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Unexpected morphological effects due to postponed maintenance of river groynes

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I. INTRODUCTION

River training works along the Dutch river Rhine branches mainly consist of series of groynes. The groynes (some 3.600 in total) are needed to 1) provide sufficient nautical depth during periods of low discharges and 2) to stabilize the main channel in plan for accommodation of floods. Postponed maintenance affects either function, although it is clearly seen that if nautical depth is compromised through damage, the discharge capacity may benefit from the damage and vice versa.

The nautical depth, however, is critical in many locations and hence, the performance of the groynes is important.

The current maintenance strategy is to upkeep the structural integrity of groynes. It occurs that the execution of these maintenance works has to be delayed due to insufficient budget and approval procedures. As a consequence maintenance is often postponed for several years leaving many groynes damaged. Inevitably, their performance is affected resulting in increased current attack on the unprotected banks and necessity for additional maintenance dredging or loss of nautical depth with all its economical consequences.

Here, the first step towards a rationalized approach for groyne maintenance is presented with focus on the nautical depth function of groynes. The rationalized approach balances maintenance costs of damaged groynes, including the development of vegetation on groynes, with the costs of reduced performance. This way the optimum of the required maintenance budget can be determined yearly. Clearly the maintenance strategy should include the often neglected effects of damaged and repaired groynes on the river bed morphology.

The rationalized approach requires reliable and detailed insight into morphological effects of (postponed) maintenance. In this study, insight was gained through the use of a one-dimensional morphodynamic model, which brought to light some unexpected morphological effects that need to be taken into account in the maintenance strategy, apart from the already complex scour and erosion processes.

II. GROYNE DAMAGE

A. *Relevant types of damage to groynes*

The nautical depth function is directly affected through postponed maintenance of damaged groynes. Examples of different types of such damage are [1]:

- steepening of the groyne head;
- general sinking of the crest;
- outflanking.

The discharge function is affected mainly through vegetation growth on the crest of groynes.

Steepening of the groyne head is usually caused through undermining or the autonomous erosion process of the river main channel. Typically, groyne heads are designed with a slope of 1:2 to 1:3. Steepening of the groyne heads results in slopes between 1:1 and 2:3.

Crest sinkage is either inflicted by a general and gradual settling of the groyne itself or through collision with ships during high water when the groynes are submerged. Typically, crest sinkage through settling is 10 – 20 cm in size.

Outflanking is a type of damage that occurs during a flood when groynes are submerged for a prolonged period of time. If the landward end of a groyne is not built properly or has become damaged, erosion may start at the attachment point. The shortcut in the flow then allows outflanking to further progress. This type of damage tends to occur more frequently nowadays which is possibly due to intensified inland navigation. Because outflanking develops rapidly and the consequential increase in flow cross section is typically very large (10 – 60 m^2), the effect on the nautical depth function is also significant.

Although not strictly a form of damage, the postponed maintenance of vegetation growth on the crests of the groynes limits the discharge capacity of the river significantly. Despite the significant effect of vegetation growth on the crests on the discharge capacity during floods, it is generally not taken into account. This type of damage was not explicitly considered in the research project and will not be discussed in detail in this paper. It is, however, important and necessary to incorporate the vegetation maintenance required for this type of damage in a maintenance strategy for groynes such as the one discussed here.

B. *Outflanking at Dodewaard*

Near the village Dodewaard a groyne on the right bank of the river Waal (km 900.330) experienced severe outflanking in the nineties. This groyne is referred to as the Dodewaard groyne hereafter. The Dodewaard groyne is located on the Middle Waal which is a relatively straight stretch of river (Fig 1). Groyne length is 100 m typically for the Middle Waal; groyne spacing is generally 200 m [2].

