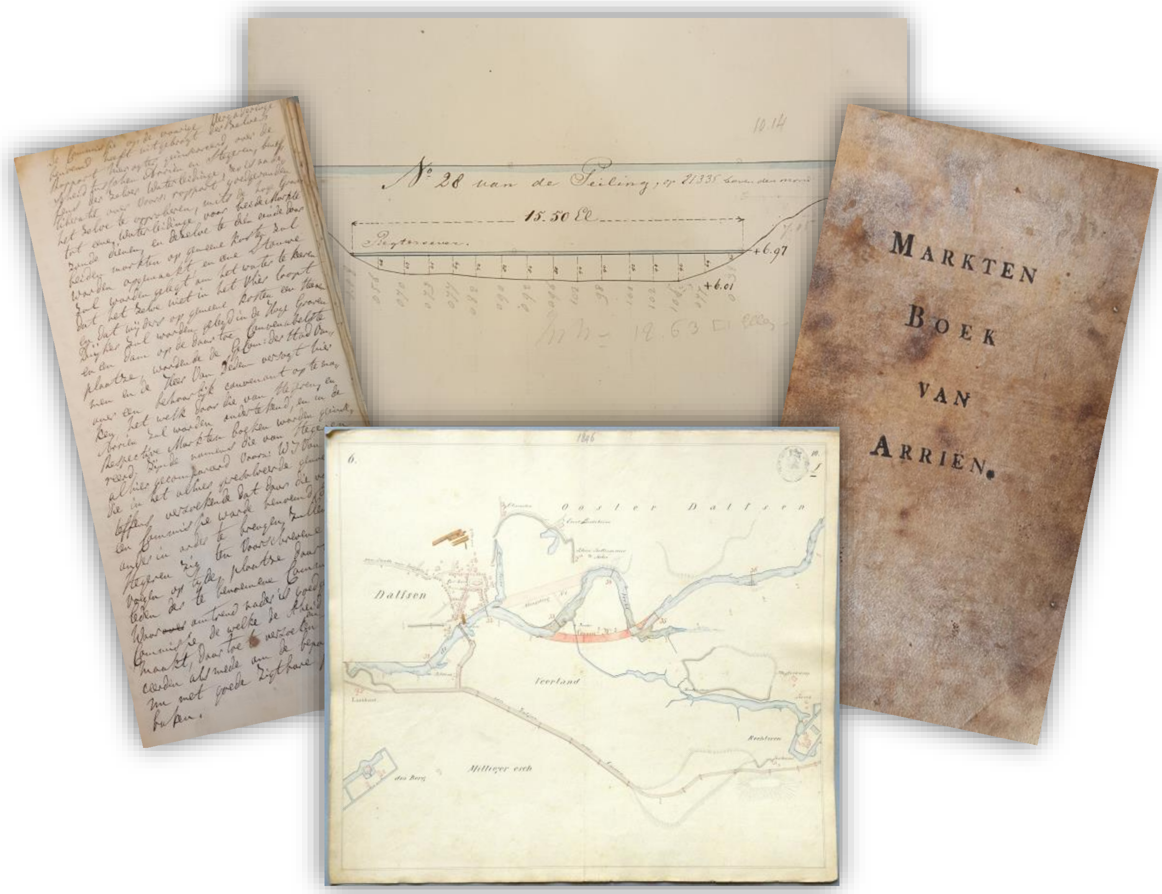
River management and its morphological consequences

Influence of river management on river morphology of the Overijsselse Vecht between AD 1750-1900



Menno Verplak

February 2019

Wageningen University

Environmental Sciences

Master Thesis

M. Verplak

Student number: 940317881100

Supervisors: J.H.J. Candel MSc, dr. R. van Beek, dr. M. Paullissen

Master programme: Earth and Environment, Soil Geography and Landscape

Acknowledgements

I would like to thank my supervisors Jasper Candel, Roy van Beek and Maurice Paulissen for their help and support. Their insights and expertise helped me in building my research and helped me with understanding processes, the historical background of the study area and conducting historical literature research.

In addition I would like to thank Luc Jehee for his time and advise for historical literature research of the marken.

Lastly, I would like to express my gratitude to Gerard Heuvelink, who helped me with the statistical computations.

Abstract

In this research river management of the Overijsselse Vecht within the period 1750 and 1900 was investigated and river morphology was reconstructed. For this research historical archives have been consulted and maps and cross-profiles from reports of W. Staring and T.J. Stieltjes (1848 and 1872) have been used. The goal of this research was to investigate the role of river management on the reported deteriorated state of the Overijsselse Vecht. Results of this research can be used for future river restoration projects.

Historical literature showed that river management, by the specified organisations, marken, dike districts, water boards and the higher authorities, the province and the government was rather limited. The marken were more concerned with their own lands, dike districts and water boards had no responsibilities and the higher authorities had a restrained attitude towards river improvement. The Vecht itself was an almost undiscussed topic within the organisations. Only the higher authorities received multiple complaints from interested parties as for example, the municipality of Dalfsen.

