Effects of softwood vegetation on groyne field morphology

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Effects of softwood vegetation within groyne fields

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Preface

This MSc. Thesis has been written as a final assignment for receiving a Masters degree in Civil Engineering at the Delft University of Technology. With this report, an effort has been made to contribute to the increase of knowledge and insight in the interaction between vegetation and morphodynamic processes within groyne fields.

The initiative for this thesis was taken by Margriet Schoor from RIZA WRR and Martin Baptist from Delft University of Technology. This thesis is a continuation of a preceding study “Wilgenaanplant in kribvakken langs de Waal 1990-1995” (VAN SPLUNDER & SCHOOR, 1997).

With this assignment, I got a chance to put the various stages of conducting research (planning, measuring, analysing, modelling and reporting) into practice. I was able to do all this within the working environment of RIZA. This allowed me to get a glimpse of how research is put at use in real-life situations. Eventually, my experience at RIZA resulted into getting a chance to apply for a job offer, which I gladly took. I now work as an (assistant) project manager at RIZA WRR.

I would like to thank the following people for making this project possible. Firstly, I would like to thank Martin Baptist for infecting me with his enthusiasm for biogeomorphology and for his support, insight and advice throughout this study. I would like to thank Margriet Schoor for making this project possible and sharing her insight in ecology and morphodynamics. Erik Mosselman I would like to thank for sharing his broad vision and insight on river modelling. Prof. de Vriend I would like to thank for his accurate advice and inspiring me with his passion for river engineering. For providing the means and a helping hand at measuring terrain elevation, I would like to thank Adri Wagener. Chris Stolker I would like to thank for being a pleasant roommate and providing me with Waqua data and many useful and practical tips. I also would like to thank all employees of RIZA WRR for their kind support and contributing to this learning experience. Finally but certainly not last, I would like to thank my girlfriend, parents and friends for their unconditional support throughout my study.
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Abstract

Softwood vegetation can be found within a significant number of groyne fields along the River Waal. Vegetation is commonly known to decrease flow, attenuate waves, alter sediment properties and trap sediment. The total effect of these characteristics on groyne field morphology however is still unknown.

Within this thesis the effect of softwood vegetation on groyne field morphology is described. The morphological development of three test locations along the River Waal have been determined based on elevation measurements from 1990 until 1995 and newly conducted measurements from 2005 and 2006. At each of the test locations one groyne field has been used for the plantation of willows while the upstream and downstream groyne field has been used as reference.

At each location the species, common osier (Salix viminalis), purple willow (Salix purpurea) and gray willow (Salix cinerea) were planted in an alternating pattern on the upper bank of the study groyne field. From these species the survival percentages and yearly averaged mortality rates have been determined.

Furthermore, hydraulic conditions (water level and discharge) have been determined at each location from 1990 until 2005 at each location. These conditions have been determined by using a 1D-model, SOBEK.

The data obtained from elevation measurements has been used to create detailed Digital Elevation Models to describe the morphological situation at the time of measuring. In order to create these models, several interpolation methods have been assessed to determine which technique would be best suited for this study. Elevation Difference Maps and series of Riverbank Profiles were derived from the Digital Elevation Models. These were used to describe the morphological development per location over time. Volumetric calculations were also made to determine the effect on the total sediment balance within each groyne field.

At each of the three test locations, the presence of softwood vegetation has caused erosion of the lower bank and accretion at the upper bank. The morphological development within the corresponding reference groyne fields differ from the test groyne field but are consistent with each other. It can therefore be concluded that the found effect at the test locations is induced by the presence of softwood vegetation. From the calculated volumetric differences, it can be seen that at locations were erosion has taken place at the reference groyne fields the presence of vegetation at the test groyne field has caused less erosion compared to the reference fields. At the locations were sedimentation has taken place at the reference groyne fields, the presence of softwood vegetation within the study groyne field has caused erosion.

The total of the processes and factors, which are mentioned throughout this report to have an effect on groyne field morphology, are bundled into a conceptual riverbank model for groyne fields with the presence of softwood vegetation. From this model a list of desired improvements for future riverbank models has been derived.
1 Introduction

The Waal River is the largest branch of the Rhine River Delta. The river is embanked and trained with perpendicular groynes to keep the main channel at the desired place, width and depth. The majority of the groyne fields show little to no vegetation. Frequent flooding and intensive grazing make it difficult for most species to grow within groyne fields. However, during the last decades the presence of vegetation near and within groyne fields is becoming more frequent and is likely to increase for the upcoming years.

Unprotected groyne fields are sensitive to erosion. Whether erosion occurs depends on their location and orientation along the river, as well as on the presence and nature of shipping traffic. Erosion within groyne fields can ultimately result in loss of function for the groynes, which in turn can affect the main channel. To prevent this, riverbanks are commonly protected with stone revetment. This however creates a nature-unfriendly transition, which interferes with the gradient between land and water. In search of eco-friendly alternatives, the department of Rijkswaterstaat Oost-Nederland asked RIZA to study the possibility of using the plantation of softwood vegetation to protect the riverbanks against erosion.

The project started in 1990 and lasted until 1995. For this study willows were the obvious species of choice, since this type of softwood vegetation can survive in frequently inundated environments and is found naturally within groyne fields. Three suitable sites along the River Waal were selected in which willows were planted. During a five-year period, these sites were annually monitored and compared to reference sites with comparable conditions but without vegetation.

After these five years, it was concluded that the planting of willows within groyne fields has a distinct impact on the morphology. Sediment is trapped within the willow planting while the riverbank steepness in front of the vegetation increases due to erosion. These morphological processes can induce the development of a retreating edge causing mortality along the front row of the willows. Whether these morphological processes will continue on a longer time scale is uncertain. It was therefore recommended to prolong the monitoring for a longer period on a yearly basis. Due to financial reasons, these recommendations were never complied with.

After a period of ten years, a vacancy for a M.Sc. student was made available to continue this study. New surveys had to be conducted to complement the data for the current situation. Based on these data new conclusions are drawn on the effects of softwood vegetation within groyne fields. Furthermore, the processes and factors, which are mentioned throughout this report to have an effect on groyne field morphology, are bundled into a conceptual riverbank model for groyne fields with the presence of softwood vegetation. From this model a list of desired improvements for future riverbank models has been derived.

1.1 Set-up of the report

Within Chapter 2 the problem outline for this study is given as well as the derived objectives. Chapter 3 will give some background on the preceding study, which includes the research approach, project area and conclusions previously found. Chapter 4 deals with the hydraulic conditions within the Waal river which is the main driving force for morphology. Chapter 5 describes the used techniques and method. Specified into measuring terrain elevation and processing data. Within Chapter 6 an analysis is given of the survival and mortality of the used vegetation. Chapter 7 deals with the analysis of the morphodynamics at each location. Within this chapter, volumetric calculations can be found as well. Chapter 8 deals with the generic processes needed for building a conceptual model. Also some desired improvements for future erosion bank models are given. Conclusions and recommendations are given within chapter 8.
2 Problem definition and objectives

The high waters levels of 1995 and 1998 raised a wider awareness that flooding of the hinterland is a realistic and threatening possibility. Due to climate changes this problem is likely to become greater in the near future. Until the last decades, the policy regarding flood threads was to raise the crest levels of the dikes. This policy no longer seemed to be sustainable and has been replaced by “Room for Rivers”. This new policy is presented in the form of a “Spatial Planning Key Decision” (SPKD). With this tool, the government presents an integrated development plan, which has set the objectives of:

1. Providing safety against extreme river floods
2. Improving overall environmental conditions

Special attention within this SPKD is paid to preservation and development of natural values. With nature development, more vegetation is to be expected near rivers. The presence of vegetation is also enlarged by the lack of maintenance near rivers. On aerial photographs taken in 2003 it can be seen that at present a considerable amount of softwood vegetation can be found within groyne fields. The consequences of softwood vegetation on groyne field morphology are yet unknown.

2.1 Problem definition

Vegetation is known to decrease flow, attenuate waves, alter the soil characteristics and trap sediment. These processes influence the deposition and erosion of sediment within groyne fields. The total and individual contribution of these processes and their accompanying timescales are still unknown.

2.2 Objectives

The objective set for this thesis is to provide insight in the morphological development of groyne fields with softwood vegetation and to describe the relevant processes in order to provide a conceptual riverbank model for groyne fields with softwood vegetation.

In order to achieve the main objective the following secondary objectives have been set:

- Establish insight on the current state of knowledge and relations between vegetation and river morphology by conducting a literature study and consulting experts in the field.
- Organize and conduct field measurements to describe the morphology for the current situation.
- Process the data for the previous and the current study so that it can be used for analysis.
- Assess commonly used interpolation methods to find the most useful method for this study.
- Determine the hydraulic conditions at each location for the period from 1990 until 2005 with the use of a 1D hydraulic model.
- Determine the survival percentage and mortality rate for the different willow species.
- Analyse the morphological changes and link them to morphological processes within groyne fields.
- Bundle the found processes and factors to provide a conceptual riverbank model for groyne fields with softwood vegetation.
- Provide recommendations for future river bank models.