Figure 1. The Middle Waal and location of the Dodewaard groyne

In December 1996, initial outflanking was discovered after the passing of a peak discharge. In order to study the optimal intervention limit for repair of this groyne, it was decided not to repair damage immediately and allow the outflanking to further progress for some time. Over a period of approximately 1.5 years, the outflanking increased apparently gradually (Fig 2.) until a final width of outflanking of 30 m and a depth of 2 m relative to the crest was reached (Fig 3.) by summer 1998. Until the repair of the groyne in December 2000, no significant further growth took place.

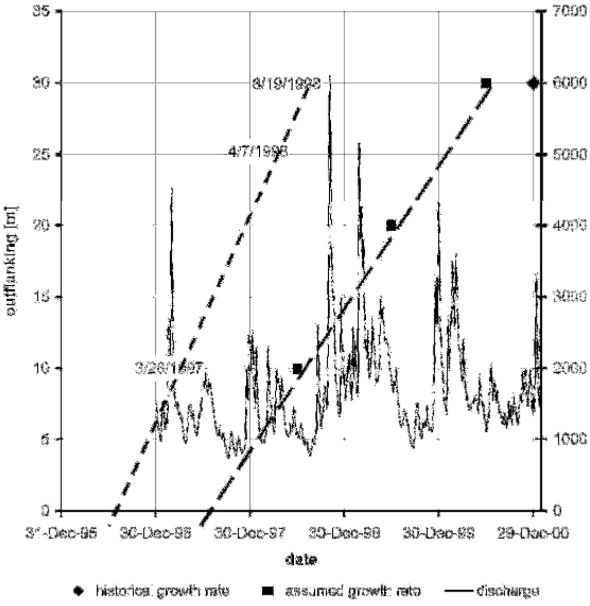

Figure 2. Progression of outflanking of the Dodewaard groyne

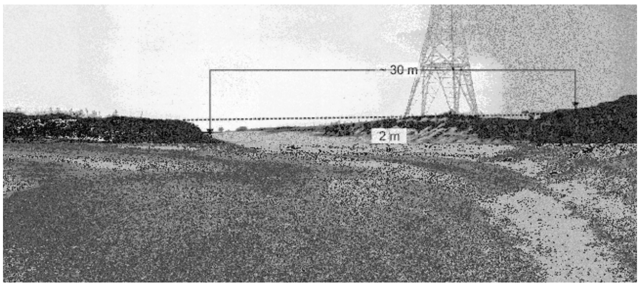

Figure 3. Outflanking of the Dodewaard groyne (approx. December 2000)

Throughout the period of growth of outflanking the bed level was monitored in plan in the Dodewaard groyne section and several sections up- and downstream.

Functional repair took place relatively quickly due to the method of repair in which wooden sheet piles are placed between the detached groyne and the floodplain after which the groyne is rebuilt into its original shape. Monitoring continued after the repair for another year.

III. INITIAL RECONAISSAINCE OF EFFECTS ON BED LEVEL FROM VARIOUS TYPES OF DAMAGE

Using a SOBEK one-dimensional morphodynamic model, the effect of three types of damage was investigated, e.g.: steepening of the head, crest sinkage and outflanking. In the model, the Waal River was schematized with one single cross section for the entire 90 kilometers of river. Damage was schematized through local alteration of the cross section.

For the initial reconnaissance of effects on bed level, constant discharges of 1,467 m^3/s (Q_{50}) and 2,400 m^3/s (Q_{90}) were used as well as a representative flood hydrograph from 2,000 m^3/s – 3,000 m^3/s. The results of the reconnaissance were extensively discussed in Akkerman, Van der Wal et al [3]. Figure 4 shows the effect on the average bed level in relation to the increased flow cross section due to groyne damage.