The reconstructed river morphology showed a narrowing river channel, lowered water levels and showed large sedimentation in especially meandering sections of the river channel. The effect of implemented groynes was locally visible and the constructions of weirs and canals was visible by a decrease in water level. Complaints from Dalfsen are recognised in the reconstructed morphology and showed troublesome water depths for shipping possibilities. The contribution of the constructed weirs influenced discharge regime and most likely caused river channel narrowing and therefore increased sedimentation. On the other hand, historical evidence suggest sporadic uncontrolled opening of the weirs, which resulted in extreme large peak discharge events. These peak discharge events might have generated enough power to transport large amounts of sediment into the river channel.

The question that remains is if the lack of river management in the period 1750 and 1900 was the cause for the deteriorated state of the Vecht. The fact that the Overijsselse Vecht lost its economic importance after the fall of the Bentheimer sandstone transport might suggest that there was no need to maintain the river. On the other hand, transportation on the Overijsselse Vecht has always been characterised by boats specialized for low water levels. This suggests that problems of the Vecht originate from a period before 1750 and that the influence of the absent of river management was rather limited.

Table of Contents

1. Introduction

This chapter introduces the problem and research objectives of this research .

1.1 Problem introduction

Present day, geomorphological processes of rivers are being restored. One of those processes is meandering [1] [2] and is considered important, because it realizes improvement of flora and fauna, increases water retention time in river systems and it develops a larger recreational value [3]. River restoration is also de case for the Overijsselse Vecht, which was a former dynamic meandering river system and where restoration should result in a semi-natural lowland river [4]. Currently the Overijsselse Vecht is a channelized river system with many cut-off meanders. In order to gain information for current potential for river meandering, studies focussed on meandering dynamics, sediment transport, water discharge and channel pattern change [5] [6] [3] [7] [8]. However, little is known about historical river management of the Overijsselse Vecht and how it affected river morphology. River restoration projects can learn from the history of the river and gain inspiration for its restoration [9].

The Overijsselse Vecht is an interesting study area, because before channelization multiple organisations were active. Furthermore, the period before channelization has been well documented in archive material. Previous research provides insight in how the Overijsselse Vecht behaved as a river system and pictures how the river was managed. The Overijsselse Vecht was an active meandering low-land river with meanders that with maximum displacement rate of 2.94 m per year [3]. Before 1800 the marken had the control Overijsselse Vecht maintenance, but slowly, in the beginning of the 19th century, the marken in western part of the river got divided. Neefjes et al. (2011) [10] suggested that after the dividing of the marken it was unclear who was responsible for the management of the Vecht. After a major flood in 1825, in the west, downstream of Dalfsen, dike districts were established and took over the tasks of the marken [10] [11]. In the east, more upstream, the marken were still active, but were also slowly divided. Neefjes et al. (2011) [10] also suggests that by disappearing of the marken local importance of river management disappeared. After again a major flood in 1877 dike districts and remaining river sections with no river management organisations were subdivided into water boards [12].

Despite all these management organisations, multiple reports about a deteriorated state of the Overijsselse Vecht were published (krayenhoff (1775) [13]. Wildeman (1809) [14], Staring and Stieltjes (1848) [15] and Stieltjes (1872) [16]). These reports outlined the idea that the Overijsselse Vecht endured major problems with sedimentation by obstructive local sand bodies, erosion and weak river banks that caused troubles for shipping possibilities. In addition, previous consulted archive material showed erosion problems for the marken and troublesome meander displacement. In the marke Beerze they used groynes to prevent erosion [17] and in near Ommen they had issues with meander displacement [18]. These problems remained till the end of the 19th century and eventually, the Overijsselse Vecht was eventually turned into a national river.

1.2 Problem statement

The multiple reports about a deteriorated state of the Overijsselse Vecht raises the question if the changing of management organisations contributed to the deteriorated state of the Overijsselse Vecht. On the other hand, effectiveness of the conducted river management can be questioned, due to the persistent problems. Therefore it is interesting to investigate how the organisations were structured and how the river management responsibilities were divided (marken, dike districts and water boards). In addition, it can be doubted if the Overijsselse Vecht was important at all. In 1853 the province of Overijssel constructed a major canal system used the Vecht as water supply. Furthermore, proposed improvements in previous defined rapports for the Overijsselse Vecht were never implemented. Lastly, transportation on the Overijsselse Vecht dropped dramatically after the fall of Bentheimer sandstone trade [10] [19] and might suggests that there was no need to maintain the Overijsselse Vecht. Because of the fact that canals received priority, improvements were not implemented and the drop of economic value of the Vecht, the attitude and role of the province and government needs to be investigated.