1 www.ruimtevoorderivieren.nl
3 Previous study

Prior to this thesis, a study had been carried out by RIZA to examine the possibility of using the planting of willows as a means of riverbank protection within groyne fields. This study took place from 1990 until 1995 and is described in “Wilgenaanplant in kribvakken langs de Waal 1990-1995 (VAN SPLUNDER & SCHOOR, 1997)”. Three different species of willows were planted at each of three selected groyne fields spread along the River Waal. During a period of five years, these locations and species were annually monitored. It was recommended to prolong the study period and repeat the surveys once every five years. Instead of five years, this continuation study started after ten years.

3.1 Project area

In 1990, three suitable locations for the planting of willows were selected based on the following considerations:

- The sites had to be situated along the river at places that were known to be eroding.
- To minimize the effects of other morphological processes the erosion of the reference groyne fields on either side of the test sites had to be of the same magnitude as the test site.
- To reduce the water-level set-up during great discharges the groyne fields had to be parallel to the major flow direction at these water levels.
- The effect of navigation-induced forces had to be similar. Preferably, the locations had to be on the same branch of the river.
- To study the possibilities of implementation along the whole river the locations had to be spread along the length of the river.

Three locations along the River Waal that complied with these considerations were selected for this study (Figure 1 to 4). At each location, three groyne fields were selected. One for planting the willows and an upstream and a downstream groyne field which were used as reference.

![Figure 1: Overview of the selected locations along the River Waal](image)
3.2 Species and planting

Three different species of willows were selected in order to determine which species would be best suited to be used as riverbank protection. The selected species were:

- *Salix viminalis* (common osier or basket willow)
  This species is commonly found within riparian areas along the Dutch rivers. It can be recognized by its narrow and long leaves with slightly rippled edges. The bush has a narrow and straight profile and can be up to six metres high. It has great regenerative capabilities and can grow adventive roots allowing it to grow in frequently inundated areas.

- *Salix purpurea* (purple willow)
  This species is found more often within the floodplain of rivers. Its leaves are narrow and long with smooth edges. Bushes are wide and can be pillowike. It can reach a height of three to six metres.

- *Salix cinerea* (gray willow)
  The *Salix cinerea* is best adapted for swampy areas. Its leaves are broad and 2.5 to 6 centimetres long. Within the Netherlands, it is one of the most common species of willows. It can also grow up to six metres high.
At each location, the willows were planted in lines of direction with an angle to the direction of the flow of the river. The different species were planted in an alternating pattern as shown in Figure 5.

An area of 25 metres wide was kept empty near the groynes. The willows were planted up to the waterline at that time (April 1990). The shape of the frontline of the willows therefore follows the waterline at that time. On average 18 rows per groyne field were planted.

3.3 Conclusions

Based on five years of monitoring it was concluded in the preceding study (VAN SPLUNDER & SCHOOR, 1997) that there is distinct impact of the planted willows on the morphology within groyne fields. Whether the planting of willows has a positive or protecting effect on the riverbank depends on the area of interest. The area covered by the willows planting shows a positive sediment balance but when looked at the whole groyne field area the sediment balance is found to be negative. This is the result of erosion of the groyne field area in front of the willows (riverwards). Due to the sediment accumulation within the plantation and erosion in front of the willows a small erosive bank can be found in the transition area. Based on five years of monitoring it was not possible to predict the long-term effect on the morphology. It was therefore recommended to prolong the study at five year intervals.
4 Hydraulic conditions

Waterflow is the main driving force for morphodynamics. For this thesis a computation of water level and discharge have been made for each test location. This has been done by using a 1D hydraulic-morphologic model called SOBEK. The SOBEK for Rhine branches model is commonly used for high water level predictions, policy formulations, recommendations and decision making. Since morphology changes over time, several different versions are available, calibrated for their corresponding geometry and hydraulic conditions. For this study three versions have been used;

SOBEK-Rijn version 2000.2
- Calibrated for high water level of December 1993 with summer bed level of 1993

SOBEK-Rijn version 2000.3
- Calibrated for high water level of November 1998 with summer bed level of 1997

SOBEK-Rijn version 2003.1
- Calibrated for high water level of spring 2002 with summer bed level of 2000/2001

4.1 Water levels

SOBEK has been used to reconstruct the water levels at the three test location during the fifteen year study period. Since the accuracy of measuring terrain elevation was expected to be in the order of 1 to 10 cm, using an estimated guess based on an energy slope and measurements from nearby gauging stations would be to crude. It was believed that the desired accuracy could be achieved using this model. At first computations were made enforcing discharges. These were obtained from a nearby gauging station at Lobith (taken from Waterbase). After comparison of calculated and measured water levels at downstream gauging stations, unacceptable level differences (over half a metre) were found (Figure 6). Water levels for the River Waal were systematically underestimated by the model, with increasing errors for lower water levels.

Figure 6 Water level differences using SOBEK-Rijn with Q-enforced compared to water levels measured at gauging station Pannerdense Kop

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2 www.waterbase.nl
Several explanations can be provided possibly providing an answer to these level differences. First of all, measuring river discharges is less accurate compared to measuring water levels. With discharges a cross-sectional area is needed at the measuring location. These cross sections are difficult to obtain and liable to morphodynamics and therefore vary in time. This negatively affects the accuracy of the calculated river discharges. Furthermore, discharges from waterbase are not actual measured discharges but derived from Q-h relations which might give a false sense of accuracy. Secondly the SOBEK-Rijn model is calibrated (determination of Q-h relations) with enforced water levels. By using discharges as a forcing, the model might calculate an erroneous discharge distribution for the river branches at Pannerdense kop. Moreover, the model is calibrated based on long term flood events using geometrics for high water level conditions. At high water levels the model is less sensitive to geometric differences due to its (wet) perimeter/surface area ratio. When using the same model at low water levels its sensitivity therefore increases. This increase can explain the inverse correlation between the water level and error differences between calculated and measured water levels. Another explanation can be hysteresis, whereas discharge may vary with equal water levels. Rising water will cause a higher discharge, while retreating water will cause a smaller discharge with the same water level. This can be subscribed to local depth variances causing the front of a long term wave to be steeper compared to rear side.

Instead of re-calibrating the model for enforced discharges new computations have been made using enforced water levels at Lobith. These computations provided a more reliable result (Figure 7 and Figure 8). Differences at location Pannerdense Kop and each are within ±10 cm. This accuracy is of the same magnitude as measured terrain elevation and therefore sufficient for this study.

In appendix 1 the differences between calculated and measured values have been given for all other gauging stations along the river Waal in downstream direction. What can be seen is that accuracy decreases in downstream direction but still remains acceptable for this purpose. Since the three test locations lie between these gauging stations, it is likely that the calculated water levels at these locations also are sufficiently reliable. The observed increase is to be expected since calculation errors also travel in downstream direction and are likely to show up at lower water levels. It is also likely that hydrology of the river area which is not integrated in this model can be an important factor. In the model no water will be lost or added, in practice this is likely to occur. Furthermore the increase of “noise” for the location of Zaltbommel and further downstream shows the influence of the tide. One graph is used to show the difference between day-averaged values instead and the 12-hour reading for Zaltbommel. What can be seen is that this reduces the “noise” due to the influence of the tide since the tide fluctuates around an average water level. The effect on the water level due to the tide at Zaltbommel has been estimated to be in the order of 15 cm.
Figure 7 Water level differences using SOBEK-Rijn with \textit{H-enforced} compared to water levels measured at gauging station Pannerdense Kop

Figure 8 Comparison of SOBEK-Rijn computations with \textit{Q-enforced} and \textit{H-enforced} and measured values
The three models mentioned earlier are each used to describe a period of five years.

1990-1995 is described by, SOBEK-Rijn version 2000.2
1996-2000 is described by, SOBEK-Rijn version 2000.3
2001-2005 is described by, SOBEK-Rijn version 2003.1

To determine the effect of using different versions, an overlapping year has been calculated with each version change (Figure 9).

As can be seen differences are negligible. However when the water level drops under 9 m +NAP a difference of up to five centimetres occurs. This is probably a result of the differences in used bed levels used with each version. It nevertheless seems remarkable that for both version changes, the 9 m +NAP elevation seems to act as a threshold. Since this occurs in both version changes this might indicate that this difference lies within version SOBEK-Rijn version 2000.3.