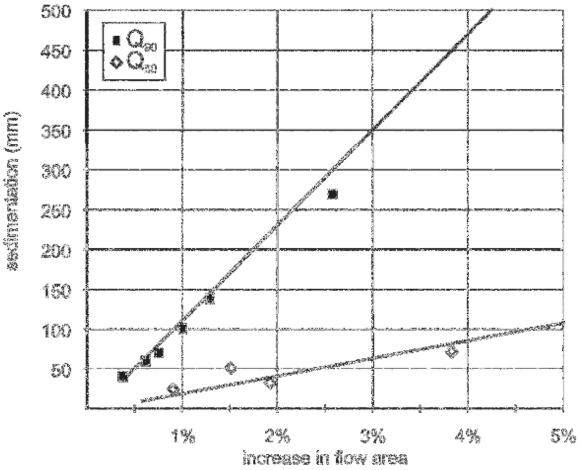

Figure 4. Effect of groyne damage (as a change in cross section) on bed levels

Furthermore, it was found that the passing of a flood wave caused a momentary peak to occur on top of the already increased bed level, which would cause significantly higher sedimentation than found from a simulation with a constant discharge.

The repair of the detached groyne was also included in the simulation. From this, it was possible to determine the manner of displacement of the sedimentation caused by groyne damage in the downstream direction. The diminution rate of the displacing sand wave was found to be very slow. Reference is made to Akkerman, Van der Wal et al [3] for a detailed discussion. Hence, hindrance from a bed level increase after repair of damage will occur for a prolonged period of time and nautical depth limitation is not immediately solved.

IV. DODEWAARD CASE AND MODELLING RESULTS

Since the initial results from the reconnaissance were found to be promising, the Dodewaard case was further investigated. The growth rate of outflanking was modeled at a rate of 10 m per year from December 1997 to the moment of repair in December 2000. The more realistic growth-rate of the outflanking as described in the previous section was not yet known, hence, this assumption was made. The one-dimensional model was run using the historical discharge (again, Fig 2.) of the same period so as to allow for comparison with the monitoring data.

Figure 5 shows the computed change in bed level due to the growing outflanking from 10 m, 20 m and 30 m from initial outflanking until the moment of repair. Bed level increase is computed proportional to depth. Because it is a one-dimensional model, the actual bed level increase may vary in plan form location and height.

The influence of peaks in the discharge is readily seen. Table 1 shows the average sedimentation per year and size of outflanking, as well as the minimum and maximum values found. The maximum values found in the simulation with the historical discharge compare rather well with the results of a simulation with a constant discharge (Q_{90}).

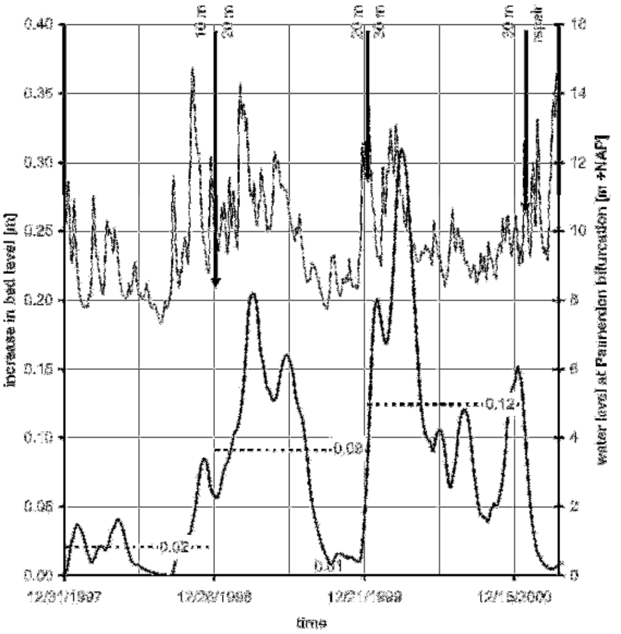

Figure 5. Computed increase in bed level due to outflanking and historical water levels. The arrows mark the schematized growth of outflanking; the dotted lines give the average increase in bed level per degree of outflanking.