In order to analyse how river management impact river morphology, it is important to know how the morphology of the river changed. W. Staring and T.J. Stieltjes [15] [16] provide detailed historical maps and cross-profiles and give the opportunity to reconstruct the Overijsselse Vecht morphology in 1848 and 1872. These reconstructions can give insight in the state of the river and if indeed obstructive sand bodies by sedimentation decreased shipping possibilities.

1.3 Research objective

Research that combines historical archive material and can reconstruct morphological change of the Overijsselse Vecht can give insight if and how historical river management influenced river morphology. Historical observations can be checked, river management influence can be analysed and a historical morphologic reconstruction can give insight for future river restoration projects. Therefore, the goal of this research is to investigate river management in the well document period 1750 – 1900 and to analyse its impact on a reconstructed river morphology. This research uses archive material and historical maps and cross-profiles to reconstruct the change in river morphology of the Overijsselse Vecht. Research questions of this research are defined as:

- How was the Overijsselse Vecht managed and who was responsible between 1750 and 1900?
- How did the Overijsselse Vecht change morphologically?

2. Background information

In this chapter the study area is introduced by discussing some basic characteristics. Furthermore, the geological and geomorphological background is treated as well as human history in the Vecht valley with the active river management organisations between 1750 and 1900.

2.1 Overijsselse Vecht characteristics

The Overijsselse Vecht (figure 2.1) is a lowland river located in the Netherlands in the province Overijssel. The river is 167 km long, has a catchment of 3785 km^2 and has its highest point at 110 m above sea level [3]. The Overijsselse Vecht is a rainfed river system where a large part of the discharge originates from Germany. In the region of the Overijsselse Vecht the mean annual precipitation is 700 to 825 mm and evapotranspiration on average is 525 mm [20]. The river crosses the border between the Haandrik and Laar and 60 km of its total is situated in the Netherlands. Before it debouches into the Zwarte Water it flows from the German border to Gramsbergen, Hardenberg, Ommen, Dalfsen and passes the city of Zwolle at the Northeastern border. The total elevation difference between the German border and river mouth is approximately 10 meter [5]. The discharge of the Dutch part of the Overijsselse Vecht is largely influenced by the Afwateringskanaal Coevorden and the Regge. High water discharges, with a recurrence time of 2 years, has a value of 111 m^3/s at Emblichheim in Germany [21] and 182 m^3/s near the river mouth at the Zwarte Water. Summer is characterised with almost no water being discharged through the river channel [3].

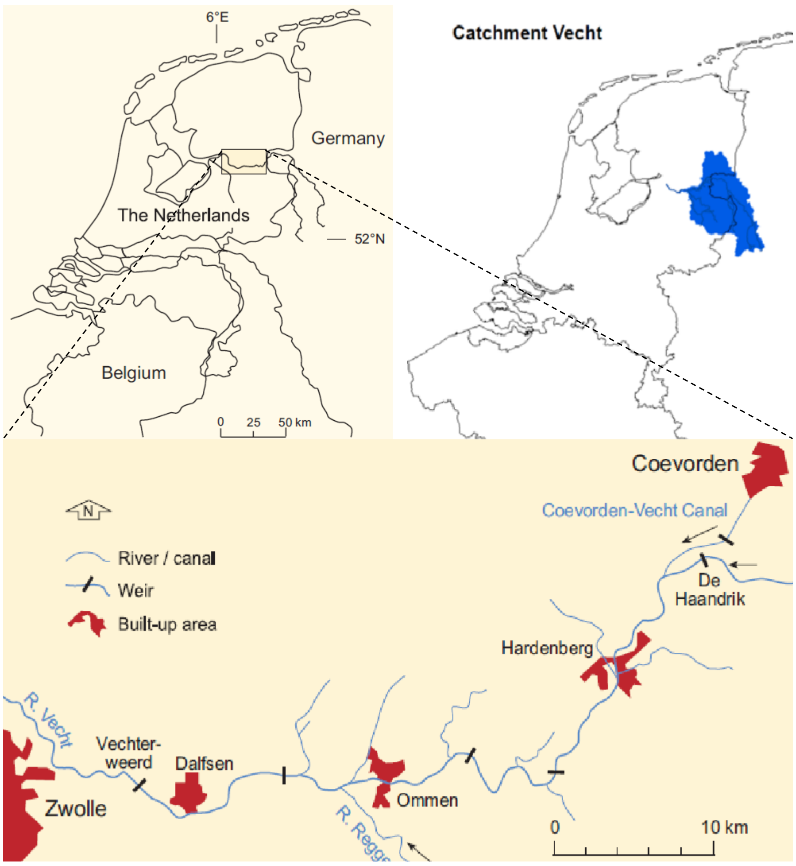


Figure 2.1 Location of study area (top left), catchment (top right) and the study area the Overijsselse Vecht (bottom). (Source top left and bottom: [3]; source top right: [7]

2.2 Geology

2.2.1 Background

During the glacial, the Saalian (238 to 126 ka ago), a continental ice sheet covered the northern part of Europe and the northern part of the Netherlands. Due to the formation of meltwater a broad valley between the pushed moraines of Overijssel and the glacial till plateau of Drenthe was formed [22]. This valley was 40 to 50 meters deep and was called the paleo-Vecht valley [23]. Later, meltwater flows resulting from retreating ice sheets filled the paleo-Vecht valley with fine to course materials belonging to the formation of Drenthe [23]. The Eemian followed the Saalian and was an interglacial. During this warmer climate vegetation increased and the paleo-Vecht got filled with fine to course river sediments. In addition, as a result of strong sea level rise, marine clays were deposited and locally peat was able to form [23] [24].