The calculated water levels for each test location are displayed in Figure 10. Within each graph the 50% water level percentile for the corresponding period is added. This means that 50% of the time the water level is above this level and 50% of the time it is under this level. It is also indicated when surveys have been conducted that are described in the following chapter.
Figure 10 Calculated water levels per location
4.2 Discharge

As with the water levels a comparison has been made between calculated and measured discharges (Figure 11 and Figure 12). Differences in discharge may show erroneous discharge distribution within the model. The calculated discharges are taken from the same computations, with **H-enforced** at Lobith, as used for the water levels. As can be seen calculated discharges are systematically overestimated (9.4% averaged at Lobith and 7.8% at Pannerdense kop) when compared to measured discharges. This seems inconsistent with the higher measured water levels found compared to the calculated values. Besides from possible human errors this inconsistency could have several other origins. As mentioned earlier, measured discharges are not actually measured but derived from Q-H or Q-HH relations, much like SOBEK. Therefore it is likely that this inconsistency lies within the modelling itself and the use of Q-H and Q-HH relations.

Since finding the difference between the given discharges from waterbase and the SOBEK model would reach beyond the scope of this Thesis, it was decided to use the given discharge from Waterbase. The discharge given at Pannerdense Kop is used for the whole reach of the river Waal since river discharges hardly vary along an uninterrupted river branch from a hydraulically point of view.

**Figure 11** Discharge differences between calculated and measured values at Lobith

**Figure 12** Discharge differences between calculated and measured values at Pannerdense kop
4.3 Direction of flow

Besides discharges, and corresponding water level variations, the direction of flow also determines where erosion or sedimentation can be expected. Within groyne fields, two different situations with respect to direction of flow can be distinguished. A situation with emerged and a situation with submerged groynes. The direction of flow will be treated per situation.

4.3.1 Emerged groynes

During low discharges (low water levels), the groynes are emerged. Flow directions within groyne fields are difficult to determine during this situation. With stationary flow, the flow pattern of most groyne fields consist of a primary eddy, a secondary eddy and a dynamic eddy as displayed in Figure 13.

![Figure 13 Flow pattern with emerged groynes (MOHAMED F.M. YOSSF, 2006)](image)

The size of the groyne field compared to its groyne length mainly determines whether a secondary eddy or just a primary eddy is to be expected within the groyne field.

Shipping activities also have a large impact on the flow pattern within groyne fields. Especially heavily loaded (multiple) tow barges have a great impact. The effect of passing barges on the flow pattern has been described by VERHEYEN VERMEER (1987). A schematisation of a passing tow barge is given in Figure 5. Since the “stationary” situation alternates with varying flow patterns due to frequently passing vessels, it is very difficult to describe an average flow pattern for the groyne fields along the river Waal.

![Figure 14 Flow patterns within a groyne field due to discharge and the passing of a tow barge (CUR, 1999)](image)

Except for the location of Druten the studied groyne fields are located in an outer bend. The curvature of the main channel on the flow pattern within groyne fields is also of great importance. This
combined with the alignment of the groynes (with respect to the direction of river flow) determines whether the main current is directed at or deflected away from the groyne field. This is described by KLINGEMAN et al. (1984). Overall, it can be said that flow patterns within groyne fields are determined by local and time varying characteristics. Since many of the characteristics are unknown and variable, it is very difficult to describe a distinct flow pattern for a single groyne field.

4.3.2 Submerged groynes

Since water level varies with different discharges, several different situations can be defined in respect to flow patterns. One of the situations is when the groynes are over flown. For the river Waal this situation actually can be subdivided again into two situations. One with submerged groynes but where the water level remains below bank full and the other above bank full. In the situation with bank full the flow pattern also covers the winterbed.

For the situation below bank full actually little knowledge is available. The direction of the main flow will be in down stream direction but the groynes are still likely to have a distinct impact. This effect is likely to decrease with increasing water levels. During this stage, shipping activities continues and therefore also plays a role.

For the situation above bank full, Waqua calculations have been made in order to visualize the 2D flow pattern and streamlines, which can be found in Appendix 2. The given discharge for this situation is that of 5 November 1998 and its measured at 9093 m$^3$/s. The interpretation of these pictures will deal with per location.

Gendt
These test locations lie within an outer bend and it can be see from the flow patterns that flow is directed slightly inlands from the up stream groyne field to almost parallel at the down stream groyne field. From the (diverging) streamlines, it can be concluded that especially in landward direction the flow velocities will decrease. When looked carefully a small nudge can be distinguished in the streamline, from the middle of the willow groyne field up to the next groyne down streams. This indicates that flow velocities increase in front of the willow population.

Druten
The test groyne fields at Druten are located at the end of a riparian area when looking in downstream direction. This means that water that flows over the winter bed has to flow out back to the channel. This can be seen from the figure with flow patterns. It can also be seen that there is a current from the upstream direction converging with the current flowing out. This occurs from the upstream groyne field up to the willow field. The outflow of the winterbed meets the current of the main channel somewhere at the lower bank. Here streamlines strongly converge and flow velocities will increase.

Gameren
At the location of Gameren water flows from the main channel into the secondary channel through the upstream groyne field of the test locations but also slightly through the willow field. Water flows back through the downstream groyne field to the main channel. Water flowing into the channel and through the willows decelerates which can be seen from the diverging streamlines. Water flowing back to channel accelerates. The deflection of flow direction is introduced by dry terrain (high terrain elevation) where a brickyard used to be.
5 Technique and method

For this and the preceding study, field surveys have been carried out in order to collect data on terrain elevation and survival rates of the willow populations. Based on elevation data, changes in morphology are analyzed. For this MSc. thesis, measurements have been carried out late 2005 and early 2006. These measurements complement the data available from the previous study to the present situation. Besides the measurements itself, attention was paid to local characteristics and processes observed within the groyne fields. These observations provided useful insight for interpreting and analysing the data later on. For instance, on getting a feeling for scale and magnitude.

5.1 Measuring terrain elevation

According to the technology available at the time, terrain elevation has been measured using several different techniques. As part of the groyne field is submerged, a two-way approach was used. The emerged section was measured using land-based equipment and the submerged section was measured using vessel-mounted equipment. The schematisation given Figure 15 has been used throughout the whole of this report.

5.1.1 Previous study

During the period of 1990 to 1995 terrain elevation was measured approximately eight times. These measurements were carried out for the study of willow plantings within groyne fields along the river Waal (VAN SPLUNDER AND SCHOOR, 1997). The methods used per section are schematised within Figure 16.

Emerged section

Measurements of the upper bank were carried out using a levelling instrument and beacon. With the use of pickets and spatially fixed points, the spatial reference across years was assured. In 1995 GPS was used for the first time. Measurements were taken in lines of sight perpendicular to the river-axis. These lines were approximately twenty metres apart with a point-to-point distance of around five metres. When using a levelling instrument, accuracy decreases with increasing distance between levelling instrument and beacon. The average length (perpendicular to the river) of the dry section of a groyne field along the Waal River is about forty metres. Due to this relative small distance a rather high accuracy could be achieved. The achieved accuracy in vertical direction is in the order of one centimetre. Accuracy in the horizontal plane is less and is in the order of one metre.

Submerged section

Measurements of the lower bank and foreshore were carried out using a single beam echo-sounding device (Seabee) attached to a vessel. Spatial reference was achieved using systems
like Micro-fix and Artemis. Both systems use timing differences received from radio signals sent from base stations (with known fixed positions) to determine the position of a (mobile) receiver. Measurements were also carried out in lines perpendicular to the river-axis. These lines were five to ten metres apart with a point-to-point distance of one metre. Although echo sounding itself can provide great accuracy measurements, movements (pitching, heaving and rolling) of the ship diminishes accuracy. The accuracy achieved using this method, is in the order of ten centimetres in the vertical direction and in the order of one metre within the horizontal plane.

Figure 16: Schematisation of used techniques for the period of 1990-1995

5.1.2 Study of 2005-2006

During the study of 2005 and 2006 the measurements of the terrain elevation were divided into eight separate surveys 2006 (Table 1). The methods used will be described in the following paragraphs with respect to the measured section (submerged or emerged).

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>17-10-2005</td>
<td>Gendt</td>
<td>MBES</td>
</tr>
<tr>
<td>18-10-2005</td>
<td>Druten</td>
<td>MBES</td>
</tr>
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<td>22-02-2006</td>
<td>Gendt</td>
<td>MBES</td>
</tr>
<tr>
<td>23-02-2006</td>
<td>Druten</td>
<td>MBES</td>
</tr>
<tr>
<td>13-12-2006</td>
<td>Gameren</td>
<td>RTK-DGPS</td>
</tr>
</tbody>
</table>

Table 1 Measurement location, date and method

During a water level rise in the beginning of begin 2006, the test locations for Gendt and Druten have been surveyed again. This was done since the measurements of 2005 did not cover the whole area of the groyne fields. Due to the two-way approach also used with the previous study a gap was present between the measurements of emerged and the submerged section. Because of the water level rise, it was possible to extend the measurements of the submerged section further into the groyne fields providing an overlap with the emerged section.

