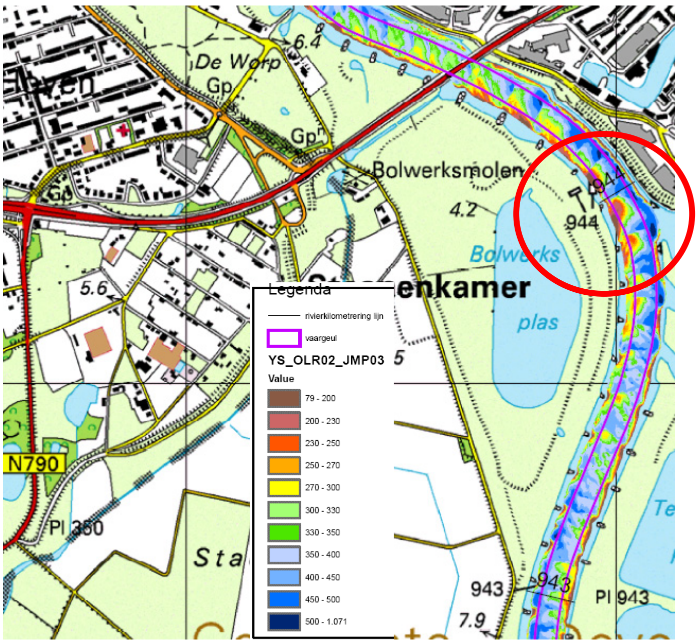

Figure 1: An example of the navigation depth in 2004 along the river IJssel. The ‘flames’ (see the circle) indicate a limited navigation depth.

At that moment, it was stated that dike reinforcement was not the intended robust solution nor can be considered sustainable. Instead, the increased flood levels should be neutralized by spatial measures (in the floodplains).

In short, that is the tension that The Netherlands are currently facing. Based on legislation, action has to be taken to guarantee the same degree of flood safety facing a larger design flood discharge. The choice has been made to solve this problem by increasing the flood conveyance. The spatial measures used, however, have morphological effects on the low water bed. At that time this consequence was not fully acknowledged, nor was the possible hindrance for navigation with potentially large economic consequences. This potential conflict of interest calls for designing a set of measures meeting the right balance between sufficient reduction of design flood levels and meanwhile, not hampering navigation (by sedimentation).

It is inevitable that local floodplain measures have morphological impact on the low water bed. This is just the consequence of diverting more discharge upstream towards the floodplain, resulting in less discharge in the main channel. As a result, flow velocity decreases and hence sedimentation occurs. Downstream the opposite occurs, and erosion will take place. Especially in projects with many side channels, a patchwork of erosion and sedimentation along the project-area will happen. The resulting shoals and erosion pits will travel downstream and may cause bottle-necks downstream as well. This is especially important when the navigation depth is already limited (without the intended measure). This is illustrated in figure 1, where shoals are shown in the river IJssel at low discharges (see also section 4).

To avoid these morphological effects as much as possible, a close integration of measures in the low water bed and floodplain is necessary. However, the division of the various management responsibilities makes this integration difficult.,

The above shows that it seems obvious that in the planning process the requirements for inland navigation are combined with the safety targets set by the "Room for the River" program. However, in the preparation phase of this program the potential impact of the flood protection plans on inland navigation has been poorly dealt with. Instead of considering inland navigation as a boundary condition ("no negative effects may occur"), the impact of proposed flood protection measures were only vaguely indicated in terms of estimated dredging quantities (based on 1D morphologic analyses). After the approval of the final set of measures of Room for the River by the Dutch Parliament, provinces and municipalities were invited to carry out the detailed design of the different measures. In this way, other stakeholders became involved aiming at increased local support for the projects. In their assignments, however, again the navigation interest was not explicitly mentioned. The terms of reference did not refer to mitigation of negative impact for inland navigation. Increasing pressure from the river manager led to the acknowledgement that also measures in the main channel had to be considered to comply with navigation demands (i.e. to prevent shoaling). To enable the design of these works detailed criteria to define navigation conditions have been developed (see section 4).

The current situation is thus as follows: a project is carried out in steps: at first a floodplain plan is designed with the objective to lower flood levels, taking into account that morphological changes have to be minimised. Then measures in the low water bed are designed to compensate for the remaining morphological effects. This may be dredging (after a period of high discharge). However, from navigation point of view it is preferred to design measures, that avoid sedimentation in the first place (e.g. longitudinal dams). The current working method makes is hard to achieve optimal solutions. If low water bed and floodplain are considered together in the design process better solutions regarding the functions flood safety, navigation, as well as ecology will be obtained. This integrated approach also enables weighing constructive measures and recurrent measures, thus enabling trade-offs between funds that have to be available immediately or that must be reserved in the future.