In the last ice age, the Weichselian, the ice sheets did not reach the Netherlands. However, temperatures were low and were insufficient to maintain vegetation. Due to missing vegetation and frozen soil, solifluction, erosion by meltwater and aeolian sediment transport resulted in a large sediment supply [5]. Under these conditions, in the broad river valley, braided river channels formed and deposited course sands with gravel and sometimes loamy layers [22] [23]. As a consequence of changing river positions an almost flat, but slightly inclining floodplain developed [5]. The last part of the middle Weichselian, the Pleniglacial, was the coldest. In the Pleniglacial vegetation was absent and multiple large scale drift sands were deposited forming the coversands [23].

In the Holocene, after the decrease of meltwater flow and increased vegetation, sediment supply decreased and the discharge regime became more regular. Large parts of the floodplains got abandoned due to incision and a narrow valley was created, the current valley of the Overijsselse Vecht [5]. In the Holocene sand drift areas were active and reworked the coversands to inland dunes. In addition, the Holocene was characterised by increasing temperatures and rising sea level which made it suitable for extensive peat growth in the catchment of the Overijsselse Vecht [25].

2.2.2 Geomorphological setting

Wolfert et al. (1996) [5], distinguished different river sections based on their geomorphological setting (figure 2.2). Three main river sections can be distinguished and section B has been divided in 4 subsections. Below the river sections with a brief description can be found and Wolfert et al provides a detailed description of these river sections.

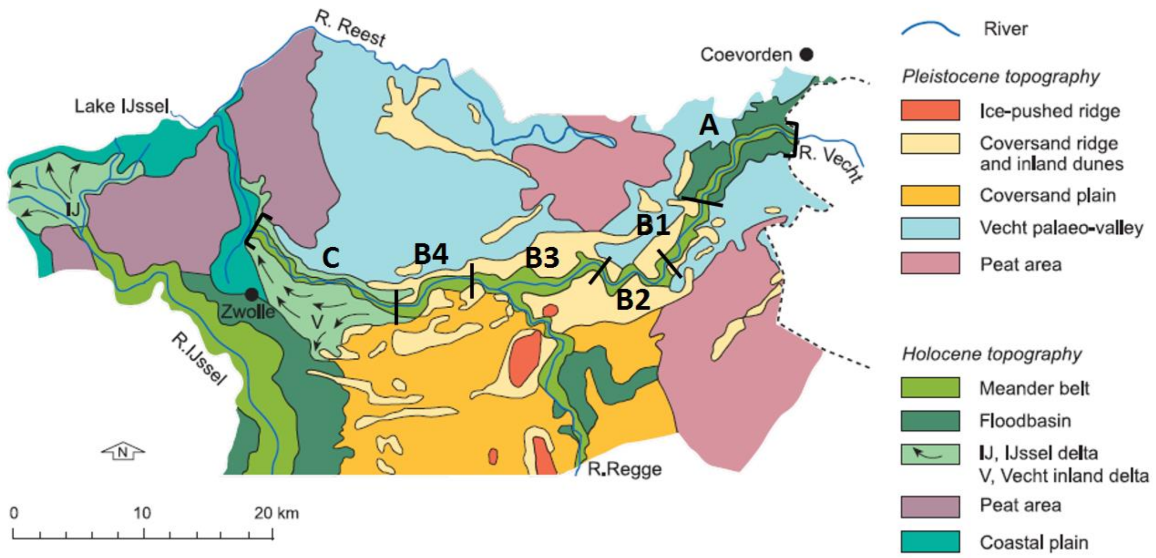


Figure 2.2 Geomorphological setting of Overijsselse Vecht [26] with sections based on geomorphology (Source: [3])

A – a small meander valley with a broad and developed floodplain.
B1 – a small meander valley with little meandering and bordered by old open fields.
B2 – well established meanders within a relative small river valley with drift sands.
B3 – broader valley with pushed sediments within the subsoil and terraces who influence meandering.
B4 – an again broader valley with no terraces and where the river could freely meander with no developed floodplains.
C – the diked area of the river with different landforms.