As for the previous study, first the measurements of the emerged section will be described followed by the measurements of the submerged section.
Emerged section
Terrain elevation of the emerged section was measured once during this period. For these measurements surveying equipment was used with LRK®-DGPS\(^3\) capability (Figure 17). DGPS is a way to improve the accuracy of GNSS\(^4\) by using two receivers instead of one. One receiver (the base station), has a known fixed location and the other (the rover) is used in the field. The base station compares its known location with the calculated location based on received signals from the navigation satellites. Differences between these two will reveal any error due to atmospheric interference, reflection, or other error sources. A correction for these errors is send to the rover improving the accuracy of the measurements in the field. Accuracy decreases with increasing distance between base station and rover. However, with the use of LRK®, accuracy can be further improved. It takes advantage of the dual-frequency from the GNSS, making it possible to survey at a greater distance from the base station even with a reduced number of visible satellites. The accuracy in the horizontal plane is 1 cm ± 0.5 ppm (parts per million with respect to the distance to the base station). The accuracy in vertical direction is in the order of 2 cm ± 1 ppm. With a range of around 40 km this results in a horizontal accuracy of 3 cm and a vertical accuracy of 6 cm.

Submerged section
The submerged sections were measured using a (Seabat 8125) Multibeam Echolocad System (MBES) attached to a vessel. This system uses an array of 240 single beams allowing surveying of a path of 3 to 4 times the water depth with a point-to-point distance of one metre. The device was slightly tilted allowing it to look further away instead of looking straight down. This way, areas can be surveyed which the vessel cannot reach due to its draft. The density of the point measurements is one point per square metre. The accuracy of the MBES is rather high. Its accuracy in vertical direction is in the order of centimetres. Accuracy in the horizontal plane is also in the order of centimetres.

\(^3\) Long Range Kinematic – Differential Global Positioning System
\(^4\) Global Navigation Satellite Systems
5.2 Processing data

The field surveys of the previous and current study provided datasets containing x,y,z coordinates of the terrain elevation of corresponding date and location. This data was converted and adapted so it could be used for further processing and analysis in GIS-software. New databases had to be constructed according to a specific format and old data had to be converted so it could be used with a newer version of the used GIS-software. The next step was to check the data for integrity. From the selected datasets surface maps have been created using several interpolation techniques. A discussion about the techniques used is given in paragraph 5.2.3. From the created surface maps profiles have been drawn. These profiles are used to analyse the changes in morphology over time described within the next chapter.

5.2.1 Analysing datasets

The first step with using GIS-software was to check the data integrity. This was done by plotting the data on a spatially referenced schematisation (DTB-2000) with an underlying aerial photo of 2003 (Figure 18). With these plots, odd points, measurement gaps or areas with low measurement densities were exposed.

As the emerged and submerged sections were not measured on the same day, the water level could have changed between measurements. This sometimes resulted in areas without elevation data. These areas are further referred to as gaps or measurement gaps (Figure 18). Largest gaps between both methods were found for the measurements of 1992 and 1994. These datasets were left out for further analysis since no reliable covering surface maps could be made based on these measurements. For all other data, it has been indicated throughout the analysis whenever and where gaps between measurements are present. The location of the gaps was always at the lower bank, since this area is usually submerged but shallow and therefore difficult to reach for both methods. Throughout the analysis datasets are referenced to by its location, its year and its month of measuring. Abbreviations have used for the locations; “Ge” stands for Gendt, “Dr” for Druten and “Ga” for Gameren. Because the data of the dry and wet section has been merged for each location the reference of year and month indicates the measurement of the last measured section. For example, Dr0510 is the data set for Druten where its last section was measured in October 2005. When referenced to a single groyne field at one location the abbreviations, “AF” for downstream, “WL” for willow and “OP” for upstream have been used. The datasets used are listed in Table 2.

<table>
<thead>
<tr>
<th>Location</th>
<th>Reference</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gendt</td>
<td>Ge-9106</td>
<td>Gap in AF</td>
</tr>
<tr>
<td></td>
<td>Ge-9311</td>
<td>Gaps at all fields</td>
</tr>
<tr>
<td></td>
<td>Ge-9505</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Ge-0602</td>
<td>-</td>
</tr>
<tr>
<td>Druten</td>
<td>Dr-9106</td>
<td>Processed data only (non-original dataset)</td>
</tr>
<tr>
<td></td>
<td>Dr-9311</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Dr-9505</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Dr-0602</td>
<td>-</td>
</tr>
<tr>
<td>Gameren</td>
<td>Ga-9106</td>
<td>Gaps in all fields, processed data only</td>
</tr>
<tr>
<td></td>
<td>Ga-9311</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Ga-9606</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Ga-0512</td>
<td>Gaps in all fields</td>
</tr>
</tbody>
</table>

Table 2 Measurement date and indication of gaps for the used datasets

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5 Graphical Information System
5.2.2 Interpolation

By comparing terrain elevation for several different stages in time, changes in morphology can be revealed. Point data obtained from measurements do not give a continuous representation of the terrain elevation, which is needed for such a comparison. By using a surface model based on the point data this can be overcome. For creating such a model interpolation is needed.

Surface modelling

Surface models can be represented as Rasters or TINs\(^6\). Raster surfaces consist of uniformly spaced cells containing z-values. TINs consist of nodes that store z-values, connected by edges to form contiguous, nonoverlapping triangular facets (Figure 19). When creating surface models, areas between measured points have to be predicted. This is achieved by interpolation. Several different techniques for interpolation are available, for example; IDW\(^7\), Natural Neighbours, Spline, Kriging, Surfis, Digipol, etc. All these techniques are based on the assumption that spatially distributed data are spatially correlated. For this study several surface models have been made based on different interpolation techniques. Note that, triangulation itself (used for creating a TIN) is an interpolation method as well.

---

\(^6\) Triangulated Irregular Network (TIN)
\(^7\) Inverse Distance Weight (IDW)
**Drawing profiles**

While surface models are useful in determining volume changes over time, it is difficult to use these models for visualizing profile changes over time. Therefore, profiles are drawn based on the created surface models. For each groyne field five profiles are drawn spaced evenly between and parallel to the groynes (Figure 20). The profiles are numbered (1 to 5) from left to right with a prefix referring to the groyne field they are in; AF for the downstream groyne field, WL for the groyne field where the willows were planted and OP for the upstream groyne field.
The profile data are converted so it could be used in Excel. In this way profiles drawn on TIN models from different data sets (years and location) can easily be compared with each other. This was done because this functionality was not available in the GIS-software. An example of how graphs are displayed within Excel is given in Figure 21. With arrows, the most characteristic morphological changes are accentuated. The number indicates the last year this change refers too. Within the willow fields the location of the vegetation border of 1990 and 2003 have been indicated.

![Figure 21 Example of how profiles are displayed within Excel](image)

### 5.2.3 Discussion interpolation methods

For this study four different methods of interpolation have been tested. Based on surface models created with these methods and profiles drawn from the surface models, the interpolation methods have been compared with each other. Which technique works best highly depends on the spatial distribution and density of the dataset. A good comparison of interpolation methods used within Rijkswaterstaat is given by VAN HALDEREN (2005).

### Surface models

The methods used for creating surface models were Tin, Idw, Kriging and Surface2D. The surface models created with these interpolation methods are visualized in Figure 22. Tin created directly from measuring points, provides a surface constructed of triangular flat facets fit exactly through measurement points (Figure 19). The created surface model shows slightly abrupt direction changes. A surface interpolated with IDW shows dents and bulges. This method has great difficulty following uneven distributed datasets for highly variable terrain. Kriging on the other hand provides a smooth and visual plausible surface model is. However, much of the original data is lost. This can be seen by the measurement points shown on the other maps that have disappeared from the surface model with Kriging. Since no estimation of the error is made, this method gives a false sense reliability. Surfis2D provides a rather jerky surface, caused by its double regression method. This is mainly affected by its search area and direction. Nevertheless Surfis2D does provide an estimate of the error made for each point, which other methods lack. This method is likely to provide better results on larger areas with less focus for detail. Based on this visual inspection TIN seems to provide the most plausible surface model.
Profiles

In Figure 23 a comparison of the used interpolation methods based on profiles has been given. Hereby each method has been compared to profiles drawn directly from a **TIN**. As expected most interpolation techniques more or less give the same shape. Only at places with a lower measurement point density (for example; the gap between GPS and Multibeam) large differences can be seen. **IDW** shows the largest fluctuations compared to other methods. This is a result of the dataset being inhomogeneous which also could be seen from bulges and dents in Figure 22. Profiles drawn on a surface interpolated with **Kriging** have a tendency to lose a lot of detail (almost a straight line). This loss of detail was also seen in Figure 22. Profiles drawn from a **Surfis2D** model show jumps (stairs) in areas with lower measurement point density (DGPS) and greater elevation changes.