The latter working procedure comes close to Life Cost Cycle (LCC) approach where one considers the investments on a long time scale. In that perspective, it might be favourable to spend more money on a proper and integrated design and save on future maintenance and management costs.

3 TENSION BETWEEN MAINTENANCE, MANAGEMENT AND SAFETY

Many of the flood protection projects include side channels, in combination with excavation (to create more discharge capacity) and nature development. These plans are judged according to their flood level reducing effects. If the project does not comply with this primary goal, the aim of the whole program Room for the River may be jeopardized.

In testing whether the projects yield enough flood level reduction, the final stage in development of a floodplain plan is important. This final stage in general is defined by local authorities together with an extensive group of stakeholders. It is assumed that this final stage visualises the end phase, both in vegetation succession as well as in morphological development. This stage deviates from the initial situation immediately after construction, when the floodplain will be bare ground, with no vegetation and 'fresh' side channels (see also figure 2). From flood safety point of view, this is a preferable situation, because the floodplain then is hydraulically smooth. From nature and landscape point of view this situation is a nightmare.

After time the executed floodplain measures may meet exactly the planned final stage in terms of yielding the targeted reduction of flood levels. However vegetation succession will proceed and side channels will degrade further, resulting in a situation that the hydraulic goal will not be met any longer. At that moment maintenance is demanded. To enable variation in maintenance choices it is therefore advised to take into account some extra space in the flood plain plans for maintenance and management.

Figure 2: From left to right and from top to bottom: design phase of a floodplain project, a project immediately after construction, a 'regular' situation and an example of an intervention situation.

A number of important levels can be distinguished in the cycle of a floodplain project to reduce flood levels

- Construction level: the flood plain after the construction phase
- Design level: The situation that the designers have in mind and put on paper to discuss with stakeholders
- Intervention level: The situation for which action is needed, otherwise the safety cannot be guaranteed.

After the construction phase, the floodplain starts to develop to the situation which the designers have in mind and which yield the exact hydraulic roughness and discharge anticipated during design flood conditions. Monitoring is needed to check the developments in vegetation succession and morphology, which very well may go in different directions than anticipated. With help of the monitoring data, the actual hydraulic situation can be established. Based on this a decision for adaptation can be made

When we put the different phases together, we end up with a situation as depicted in figure 3. Before the execution of the flood plain project the water level is at 'A'. The target is to reduce the water level to 'D'. After the construction, the (hypothetical) water level at design conditions will be at 'B', well below the target. When vegetation and morphology develops, the water levels at design conditions rise. Whenever level 'C' is reached, action needs to be taken, which sets back to 'D' again. Between 'C' and 'D', there is room for maintenance and management, which takes care of small scale set backs.

Monitoring is hence essential for determining whether intervention levels will be crossed. In that case, vegetation succession and/or morphological developments have to be set back to levels that safety is guaranteed for the next period. This can be done using the concept of cyclic rejuvenation (Kater, 2005).

Developments in vegetation succession have to be controlled by maintenance. Morphological developments in side channels can be counteracted by dredging, other more innovative measures are thinkable. In general side channel behaviour is determined by 3 types of control: channel discharge, sediment intake and sediment transport through the channel [Ghmire 2003]. For the latter control narrowing the entrance of a side channel can be evaluated. Consequence of entrance constriction is increase of flow velocity increases, and hence the side channel is 'flushed'. This idea and similar ideas are now being studied at Rijkswaterstaat and Twente University.