Outflanking [m]	Q_{90}	$Q_{historical}$		
		min	avg	max
10	0,095	0,000	0,022	0,075
20	0,190	0,012	0,090	0,191
30	0,270	0,029	0,126	0,289

TABLE I. COMPUTED BED LEVEL INCREASE AT DODEWAARD, COMPARISON OF CONSTANT DISCHARGE (Q_{90}) COMPARED TO HISTORICAL DISCHARGE

Additionally, Fig. 5 also gives insight into the time-lag that exists between the response of the bed level increase and the peak in discharge: the maximum bed level occurs 3 to 4 weeks after the peak has passed.

This means that the water level will have lowered while the bed level is still increasing. In the last year before the outflanked groyne was repaired, the 30 m outflanking causes a bed level increase of 0,29 m, 4 weeks after the peak in discharge has passed; the water level has then dropped with 0,10 m, so that a loss of water depth of 0,39 m occurs. Again, this is an average value proportional to the depth in the cross-section and local values may be even higher. This may cause hindrance to shipping where available depth is critical, which is the case on the larger part of the Waal river.

On the Middle Waal, a survey is carried out daily to determine the Least Measured Depths. The information is passed on to shipping companies whom alter the degree of loading of their vessels to avoid the ships running aground. Hence, the hindrance does not present itself in nautical sense alone but also in an economical way because ships can carry less cargo.

In a further step, the dissolving of the local bed level increase was investigated after repair of the outflanked groyne. In the Dodewaard groyne section, the bed level returns to its original level within approximately 2 months. The sand wave has started to travel downstream. An important result was that it takes approximately 7 months for the height of the sand wave to decrease 50 percent. The problem of nautical hindrance is therefore not solved instantaneously after repair, but will persist for a long period of time. Since the peak discharges are likely to occur during winter when water levels are high, hindrance may increase significantly during summer when the traveling sand wave reaches shallow areas downstream and water levels are low, despite the fact that it may have decreased in height.

V. COMPARISON OF MODEL RESULTS WITH MONITORING DATA

The results found from the modeling of the Dodewaard case have been compared with monitoring data. The monitoring data, however, consisted of bed levels in two dimensions. In order to allow for comparison with one-dimensional model results, bed levels were averaged for each groyne section in longitudinal as well as transverse direction.

The dataset consisted of large sets of bed levels, taken at irregular intervals. Sometimes, bed levels were surveyed only on the lefthandside of the river axis, rather than across the full width.

The change in measured bed levels have been compared with the change in computed bed levels (Figure 6). In terms of trends in bed development, the model seems to yield good results. Because the model was simplified to one cross-section and a constant bed gradient, results do not match in absolute values.

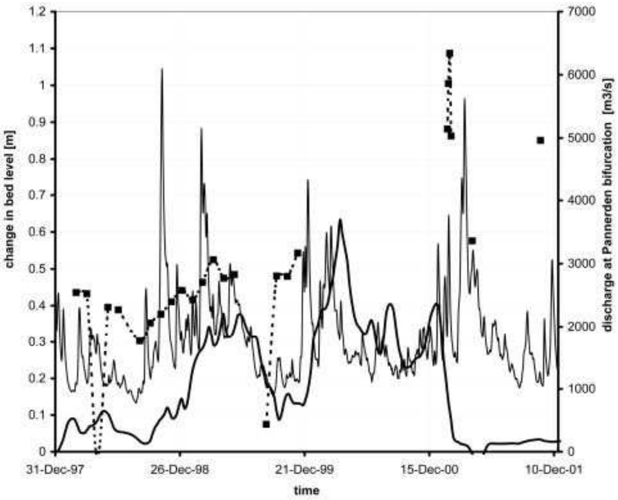

Figure 6. Change in measured and computed bed levels

The difference near the end of 2000 is probably due to the fact that it was later discovered that the development of the outflanking had taken place faster than initially assumed. Additionally, in this period, only one side of the river main channel was surveyed, so that difference may occur.