Conclusion

After comparison with each other, TINs created directly from the measurement points seems to provide the best surface models and profiles. This method gives a good representation without adding too much “noise” from the interpolation method itself and without too much loss of detail. One of the advantages of using TIN surfaces is that original information is not degraded in any way. The other interpolation methods are based on grids. However, point data and grid cells hardly ever spatially correspond. Values for empty cells have to be assumed and cells with multiple point data are constructed of averages. Grid based interpolation techniques however are likely to provide more reliable results for areas unmeasured (gaps). Since throughout the study used has been made of TIN, areas with large measuring gaps (relative to the average measurement point density) are indicated as such, or are left out during analysis. This way it is prevented that conclusions are drawn based on a false representation of the terrain elevation.

---

*Figure 22 Several interpolation methods compared.*
Figure 23 Profiles drawn on various interpolation techniques
6 Analysis - vegetation

For each of the three locations, mortality rates for the different willow species were determined. Mortality rates were derived from survival percentages found during field surveys. The results found will be treated per study period.

6.1 Previous study

From 1990 to 1995 the number of deceased species and their location were determined during each survey. From these numbers, survival percentages were established as well as a spatial presentation of absent vegetation for the years of 1991 and 1995 (VAN SPLUNDER AND SCHOO, 1997). Based on these numbers it was clear that for all species the greatest losses occurred within the first year of this study period. It was concluded that whether or not twigs would be able to sprout, is mainly influenced by its sensitiveness to drought. For the Grey willow (Salix cinerea) and Purple willow (Salix purpurea) losses were found throughout the whole groyne field. For the Common osier (Salix viminalis) losses were mainly found at the riverside. The Grey willow proved least successful overall and especially on higher located areas. This can be explained by the fact that this species is commonly found in frequently inundated areas like swamps and on sea clay and therefore is likely to have suffered from dryness [WEEDA et al., 1985].

After the first year, losses for all species occurred mainly at the riverside. In a progress report of 1991 [VAN SPLUNDER AND SCHOO, 1992] it was mentioned that the inundation period negatively influences bush height. During inundation sprouting and rooting stops and after longer periods of inundation root structures start to disintegrate. It is likely that this process restrains growth, making the front rows more vulnerable to wave attack and currents. Wave attack and flow velocities are also larger along the frontline. Higher up, wave energy will be increasingly dissipated and flow velocities will be reduced due to interaction with bottom and vegetation. This dampening effect is increased by fallen trees at the front row giving shelter to the next row of vegetation (Figure 24). These species are likely to be swept away during high discharges leaving the next row unprotected and thus repeating the process.

![Figure 24 Frontline of fallen trees giving shelter to the vegetation behind](image)

In the report of “VAN SPLUNDER AND SCHOO” [1997] it was also mentioned that mortality within a single groyne field was found to be higher at the downstream side. This is believed to be an effect of local differences of flow velocities within a groyne field. Furthermore, it was found that bush height is negatively influenced by increasing grain size. This was linked with the location along the river. Coarse sand is found further upstream (Gendt) and fine sand is found more down streams (Gameren).

At the end of the study survival rates for the Common osier, Grey willow and Purple willow were respectively 70%, 55% and 35%. This would make the Common osier best suited for survival within groyne fields of these three species.
6.2 Study of 2005-2006

As for the previous study, the number of surviving willows was counted. Due to the absence of previously used markers it was not possible to determine the spatial location of absent trees. Differentiation between the different species could only be made at the location of Gendt. Gameren and Druten were observed in winter, where the willows were leafless. Without a biologist assisting in the field, it was impossible to distinguish purple willow from grey willow. For these locations, the categories have been limited to the Common osier and other species combined.

Although no spatial representation per species could be given it was possible to give an indication of how the outline of the vegetation had changed between 1990 and 2003 (Figure 25).

![Figure 25 Vegetation outline for Gendt, Druten and Gameren](image)

The reference year is 2003 since the most present aerial photo from which this outline was constructed was from this year. The outline of 1990 is based on DGPS measurements of 1995 from which the original locations of the species have been calculated. During this period the planted willow area has decreased with an estimated 20%.

As can be seen, for each location the front line has retreated landwards. This is consistent with the assumption that vegetation suffers most during low discharges due to wave action and currents within the groyne field. It can also be seen that the upstream side of each vegetation outline has become somewhat streamlined compared to the downstream side. This is thought to be an effect of flow during high discharges. The upstream area and protruding vegetation will experience higher friction forces, increasing the chance of being grubbed out. The assumption that mortality rates increase in downstream direction no longer seems to hold.

Based on the most landward row the outline 1990 for Gendt seems a little bit off (too much riverwards). This is thought to be the result of erroneous spatial reference of the DGPS in 1995. This does not affect the relative measurements for the location Gendt, therefore the shape of the outline itself is still reliable. At the location of Druten spontaneous germination was found at the back, explaining the landward shift of the outline.
Approximately 25% of the willows at Gendt have been cut down (Figure 22). The reason for this is unknown but it was suggested that this has been done to improve radar sight for shipping traffic. Based on aerial photographs this must have taken place somewhere between 2000 and 2003. Obviously this negatively influences the survival rate for the willows at Gendt.

### 6.3 Survival percentages and mortality rates

From the combined data from the current and previous study new graphs have been made showing the survival percentages for the different species at each location per year (Figure 26).

#### Figure 26 Survival percentages per species for each location

From these survival rates mortality rates have been calculated (Figure 27). This was done based on the following formula:

\[
R_n = 100\% - \left( \frac{P_{0+n}}{P_0} \right)^{\frac{1}{n}} \times 100\%
\]

- \( R_n \): Average mortality rate during period \( n \) (% per year)
- \( n \): Time interval (years)
- \( P_0 \): Survival percentage at the start of a time the interval (%)
- \( P_{0+n} \): Survival percentage after a time interval \( n \) (%)

\( P_0 \) indicates the survival percentage of the first year of the period you are interested in. \( P_{0+n} \) indicates the survival percentage of the last year of the period you are interested in. Summarized, this formula breaks down the mortality rate for a period of multiple years into an average mortality rate per year. Because the calculations are based on survival percentages, the second term is subtracted from 100% to convert into mortalities. For Figure 27 a time interval of \( n = 1 \) was used.
As can be seen the greatest losses for all species indeed occurred during the first year for all locations. Furthermore, *Salix cinerea* proved least successful over the whole study period. At the location of Gendt just a single specimen was found. The species of *Salix purpurea* and *Salix viminalis* eventually proved more or less equally successful at location of Gendt (2% difference). At the other locations, *Salix viminalis* was probably most successful. To confirm this, it is recommended that further surveys should be conducted outside the winter season. Due to the cuttings at Gendt the overall mortality was in the order of 5% larger compared to the other locations. Furthermore it should be noted that at each location some species of spontaneous vegetation was found between and even outside the plantation area. However, these were low in number compared to the willows and therefore left out of this study.

Based on the size differences for the vegetation outline (Figure 25) (estimated at 20%) a larger survival percentage would be expected as was found from the analysis. This means that the population has also become less dense over time. Natural processes of aging, diseases, mutual competition for resources can partly explain this difference. As mentioned earlier drought also could partly explain this difference.

From the average mortality rates, it can be seen that after the first year mortality rates tend to decrease but eventually increase again to about twice the smallest experienced mortality rate. Since mortality rates are averaged, no information is available about the distribution of mortality during the last ten years. So there is an uncertainty as to when or how this increase was induced. The increase is most likely the result of completion for mutual resources. However, it can also be imagined that with a decreasing or a less dense population its resistance to wave action and water flow also reduces. Subsequently this could lead to a higher mortality rate.

Since spontaneous vegetation also occurs along the River Waal it seems more plausible that a form of steady state can be achieved between the survival “strength” and “load” enforced by river and habitat. In order for this to actually occur, succession will be needed.
7 Analysis - Morphodynamics

For each location (Gendt, Druten and Gameren) elevation difference maps have been made for the period of 1991-1995 and 1995-2005. These maps cover the groyne field with the planted willows and the upstream and the downstream groyne field at each test location. The difference maps have been constructed from the surface models described earlier. The surface map of the first year of each period has been subtracted from the last year. Positive numbers therefore indicate sedimentation and negative numbers indicate erosion. Based on these maps and drawn profiles morphological changes over time are determined at each location. The observed changes will be described per location and per groyne field.

7.1 Gendt

The groyne fields near Gendt are situated in an outer bend on the right side of the river. These fields are known to be eroding. Somewhere between 1992 and 1993 material has been dumped at the foreshore. This was probably done during dredging activities. Since about 15 years, dredging companies are obliged to redistribute dredged material within the river area itself. The dumped material is clearly visible on the difference maps of 1995 – 1991 (Figure 28). Profiles show that this interference has had great influence on morphologic changes of the foreshore. To what extent it influenced processes further into the groyne field is unknown. Morphological changes will be shown per groyne field in the following subparagraphs. In the period 1995 – 2005 all groyne fields show sedimentation mainly near the upstream groyne and erosion in downstream direction, as can be seen in Figure 28.