2.3 Human history

2.3.1 Background

The first human traces are more than 70.000 years old and originate from the Neanderthals. The Neanderthals were hunters and gatherers and this human species was first found in 1856 in the German Neanderthal. Around 35.000 years ago the modern man entered Europe and within the Vecht valley the oldest archaeological finds are from 14.500 – 10.000 years ago [10]. The modern man were also hunters and gatherers and stayed in simple tent constructions. During the Neolithic (5300 – 2000 BC) farming practises developed and entered the Vecht valley. It took a long time before extensive agriculture was established in the Vecht valley, but around 3400 BC real farmers established [10]. These farmers were accounted to the 'trechterbekercultuur' (funnel cup culture) due to their striking decorated pottery [27]. They mostly settled on the higher sand grounds which flanked the Overijsselse Vecht. Settlements were mostly not more than one or two farms and were sometimes rebuilt after a few generations on different locations. In time, especially during the Iron age (800 – 13 BC), population increased [5] and later, although the Overijsselse Vecht was not part of the Roman empire, the Romans had influence on the society. This has been concluded when in 1960 the first settlement out of the Roman time was discovered [28] and due to the discovery of a small statue of the Roman god Mercury. After the fall of the Roman empire it was thought that the Vecht valley was hardly populated, but new evidence show different and suggest a continuous population. In Wijthmen finds have been found from Roman and Early Middle ages [29]. In the High Middle ages (1100 – 1350 AC) the population accelerated and large surfaces of soil were reclaimed. The period after middle ages is characterised by increasing population, using the Overijsselse Vecht as a transport route and large scale peat reclamation. Figure 2.3 gives an impression how the Vecht area looked like in the Middle Ages and shows the peat located in the area [30]. After a hiatus of break of 200 years in 19th century peat reclamation accelerated due to large scale canals constructions [31]. In the 20th century the Overijsselse Vecht got completely channelized.

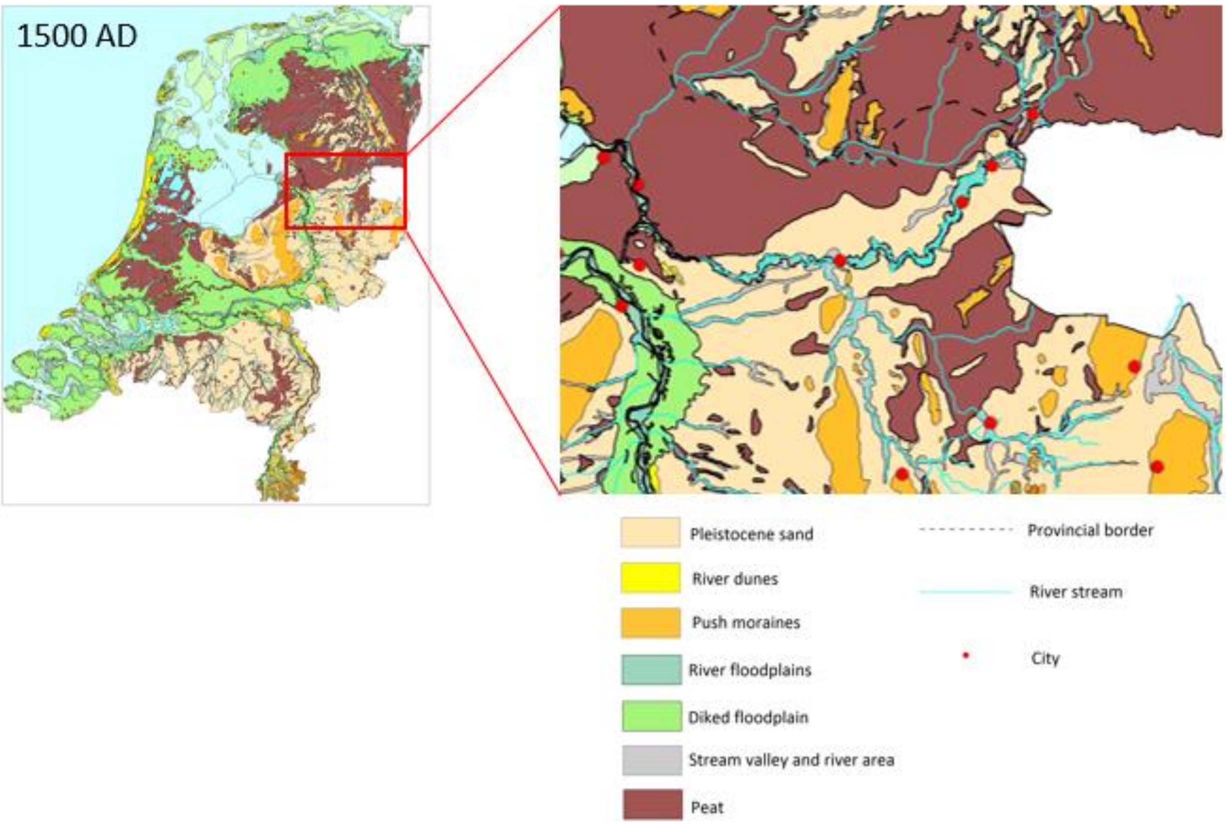


Figure 2.3 On the left the map of the geographical situation of the Netherlands in 1500 AD. On the left the Vecht valley area with on the North and the South largely covered with peat [30].