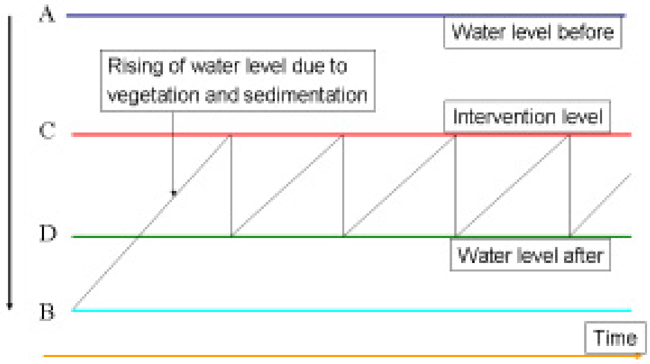

Figure 3: Schematic view of reducing flood levels by a floodplain project and the system of intervention

4 GUIDELINE FOR MORPHOLOGICAL ANALYSIS

The principle of flood protection according to the room for the river principle is to increase the flood conveyance. Eventually this will lead to morphological reactions in the main channel bed and hindrance for navigation. How severe this is depends on the current situation and on the impact. To this end it is needed that a reference level is defined which is characterised by minimum fairway dimensions during low discharges. These dimensions are different for the different Dutch Rhine river branches. For the Waal River dimensions are: a fairway width of 150 m and a depth of 2.8 m below the low water reference level (denoted by LWR-2.80, LWR being the water level that is exceeded in 95% of time, 2.80 m being the draught needed) An extra criterion has been formulated to cope with the dredging policy to dump dredged material again close to the dredging location. To prevent the cross-section to be filled entirely to the level of LWR-2.80 m it is also desired that the mean depth in the fairway is at least LWR-4.0 m, so the LWR-2.80 m level is restricted to a single spot in the cross-section. To test whether these conditions are violated, morphological analyses have to be carried out, and preferably, these should be carried out with a 2D-morphological model. However in simple cases, first other approaches can be followed, before the effort pays to apply a 2D model. At the location of a floodplain project the following approach is in general followed:

1) check the existing bathymetry and fairway dimensions
2) estimate mean aggradation/degradation following e.g. uniform flow and morphological equilibrium analysis (quick, first assessment)
3) if enough room (i.e. navigation depth in the fairway at LWR is at least 4.0 m) remains available after completing the project then stop the analysis. Apparently, the morphological consequences are no risk for navigation.
4) Otherwise: initial erosion and sedimentation can be predicted using output of a 2D hydraulic model. Hence, estimate sedimentation and erosion based on hydraulic calculations.
5) When the projects approach their final design phase, 1D morphological analysis can be carried out. This can be cumbersome and has in general low detail (spatial resolution of 500 m). This means that the interpretation of the impact on the fairway is difficult
6) If available, use a 2D morphological model. In the Netherlands this model is used in 2 ways:
    a. To predict the bed level changes for a certain restricted river reach (in the order of 10 km)
    b. To predict the impact on the river bed for an entire river branch: package test.

5 CASE STUDY: FINE TUNING FLOOD PROTECTION MEASURES TO LIMIT IMPACTS FOR NAVIGATION

In this case study, the potential of the aforementioned 2-D morphological model to fine-tune the design of a flood protection measure along the river Lek is demonstrated (Van Vuren & Barneveld, 2008). The Lek is one of the Rhine branches in the Netherlands. We show how such a model can be of use in order to express the impact on the river's navigability and dredging works. In this particular case, integration of objectives for safety and navigation were incorporated early in the design process, in line with the new proposed integrated planning and design process.

We consider a flood protection measure proposed in the Lek. The measure consists amongst others of widening the main channel from 100 to 200 m. In the original design, the widened channel was separated from the main channel by a longitudinal dam containing four openings, as illustrated in figure 4.

The impact of closing the openings step by step is investigated by means of a 2-D morphological model. The model contains a functionality for sediment management to assess dredging strategies. As the model incorporates complex time-dependent multi-dimensional phenomena, such as curvature-induced point bar and pool patterns in bends, impact assessment is possible at the small and intermediate spatial scales (in the order of hectometres and kilometres).

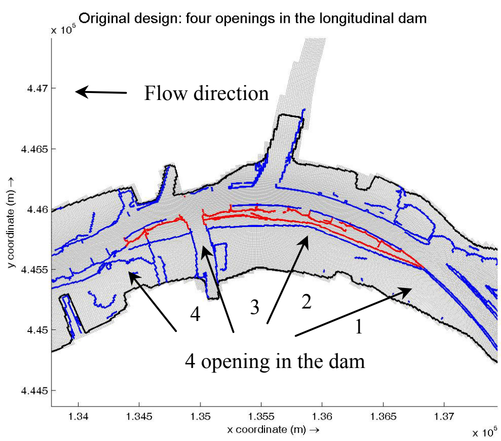

Figure 4: Project area and location of channel widening – original design

A discharge time series is imposed as a hydraulic boundary condition at the upstream boundary.