![Figure 28 Elevation difference maps of 1995-1991 and 2005-1995 at Gendt](image)

Downstream field

The downstream groyne field is characterized by the formation of a steep erosive bank (Figure 29). This steep erosive bank could first be seen in 1993 and has gradually shifted inland (Figure 30). At present, the bank is over 4 metres high. Together with the formation of this bank, the natural levee has retreated inland, 25 metres at the top and over 40 metres at the base (compared with 1991). Bank failure occurs whenever driving forces (wave attack, flow, gravitation, etc.), exceed resisting forces (friction and cohesion). Material released during a collapse is distributed within the groyne field and finally transported out of the groyne field towards the main channel. If this erosion process continues without interference, loss of function of the upstream groyne field is expected over time due to outflanking. When water is allowed to flow free at the front and back of the groyne it no longer effectively fulfils its function of normalizing the main channel.

The material that was deposited during dredging activities at the toe of the foreshore has made the slope less steep (best seen at the centre of the groyne field) and caused the foreshore to extend further into the river. Compared to 1995 the largest changes for the submerged section are found near the groynes (Appendix 3). The groynefield beach has slightly tilted since 1995. It has become lower in downstream direction and higher in upstream direction, causing the beach to level over its width.
Willow field
The lower bank of the groyne field with willow vegetation has been subjected to erosion (lowering of up to a metre) over the whole width from foreshore to natural levee (Figure 31). This process has been ongoing since the start of the study (Figure 31). The natural levee itself has become steeper due to erosion at the front of the willows and sedimentation within and at the back of the willows. This development is thought to be an effect of the vegetation planted. Vegetation is known to reduce or withstand erosion and it is known for its sediment capturing capacity (BAPTIST, 2005). While the unprotected part of the upper bank becomes lower due to erosion, the elevation difference between these two areas causes a steep slope/erosive bank in front of the vegetation. Due to the formation of this slope/erosive bank, wave action and water flow now act at the same place for a wider water level range, possibly enlarging the elevation difference. This process is found to take place to some extent at all test locations. This effect is greatest at the centre of the groyne field diminishing to zero in the direction of the groynes. Compared to the reference groyne fields (up and downstream) less erosion (or even sedimentation) occurred on the beach. However it seems that erosion of the lower bank is greater within the willow groyne field annulling the positive effect on the upper bank for the total sediment balance. Changes of the foreshore due to the dredge deposition are more or less the same compared with the downstream field.

Upstream field
Most significant for the period of 1995-2005 within this groyne field is the erosion of the upperbank at the centre of the groyne field. This erosion has caused the transition between upper and lower bank to become more concave. At this moment, the formation of an erosive bank is likely to commence. Whether this will be the case could be a point of interest of a further study. At the start of the project (1990), an erosive bank of about one metre existed at the natural levee. This erosive bank had disappeared during the period till 1995. This was thought to be the result of dredge depositing (DUIJN, 1996). As it seems now this disappearance could also be the result of ongoing lowering of the lower bank and overall retreat of the upper bank causing a landward shift of the transition between these two. As with both other groyne fields near Gendt, the deposition of dredge material has caused the foreshore to extend further into the river.
Figure 30 Profile AF4 for the downstream groyne field near Gendt

Figure 31 Profile WL3 for the willow groyne field near Gendt

Figure 32 Profile OP2 from the upstream groyne field near Gendt
7.2 Druten

The willow groyne field near Druten is located at the south bank of the river. Erosion on this side of the river is believed to be twice as pronounced as on the north side (TEN BRINKE ET AL., 2004). This difference is thought to be the result of loaded vessels (from the port of Rotterdam) sailing along the south side and empty or partly loaded vessels sailing along the north side. As can be seen (Figure 33) erosion mainly occurred at the lower bank both during the first and second study period. In all the groyne fields at this test location softwood vegetation was found, as can be seen in Figure 34. This confirms to the assumption that more and more vegetation can be found in and around groyne fields.

![Figure 33 Difference maps of 1995-1991 and 2005-1995](image)

**Figure 33 Difference maps of 1995-1991 and 2005-1995**

### Downstream field

The downstream groyne field has a width of a hundred and ten metres, which is relative small compared to the average width of 200 metres along the river Waal. As a result it is likely that the flow patterns within this groyne field differ from the other two. This would explain the different shape of the beach outline (Figure 34).

Since the start of the study sedimentation has occurred at the upper bank. This has resulted into an elevation rise of up to one metre. The lower bank however is showing a less steady development (Figure 35). Until 1995 sedimentation occurred (half a metre elevation rise). After 1995 erosion has occurred which resulted in a lowering of the elevation level of up to one metre. The foreshore has also shifted back and forward during the test period. Due to the groynes, turbulence intensity and vorticity along the foreshore are greatest, causing a lot of morphological activity. Therefore, the foreshore area is thought to be more dynamic, and morphological changes are expected to be larger than within the groyne field. This applies for all groyne fields.

![Figure 34 Possible flowpattern for groyne fields near Druten](image)

**Figure 34 Possible flowpattern for groyne fields near Druten**
Willow field
Compared to the reference groyne fields, erosion of the lower bank seems more severe (Figure 33). The affected area where erosion took place extends further landwards up to the vegetation border (Figure 36). The increase of eroding area seems consistent with the retreat of the vegetation border. As seen at the location Gendt, a small erosive bank/steep slope has formed at the vegetation border. Sedimentation of the upper bank is of comparable magnitude as found at the reference groyne fields. Therefore the willow planting does not seem to have an enlarging effect on the deposition of sediment. This differs from the location Gendt where the willow vegetation also seemed to induce an increase of sedimentation at the upper bank. A possible explanation can be found at the upstream groyne field.
The location and shape of the foreshore has been stable over the whole study period and seems to be less dynamic than the downstream groyne field.

Upstream field
At the upstream groyne field, deposition of sediment on the upper bank is greatest. This could be explained by the occurrence of spontaneous vegetation catching sediment, also the occurrence of dense vegetation at the upstream groyne in the nearby groyne field (Figure 34) may have influenced sedimentation. This vegetation might give shelter at high discharges allowing sediment to settle. Due to this increase in sediment deposition, water reaching the downstream (willow) groyne field will contain on transport less sediment. Which in turn might explain the moderate sediment deposition in the willow groyne field.
Compared to the other groyne fields the profile at the centre of the upstream groyne field is lacking a distinct foreshore. This area however has been stable during the whole test period.
Figure 35 Profile AF3 for the downstream groyne field near Druten

Figure 36 Profile WL3 for the willow groyne field near Druten

Figure 37 Profile OP4 for the upstream groyne field near Druten
7.3 Gameren

The test fields at the location of Gameren are situated at an outer south bank of the River Waal. In the period 1996-1999 three secondary channels were excavated of which one was located in the upstream groyne field of the test location near Gameren. Due to this intervention, the flow pattern during higher water levels changed drastically which also affected the downstream test groyne field (BAPTIST et al., 2005). Since the upstream groyne field is now used as inlet for the secondary channels this field will no longer be used as a reference groyne field.

The elevation data of 2005 for this location showed the largest gaps between DGPS and MBES as compared to the other locations. Unfortunately, it was not possible to carry out additional MBES measurements during the water level rise of 2006. As can be seen from difference maps (Figure 38) erosion mainly occurred at the lower bank. This was also experienced at the other locations. During the last study period, this erosion however seems less severe.

Figure 38 Difference maps of 1995-1991 and 2005-1995

**Downstream**

A relatively gentle slope characterizes the profile of the downstream groyne field (Figure 40). At the top of the natural levee, deposition of sediment occurs in the downstream corner (Figure 40) and erosion is experienced at the upstream corner (Figure 41). This is probably the effect of the altered flow patterns during high water levels (Appendix 2). Near the upstream groyne, water flows back towards the main channel causing erosion. Near the downstream groyne, water flows inwards depositing sediment.

**Willow field**

Due to a rather high water level during the DGPS measurements, it was not possible to perform a measurement along the front line of the willows. Nevertheless, the measurements show a clear trend of sedimentation in and behind the willow field (Figure 20). This is the same trend as has been observed at the study areas near Gendt and Druten. At the location of Gameren the formation of a small erosive bank at the front line of the vegetation could be seen best.

Figure 39 Mini erosive bank formation at Gameren
Figure 40 Profile AF3 of the downstream groyne field near Gameren

Figure 41 Profile AF4 of the downstream groyne field near Gameren

Figure 42 Profile WL2 of the willow groyne field near Gameren
7.4 Volumetric calculations
The created surface maps have also been used to calculate volumetric differences over years. With these calculations, the total effect of erosion or sedimentation per groyne field is visualized.