2.3.2 Management organisations

Within the period of 1750 – 1900 multiple management organisations were active and it was unclear which responsibilities they had and how they executed river management. Below these management organisations are briefly introduced.

2.3.2.1 Marken

Marken are organisations where the members share the user rights of pieces of land, heather, meadows, peat, forest etc. [32] [33]. Members had rights to graze a particular amount of stock on their fields or to dig soil for fertilization and chop wood. How and when the marken exactly appeared is not clear, but the first historical mention of a marke is in 1207 [34]. In the following century we see that whole Overijssel is getting covered by marken and in 15th century marken were established in almost all provinces. Figure 2.4 gives an overview of all the marken that were established around the Overijsselse Vecht valley.

At the end of the 18th century the first attempts were taken to separate the marken and to divide their lands [35]. Lands that the marken used graze their cattle and to get fertilizer for their agriculture (plaggencultuur) were seen as a waste of production resources. Slowly, the government wished to exploit the 'plaggencultuur' and to transform them into productive arable lands [10]. In 1782 a report was written by the province of Overijssel about the dividing of the marken lands [36], but based on this report the marken were not divided [37]. Again in 1809/1810 the government did a major attempt, but suffered resistance from the marken [10]. It took until 1835 when marken started to be divided. This was the result of pressure of the Overijsselse Agriculture society [36] and due to a massive flood in 1825. This flood caused 64 dike failures, the death of more than 300 people and was the reason that below Dalfsen the marken were transformed into dike districts [10]. In the eastern part of the Vecht valley it took longer before the marken lands were divided. Not in every marken was the dividing voluntarily which led between 1895 and 1903 to a verdict by the court to divide the lands [38] [39] [40]. Even now, some marken still exist, but only as social groups. It can happen that there are still some small pieces of land which are under common possession.

Figure 2.4 Map of the marken along the Overijsselse Vecht, including the first date of the first known record [10].

2.3.2.2 Water districts

In 1835 nine dike districts were established following the flood of 1825 and the pressure of the agricultural society. In 1815, after a change in the constitution, it was already possible to establish dike districts, but due to resistance of the marken, dike districts could not yet be established. Around the Overijsselse Vecht three dike districts were established: 3rd dike district the Noorder Vechtdijken, 5th dike district the Zwartewaters and the Vechtdijken and the 6th district the Zuider Vechtdijken (figure 2.5). The tasks and responsibilities of the dike districts were defined in the constitution for dike districts which was adjusted and altered in 1847. After the constitution for water boards in 1879 was created, the districts were transformed into water boards [11].

Figure 2.5 The nine former dike districts: I Vollenhove; II Hasselt and Zwartsluis; III Noorder Vechtdijken; IV Mastenbroek; V Zwartewaters and Vechtdijken; VI Zuider Vechtdijken; VII Zalland; VIII Zalk; IX Kamperveen [41].

2.3.2.3 Water boards

The dike districts were established after a major flood in order to encounter floods, however a major flood took pace in 1877. This flood led the creation of a new constitution, the constitution of the water boards in 1879. After the king's approval in 1880 water boards were able to be established. The active dike districts were formed into water boards and the constitution made it able for landowners to establish their own water board. The first water board in the East was established in 1883 and in the coming years many water boards followed (figure 2.6) [12].

Where the dike districts were established to encounter future floods, the water boards were established with the same reason. Because after the flood of 1877 problems were apparently not solved. This led to the constitution for water boards in 1879 and after the Kings approval in 1880 water boards were able to be established.