VI. CONCLUSIONS AND FUTURE WORK REGARDING MODELLING GROYNE DAMAGE

In a qualitative way, the one-dimensional model seems to predict changes in bed level due to outflanking rather well when compared with monitoring data, despite the deficiencies in the available dataset for exclusive verification.

In order to further verify the model quantitatively, measurements taken at the Haaften test location of Rijkswaterstaat where three groynes along the Waal River will be altered provide a good starting point. Additionally, comparison of changes in bed level found from a two-dimensional model may allow for verification of the one-dimensional approach adopted here.

If the model is quantitatively verified, other types of groyne damage can be investigated in greater detail and band width analysis can be carried out.

In the project Room for a River the lowering of groyne crests along a major stretch of the Waal River is considered as a promising measure to increase the safety against flooding. A lowering of about 1 m in the case of a typical groyne for the Waal River is comparable with the maximum outflanking in the Dodewaard groyne. Hence, the observed 0.4 m reduction in water depth may also apply for this measure. Operational mitigation via additional dredging may be rather complex and deserves additional study.

The one-dimensional approach itself allows for developing a good understanding of the processes that occur due to groyne damage, as well as extensive sensitivity analysis in terms of loss of nautical depth. In particular, the one-dimensional model gives excellent insight into important instationary phenomena that occur.

Schematization of the model may be improved when compared to two-dimensional models and future work includes comparing schematization of groynes and groyne damage. Although the two-dimensional models give good insight in plan form changes in bed level, it should be recognized that these models provide less insight into the instationairy effects that have proven to be very important if one is to maintain nautical depth.

VII. A NEW APPROACH TO MAINTENANCE

A. *(Unexpected) morphological effects due to postponed maintenance*

As found from the research, the relation between damage to groynes and river bed morphology and loss of nautical depth is a highly complex erosion and sedimentation problem, both on a local as well as on a larger scale.

Locally, the groyne head scour hole varies in size due to variations in discharge, as does the deposition downstream of the scour hole. In itself, this forms a potential depth limitation. Possibly, this depth limitation becomes more critical due to postponed maintenance. Whereas on a larger scale, the bed level between opposite groynes increases, causing a potential depth limitation in the main channel itself.

In both cases, the influence of peak discharges must be taken into account because sediment transport increases dramatically during the peak discharges. After the peak has passed, the water level decreases faster than the bed level decreases, causing a potentially more severe nautical depth limitation than expected.

Additionally, if the damaged groynes are repaired, the sand wave will progress downstream and local equilibrium depth (between opposite groyne sections) is re-established. Although the height of the sand wave will diminish as it travels downstream, it may again cause a nautical depth limitation when it passes already critical locations in terms of available water depth.

B. *Maintenance strategy*

Currently, the aforementioned complex and unexpected scour and erosion processes caused by groyne damage are not taken into account in the maintenance strategy, which focuses primarily on maintaining the structural integrity of the groynes, rather than focusing on the upkeep of their functioning. Although this is a good strategy in itself, shortage of maintenance budget requires that repair works are well considered since many groynes are damaged.

This implies that possibly, maintenance may need to be postponed on some groynes whilst damage on other groynes is given priority. Alternatively, anticipative dredging may have to be carried out to prepare for future sedimentation. Either way, loss of performance of groynes and hence, available nautical depth must be accepted. Hence, detailed and reliable insight into the scour and erosion processes caused by postponed maintenance is a prerequisite.

The one-dimensional approach as discussed here allows establishing a relationship between the state of maintenance of groynes and the consequences for the available water depth or the need for anticipative dredging.

It is easily developed into a decision support system that allows the river warden to prioritize maintenance work and budgeting and whilst maintaining an optimum available water depth on the river. Also, the decision support system may assist in finding an optimum in the order in which maintenance to groynes is carried out whilst minimizing hindrance for shipping, taking into account the effect of the traveling sand waves after repair and depth limitations downstream.

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