At each groyne field a uniform area has been defined. This area has been defined based on the groyne heads. The riverward edge has been defined as 20 metres landward from the groyne heads. This way the foreshore has been excluded. This was chosen because the foreshore is thought to be less influenced from the processes within the groyne fields and more affected by processes within the main channel (for example the dynamic eddy). Due to the large elevation difference at the foreshore, small fluctuations in the position of the foreshore can have a large effect on the sediment balance. The landward edge has been chosen as 15 metres landwards from the groyne root. This way, the lower and upper bank are completely within the area of interest. On each side, a distance of 15 metres has been kept from the groynes. This distance was also kept during measuring and is therefore excluded.

The results of these calculations are given in Figure 44. For each location two graphs are given. The first graph displays the total volumetric difference (m^3) for the first and the second study period. These graphs are cumulative, so the total difference of the whole study period of 15 years is therefore the sum of these two. The second graph displays the total volumetric difference (m^3) divided by the defined area (m^2). This graph can be used to compare the volumetric difference between groyne fields and locations. By dividing it by the defined area the influence of the differences in length and width of each groyne field is eliminated.
Figure 44 Volumetric differences per location, per groyne field and per study period

The most significant observation is that at each location the willow field (WL) has been eroding throughout the whole study period independently of what occurred at the reference fields.

At the reference fields at the location of **Gendt**, erosion has been more severe compared to the willow field. This difference has become more significant during the second study period, which can be ascribed to a longer duration (11 years compared to 5). The erosion of the downstream groyne field (AF) clearly shows the large impact of the large erosive bank.

At the reference fields at the location of **Druten**, accretion has taken place. Especially in the upstream groyne field (OP), sedimentation has taken place during the last study period.

At the location of **Gameren** all fields have been eroding during the first period. During the second period, accretion has taken place at the downstream groyne field. This change can be ascribed to the different situation after the excavation of the secondary channels in 1999. For the second period no measurements were carried out in the upstream groyne field and is therefore not represented in the graphs.
7.5 Overview

In the previous paragraphs of this chapter, the morphodynamics per location and per groyne field has been described as well as a volumetric calculation per location and groyne field. In this paragraph, all these observations are combined in order to look for similarities and differences. For the locations of Gendt and Druten a schematisation (Figure 45 and Figure 46) is given of the total morphological profile differences after a period of fifteen years.

![Gendt-AF Gendt-WL Gendt-OP](image)

Figure 45 Schematisation of the profile changes for the groynefields at Gendt (red: erosion, green: accretion)

![Druten-AF Druten-WL Druten-OP](image)

Figure 46 Schematisation of the profile changes for the groynefields at Druten (red: erosion, green: accretion)

It is not possible to provide such a schematisation for the location of Gameren since the observed changes per groyne field were not unambiguous. Partially this is the result of measurement gaps within the last survey data making it impossible to provide a complete overview of morphology of these groyne fields. Furthermore, the excavation of secondary channels at this location is likely to have such an impact that morphological processes have been disturbed during this study period. In the following paragraphs a summary of the observed morphological changes per and between locations is given linked with the generetic process.

7.5.1 Gendt

Overall observed morphological changes
- **Erosion within all groyne fields**
  
  This can be seen from the volume differences calculated and by looking at the drawn profiles. This is likely the result of the test locations being situated at an outer bend with slightly inwards directed flow at each of the groyne fields.
- **Accretion at the foreshore**
  
  This can best be seen from the drawn profiles. Deposition of dredged material between 1992 and 1993 is probably the reason for the observed accretion. Although some of the material has eroded over time the deposition of the material is thought to have a permanent effect on the foreshore. The hypothesis is that a new equilibrium will commence with an extended foreshore.
Differences between willow field and reference fields

- **Accretion at the upper bank**
  As can be seen from the difference maps and the drawn profiles accretion has been taking place between the willow plantings in landward direction. This is thought to be the result of the sheltering effect of the willows against water flow and wave attack and strengthening of the soil properties by its root structure. Sediment is thought to be deposited during high discharges.

- **Erosion of the lower bank**
  Compared to the reference fields the lower bank of the willow field has been eroding since the plantation of the willows. This is thought to be the effect of deflection of flow around the willow population. Water flowing in during high discharges is obstructed due to drag by the willows. Water flowing around the willow population accelerates causing erosion in front of the willow population.

### 7.5.2 Druten

**Overall observed morphological changes**

- **Sedimentation within the reference fields**
  As can be seen from the calculated volume differences and the drawn profiles, sedimentation occurred overall and especially at the upper bank for both reference fields. This has not been observed at the other locations. Compared to the other locations (Gendt and Gameren) the direction of flow during high discharges is from winterbed to the main channel (outflow). Furthermore, Druten is the only location situated at a straight section of the river. It therefore seems likely that the reason of sedimentation at the upper bank has to be found within these different flow patterns during high discharge and its location along a straight part of the river.

- **No distinct development of the foreshore**
  Based on the drawn profiles no distinct development of the foreshore can be seen. Throughout time, the foreshore has shifted more or less around an equilibrium position. The location of the foreshore is enforced by the location of the groynes. Since these have not changed it is likely that without interference (for example dumping of dredged material) the location of foreshore will not change.

**Differences between willow field and reference fields**

- **Accretion at the upper bank**
  As seen at the location of Gendt the difference maps and the drawn profiles show accretion between the willow plantings in landward direction. The same explanation as at location of Gendt is therefore thought to apply.

- **Erosion of the lower bank**
  This has also been observed at the location of Gendt where the lower bank of the willow field has been eroding since the plantation of the willows. The same explanation can be given as for the location of Gendt.
7.5.3 Gameren

As mentioned earlier the observed changes per groyne field were not unambiguous. This is probably the result of changing situation due to the excavation of secondary channels.

**Overall observed morphological changes**

- *Erosion in all fields during the first study period*
  Based on the volume difference calculation erosion was found at each groyne field during the first five years of the study. This again is thought to be the effect of the location of Gameren being situated at an outer bend.

- *Sedimentation in downstream groyne field during the second study*
  The observed accretion in the downstream groyne field during the second study period is thought to be the effect of outflow during high discharges. Based on the flow patterns given in Appendix 2, it can be seen that for this groyne field the flow direction is opposite to that of the other two groyne fields. This is the result of the changing situation due to the excavation of the secondary channels.

**Differences between willow field and reference fields**

- *Accretion at the upper bank*
  The only distinct morphological development observed is the accretion of sediment at landside of the willow plantation and the formation of a small erosive bank (Figure 39). This has also been observed at the other locations and is therefore thought to be a generic effect of the plantation of willows.

- *Erosion of the lower bank*
  Although this has not been measured, observations in the field strongly suggest that erosion of the lower bank has been taken place. This is also suggested by the formation of a small erosive bank at riverside of the willow population.
Towards a conceptual model

Throughout the report, several processes and explanations have been mentioned to provide an answer for observed morphological differences between groyne fields, locations and time periods. These processes and explanations are summarized in this chapter. The total of these explanations and processes can be used as a conceptual model.

8.1 Generic processes

During the analysis it became apparent that the **location** of the groyne fields is of importance. Groyne fields located at an inner or outer bents or on a straight part of the river will show different morphological development. Outer bents are likely to show erosion and inner bents are likely to show accretion caused by **secondary flow**. The location is also of importance during high discharges. Whenever water flows from the main channel through the groyne field into the winter bed, sedimentation is expected due to reduction of flow velocities (due to friction). Water flowing out is likely to induce erosion due to acceleration (increase in shear stress). Besides location, the **orientation of the groyne** itself is of importance. This mainly determines whether flow is directed inwards or outwards of the groyne field. Furthermore, the **length of the groyne** and the **width of groyne field** are also of importance. These characteristics mainly affect the flow pattern within the groyne field during low discharges as described in paragraph 4.3.2.

It became also apparent that the elevation of the **water level** induces several different conditions with respect to water movement. For the situation along the river Waal these can be divided into three significantly different situations (Figure 47).