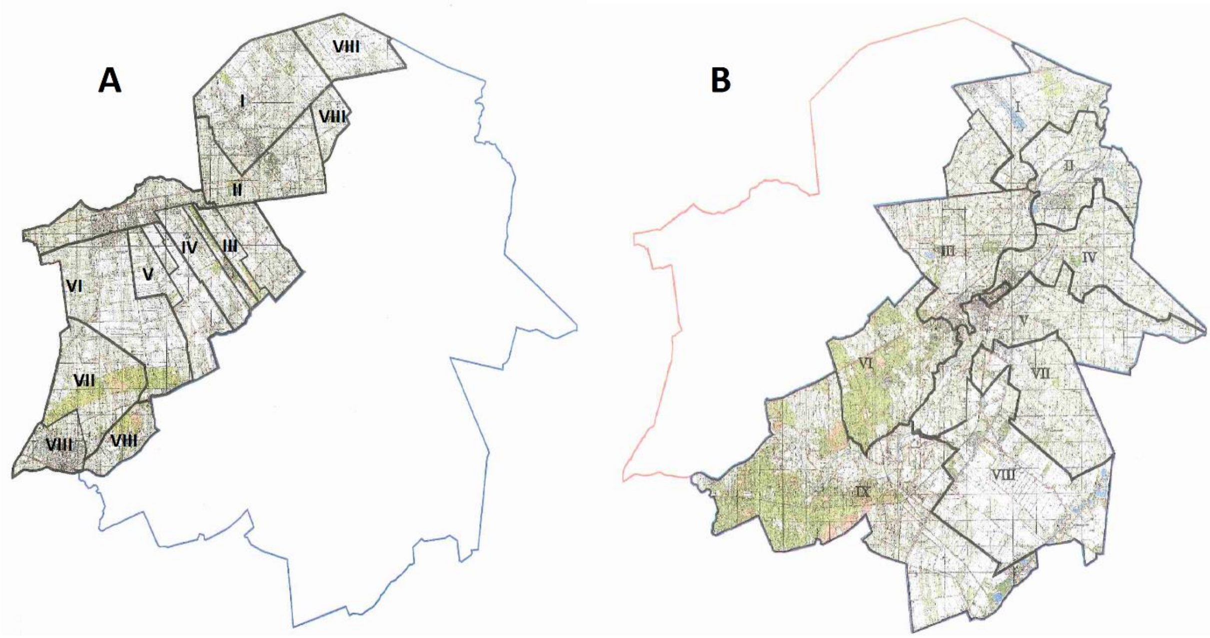


Figure 2.6 Map of the water boards around 1857. A: I De Schuine Sloot; II De Lutterscheiding; III Het Heemserveen; IV De Schutswijk; V De Saamswijk; VI Beoosten Het Ommerkanaal; VII Het Arriërveld; VIII No water board. B: I Anerveen; II De Meene, III De Molengoot w with De Schanswetering and De Kruserbrink; IV Holtheme; V Radewijk en Baalder, VI Het Rheezer en Diffelerveld; VII Het Bruchterveld; VIII Het Beerzerveld; IX No water board [12].

2.3.2.4 Government and the province

The government established the first national water state (Rijkswaterstaat) in 1798. The water state developed in time and in 1804 they decentralised the water state with in every province its own department. Those departments were responsible for the maintenance of the waterworks in their region and act as contact point for the minister of the water state, who has upper supervision over the water state. After multiple reorganisations Overijssel became the 4th out of 11 districts in 1849. In 1882 the services of the national water state were withdrawn by the minister of the water state which resulted that the provinces created their own water state. Provincial executive of Overijssel gained supervision, but the Crown kept upper supervision [42]

3. Methods

In this chapter the methodology of this research is described.

3.1 Framework

This research uses historical records, books and reports together with historical maps and cross-profiles to reconstruct river management and river morphology between 1750 and 1900. Based on those reconstructions impact of river management on river morphology has been analysed. In order to deal with the feasibility of this research regarding time restraints, not every individual management body could be investigated. In addition, again based on time restraints and data availability, only two sections have selected for a more in depth analysis. Lastly, the finding of this research and explanations are discussed.

3.2 Archive research and data collection

3.2.1 Historical literature

In order to determine how management organisations, between 1750 – 1900, managed or influenced the Overijsselse Vecht, archive material has been consulted. River management is defined as everything that has a relation with erosion prevention, increasing navigability and water safety. In addition, organisational structure is of interest in order to identify structural changes and differences between the organisations, which might explain changes in river management. For this research the Historical Centre of Overijssel has been chosen as the most important archive due to the abundance of information. Search terms were used to map available information within the archive storage using the online inventory. In order to remain within the subject and not to find irrelevant information, search terms were based on published literature and management organisations, defined in chapter 2. Search terms used were based on river management and organisational structure of the identified management organisations. These terms were formulated as ‘de Vecht’, ‘rivier management / beheer’, ‘marken’, ‘dijkdistricten’, ‘waterschappen’, ‘(nationale / provinciale) waterstaat’, ‘vergaderingen’ and ‘taken’ or ‘verantwoordelijkheid’. Search terms were used on its own or in combination with other search terms as for example with the Vecht or with a management organisation. The defined search terms are rather broad and can sometimes give many results. More specific search terms have been used, but this resulted in no or too little relevant archive material. This is the consequence of little or the absence of an extended content explanation in the online archive inventory.

Based on the mapped inventory, expert knowledge, in this case water and area development counsellor Luc Jehee, and coverage degree over the whole Vecht valley, particular sources were selected for further investigation. Specific management organisations that were selected are the marken Haerst, Varsen and Arriën, the dike districts III de Noorder Vechtdijken and VI de Zuider Vechtdijken and the water boards de Noorder Vechtdijken and the Zuider Vechtdijken. Location of these organisations can be found in chapter 2. The marke Ane was also selected for this research, but due to time restraints and because the expectation for finding new relevant information was low, the marke Ane was dismissed from this research. For a more detailed description of selected archive materials appendix A can be consulted.