In the final design three openings (nr. 1, 2 and 4 in figure 4) in the longitudinal dame are closed to mitigate negative impacts on navigability. This implies opening nr. 3 in figure 4 is left. This opening is required for cross-traffic of shipping vessels from the Merwede canal.

Figure 5 shows the bed level changes after a period of 6 years for 1) the original design, and 2) the optimized design. Hardly any sedimentation occurs in the reference situation. The figure indicates that closing three of the four openings in the dam can reduce the significant accretion that occurs in the original design.

In the original design severe accretion (over 2 meters) occurs in the main channel. The design influences the discharge distribution between the main channel and the floodplains (including the widening): a greater part will be conveyed through the floodplains. The flow velocity in the main channel drops significantly, and inevitably results in sedimentation in the main channel.

It appears that the most upstream situated opening (nr. 1 in figure 4) is highly important for this sedimentation. This opening enables continuous flow of discharge through the widened channel at all discharge levels. Closing this opening by extending the longitudinal dam prevents continuous flowing during discharges below 900 m^3/s. This means only 30 days a year discharge is conveyed through the channel. Closing also two of the remaining openings appeared necessary to further reduce the accretion in the main channel, see figure 5. However, not all accretion could be mitigated.

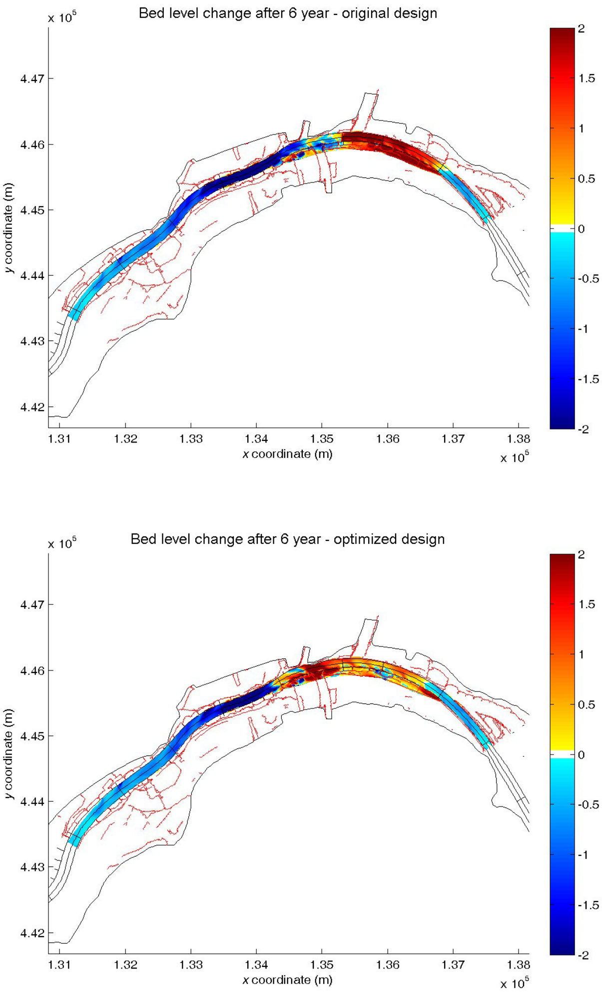

Figure 5: Bed level change after a period of 6 years for 1) the original design, and 2) the optimized design.

Figure 6 shows that the navigable percentage as a function of ship draught drops tremendously in the original design as compared with the reference situation. Closing three of the four openings in the dam improves the navigability significantly. The figure illustrates that ships can navigate at a draught of 2.8 m 96% of the time. In other words, the optimized design does fulfill the navigation channel requirements as stated in Section 4.

The river manager uses dredging for maintenance or further improving navigation conditions. Figure 7 presents the dredging volume that is required in a period of 10 years to fulfill the navigation channel requirements on the long term for the original design and the final design. In the present state no dredging works are required.

In conclusion: the advanced 2-D model is a promising tool for evaluating river intervention measures in order to improve the navigability. Changes in the design of flood protection measures can be easily assessed, and stepwise an engineer can fine-tune a design such that the design fulfills the required navigability conditions and accepted maintenance dredging works, but also fulfills the flood protection objectives.