![Figure 47](image)

**Figure 47** Different situations with respect to water level

When the water level is **above bankfull** the flow of the winter bed interacts with the flow in the main channel, this can be seen from the flow patterns in Appendix 2. Whether erosion or sedimentation occurs, again mainly depends on the location of the groyne field. When the water level is **below bankfull** but with the groynes **submerged** the main direction of the flow will be that of the main channel axis. The groynes still affect the flow but its influence decreases with increasing water level. During this stage it is believed that sedimentation takes place. This is based on observations during the field surveys before and after an increase of discharge at the location of Druten. During this period it was observed that up to 10 cm of sand was deposited. Whenever the water level is **below bankfull** and with the groynes **emerged** there will be a flow pattern as schematised in Figure 13. During this stage the influence of shipping traffic will be most significant. The **drawdown and return current** (primary water movement) will affect the flow pattern within the groyne fields. The secondary water movement (**waves**) also will play a significant role. It is believed that erosion takes place during this stage of **emerged** groynes.
The influence of vegetation on fluvial processes is schematised in Figure 48

As can be seen there are many relations between the fluvial processes and vegetation. Not only does vegetation influence these processes but these processes also have an affect on the vegetation. For example, inundation or drought are limiting factors for vegetation. Flow can influence vegetation for example by grubbing out protruding vegetation at high discharges. On the other hand, vegetation influences flow by causing friction and therefore cause deceleration due to energy loss. By deflecting flow around the vegetation flow will accelerate. This can induce erosion due to a higher shear stress. Due to the lower flow velocities between vegetation water will lose its sand carrying capacity. Most sedimentation will occur due to this loss of sand carrying capacity, explaining the sand trapping capacity of vegetation. Furthermore, vegetation is known to attenuate waves (for example from shipping activities) which also decreases the possibility of erosion. Besides affecting flow, vegetation also influences geomorphology by reinforcing the soil with its root structure and altering its soil properties. This also diminishes the possibility of erosion.

Whether or not vegetation will survive within groyne fields depends on its regenerative capabilities and succession. This mainly plays a role on a longer timescale.

The main observed effect of vegetation in groyne fields, was erosion of the lower bank and accretion at the upper bank (Figure 49).
The effect of an **increase in slope** itself also influences the morphology within groyne fields. This can be explained by Figure 50.

![Figure 50 Influence of the slope on the affected location](image)

What can be seen is that with a steeper slope the affected area with respect to water flow and wave attack is much smaller than then with a gentle slope. This means that for an eroding situation this will also take place at a smaller location, possibly increasing the slope. This however was not found explicitly in the measurements or during field surveys. Based on the profiles drawn, it is believed that the slope can increase but at some point is more likely to shift inlands rather than increase further.

One important factor playing a significant role on morphology which is not mentioned earlier in this chapter is **interference from humans**. For this study, the cut down of willows and the dumping of dredged material at Gendt but also the excavation of secondary channels at Gameren all had or will have a distinct impact on the morphology. It should also not be forgotten that the construction of groynes, dykes and civil structures all affect the morphology. Otherwise, there would have been no need to construct them in the first place.
8.2 Desired improvements for future models

During this study, it became apparent that the relations between morphological processes, hydraulics and local characteristics are very complex. They all interact and influence each other making it difficult to predict morphological development. This has also been experienced in attempt of using known bank erosion models to predict this development. Because of the complexity of the interactions, the used models each describe certain processes within the groyne field but none of them fully describes them all. Since most processes seem to have a significant role on the morphology during certain situations, it is not yet possible to accurately predict future morphological development. Therefore a list of desired improvements for future riverbank models is given.

- The model needs to be able to deal with accretion as well as erosion. At present, most models only deal with erosion.
- The slope of the bank should be treated as a variable and not as a constant. Most models assume the presence or development of a steep bank. This will not hold for the river Waal and probably for many rivers. Furthermore, from this study it can be seen that the slope of the bank affects many processes and changes with changing morphology and should therefore be included.
- With high discharges, completely different processes play a role on the morphology as with low discharges. None of the models used, properly described this situation. Flow and its direction will probably be the main driving force during this situation. It is therefore recommend to include this situation within a new model.
- As groyne flow is difficult to describe, redistribution of sediment within the groyne field is still difficult to model properly. This should be improved for future models.
- The same goes for the interaction of the main channel and the riverbank. Sediment transport from and towards the channel is still poorly described but will be needed for a thorough riverbank model.
- The interaction of flow and vegetation is often left out from riverbank models (only waves are treated). In order to describe the impact of vegetation at least the attenuation of waves and flow and the altering of soil properties should be included. The main parameters that probably should be included are turbulence, flow velocity and bottom shear stress.
- The interaction between hydrology and hydraulics is often left out. Since riverbanks lie within the transition area between these to it is recommended to include this in future riverbank models.
9 Conclusions and recommendations

From this study, it can be concluded that there is still a lot to learn about groyne field morphology. The complexity of the relations between morphological processes, hydraulics and local characteristics makes it difficult to describe and predict the total effect on the morphology. Since the morphology in groyne fields still cannot be modelled properly, it is recommended to encourage research providing a better understanding of the relevant processes.

With this study, an attempt has been made to describe the influence of softwood vegetation within groyne fields. The most important conclusion is that, regardless of the local characteristics, the presence of vegetation induces erosion on the lower bank and sedimentation on the upper bank (where the vegetation was planted). The morphological development within the corresponding reference groyne fields differ from the test groyne field but are consistent with each other. It can therefore be concluded that the found effect at the test locations is induced by the presence of softwood vegetation. This effect was observed to be largest at the centre of the groyne field and decreases in the direction of the groynes. Since this effect is still ongoing it is recommended to prolong this study at least once more after a five year period.

From the calculated volumetric differences, it can be seen that at locations where erosion has taken place at the reference groyne fields the presence of vegetation at the test groyne field has caused less erosion compared to the reference fields. At the locations where sedimentation has taken place at the reference groyne fields, the presence of softwood vegetation within the study groyne field has caused erosion. This suggests that softwood vegetation has a protective effect within eroding groyne fields and that it induces erosion in non-erosive groyne fields. Since this theory is based on the observation of only three study locations it is recommended to test this theory for more locations.

Another point of recommendation would be to analyse the development of the vegetation. At present, 5 to 15 percent of the original willow population is left. It would be interesting to know if this small group of willows will survive or eventually would disappear. It is also recommended to involve a biologist in this analysis for better determination of the species.


Boer, G. J. de (2000). Vrije eroderende oevers; De uitwerking van een nieuwe modellering. TU-Delft, Faculty of Civil Engineering.


Appendix 1 - Difference between SOBEK and measured values

Effects of softwood vegetation on groyne field morphology

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Appendix 1 – Difference between SOBEK and measured values

November 2006

Difference between Sobek value and 12:00-reading

Difference between Sobek value and 12:00-reading

Time [Years]

Waterlevel [m+ NAP]

Measured - Sobek [m]

Tiel-Waal 12h (Measured)

Tiel-Waal (Sobek)

Difference

Zaltbommel 12h (Measured)

Zaltbommel (Sobek)

Difference

Time [Years]

Waterlevel [m+ NAP]

Measured - Sobek [m]
Appendix 1 – Difference between SOBEK and measured values

November 2006

Effects of softwood vegetation on groyne field morphology

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Appendix 2 - Streamlines and flow directions
Druten
Effects of softwood vegetation on groyne field morphology
Appendix 3 - Profiles

Gendt

Profile reference;
AF = Downstream groyne field
WL = Willow groyne field
OP = Upstream groyne field

The profiles in the graphs are referenced to by year and month (JJMM)
For example;
0510 = Measurement from October 2005
Effects of softwood vegetation on groyne field morphology

Gendt-AF1

Gendt-AF2
Effects of softwood vegetation on groyne field morphology

Appendix 3 – Profiles
November 2006
Effects of softwood vegetation on groyne field morphology
Appendix 3 – Profiles

November 2006

Gendt-OP3

Gendt-OP4

Effects of softwood vegetation on groyne field morphology
Appendix 3 – Profiles

November 2006

Relative distance (m)

Elevation (cm + NAP)

Gendt-OP5

9106 9311 9505 0510 0601

50% Percentile

M.Sc. Thesis, M.T.B. van den Broek
Profile reference:
AF = Downstream groyne field
WL = Willow groyne field
OP = Upstream groyne field

The profiles in the graphs are referenced to by year and month (JJMM)
For example;
0510 = Measurement from October 2005
Appendix 3 – Profiles

Druten-AF1

Druten-AF2
Effects of softwood vegetation on groyne field morphology
Appendix 3 – Profiles

November 2006

Effects of softwood vegetation on groyne field morphology
Effects of softwood vegetation on groyne field morphology
Profile reference;
AF = Downstream groyne field
WL = Willow groyne field
OP = Upstream groyne field

The profiles in the graphs are referenced to by year and month (JJMM)
For example;
0510 = Measurement from October 2005
Appendix 3 – Profiles

Effects of softwood vegetation on groyne field morphology

Gameren-AF1

Gameren-AF2
Effects of softwood vegetation on groyne field morphology
Appendix 3 – Profiles

November 2006

Effects of softwood vegetation on groyne field morphology

Gameren-WL4

Gameren-WL5

Elevation (cm + NAP)

Relative distance (m)

Elevation (cm + NAP)

Relative distance (m)
Appendix 3 – Profiles

November 2006

Gameren-OP1

Gameren-OP2