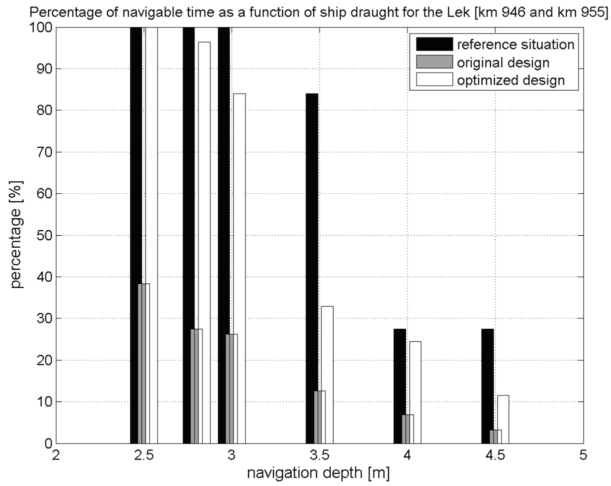

Figure 6: Percentage of navigable time as a function of ship draught for 1) the reference situation without flood protection measure, 2) the original design, and 3) the optimized design; for the situation without dredging.

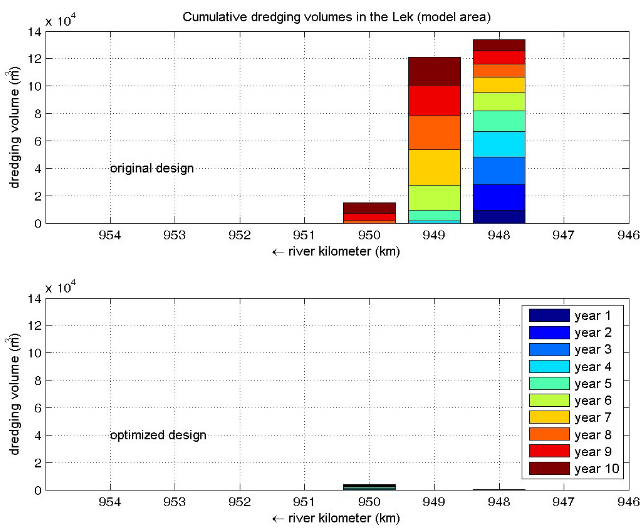

Figure 7: Dredging required to further improve the navigability for 1) the original design, and 2) the optimized design.

6 DISCUSSION

When the relevant criteria and demands of the major interests are openly discussed in the first stages of the preliminarily designs of flood protection projects, more strategies will result to solve problems and demands of the different interests. This integral approach is advocated at almost every level of public governance, however in practice proper integration appears to be hard, resulting in sub-optimal designs.

Late integration of (in the Dutch case) the inland navigation interest with flood protection and ecological interests have resulted in painful discussion, loss of planning time, increasing project costs and probably sub-optimal designs.

In principle few solutions are available to mitigate the morphologic impact of measures that increase flood conveyance (i.e. room for the river measures). The bed aggradation can of course be dredged, however to prevent (further) autonomous bed erosion, the dredged spoil should also be deposited in the upstream part of the river, to prevent an erosion wave to travel downstream. An alternative to the regular dredging is the creation of a sediment trap at the expected shoaling site or immediate upstream of this location. Narrowing of the site where aggradation will occur is a constructive solution, however this should be extended over the entire reach where part of low water bed discharge is conveyed through the floodplain. As a consequence, this may affect flood levels again. Taking into account the three functions concerned (flood protection, navigation and ecology) constructing longitudinal dam seems to be best fitted to serve all three functions. This may be seen taking into account that:

1) Between the longitudinal dam and the free bank an extra flood channel is created with large conveyance potential (as an alternative to groynes)
2) A longitudinal dam acts like a series of groynes, serving a good alignment to the fairway and protecting the river bank.
3) The river bank can be stripped from embankments as it is protected by the longitudinal dam. Optimal ecological conditions are available at the new natural bank. In the channel between longitudinal dam and bank, side channels can flow in and out without direct impact on the bed level in the low water bed, thus no hampering of navigation is at stake.

The concept of the longitudinal dam (for an example, see figure 8) forces the early cooperation of all interests involved and reduces the time that an integrated approach is demanded. After deciding on the general lay-out of the alignment of the low water bed, i.e. where are the locations of longitudinal dams, the different interests can develop their own plans to a large extent separately. In all the analyses that weigh the different strategies (dredging, side channels, longitudinal dams, etc) and focus on the inland navigation, advanced 2D-morphological models are necessary for a proper assessment.

Figure 8: Longitudinal dam in the Rhine river at Walsum-Stapp

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