At the historical Centre of Overijssel in Zwolle document were requested and scanned on particular terms. Similar terms or finding relevant archive material are used, but also more specific terms are used. Example of these terms are, ‘kribben’, ‘erosie’, ‘ondieptes’ en ‘transport’. In the marken books of Arriën June was an specific search term, due to the enormous growth of Junner koeland in the marken Arriën (see chapter 5). When document corresponded with the search terms, photos (example figure 3.1) were taken for further research at Wageningen University.

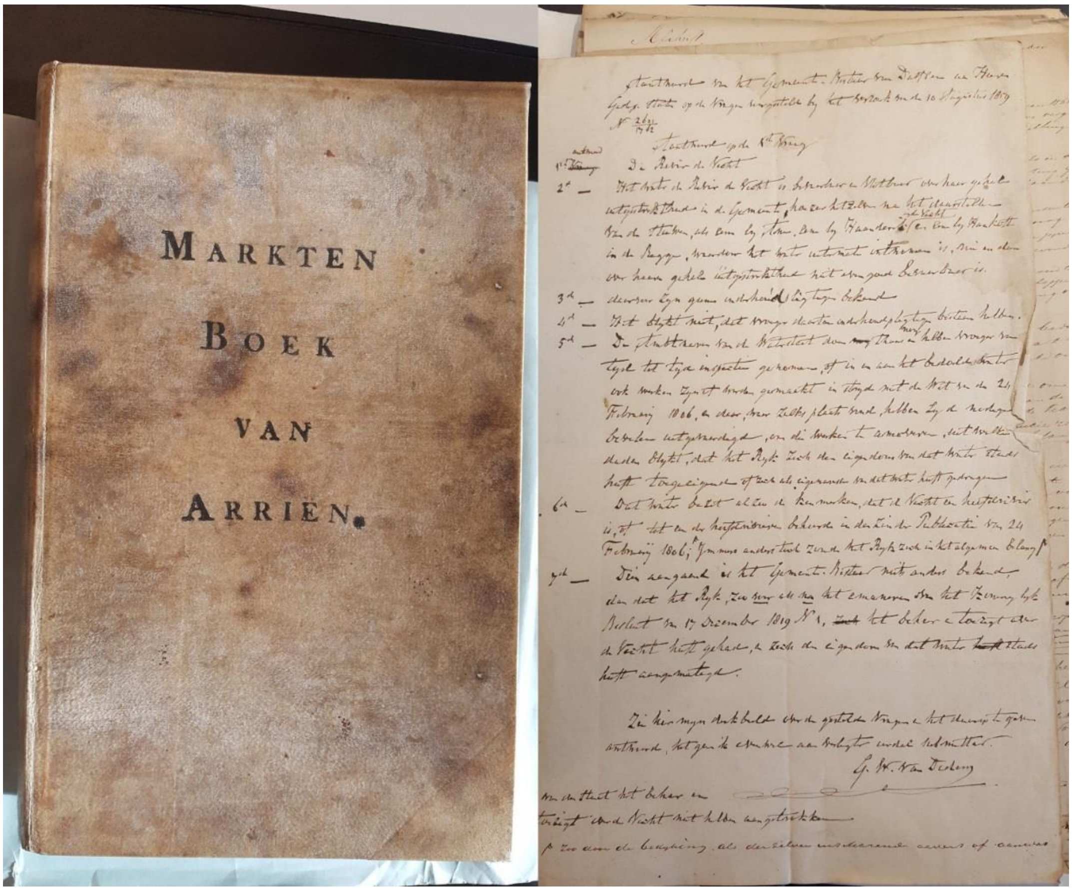


Figure 3.1 Example of the marken book of Arriën (markenbook Arriën [43]) and rapport of the municipality of Dalfsen [44].

3.3.2 Historical morphological data

The archive was not only used to gather historical literature and reports, but also to gather historical morphological data of the Overijsselse Vecht. Commissioned by the province, W. Staring and T.J. Stieltjes in 1848 and again T. J. Stieltjes in 1872 conducted measurements over most of the river systems in Overijssel, including the Overijsselse Vecht. Their measurements give an unique opportunity to investigate the changes in the Overijsselse Vecht in a relative short time period. W. Staring and T. J. Stieltjes noted these measurements down in maps, cross- and length-profiles. For the year 1848 21 maps, 97 cross-profiles (1:100) and for the year 1872 21 maps, 157 cross-profiles (1:100 and 1:200) and the corresponding length-profiles (1:5000) (including the year 1848) are available.

Before data was collected, suitability of the measurements were checked in order to execute a proper comparison. Suitability of the measurement locations were determined by multiple aspects: the measurement location from 1848 and 1872 should be on a relative same location, both the measurement locations should be in the same river situation (straight or in the river bend) and they should have a comparable width. Figure 3.2 shows an example when a measurement is accepted and when not.

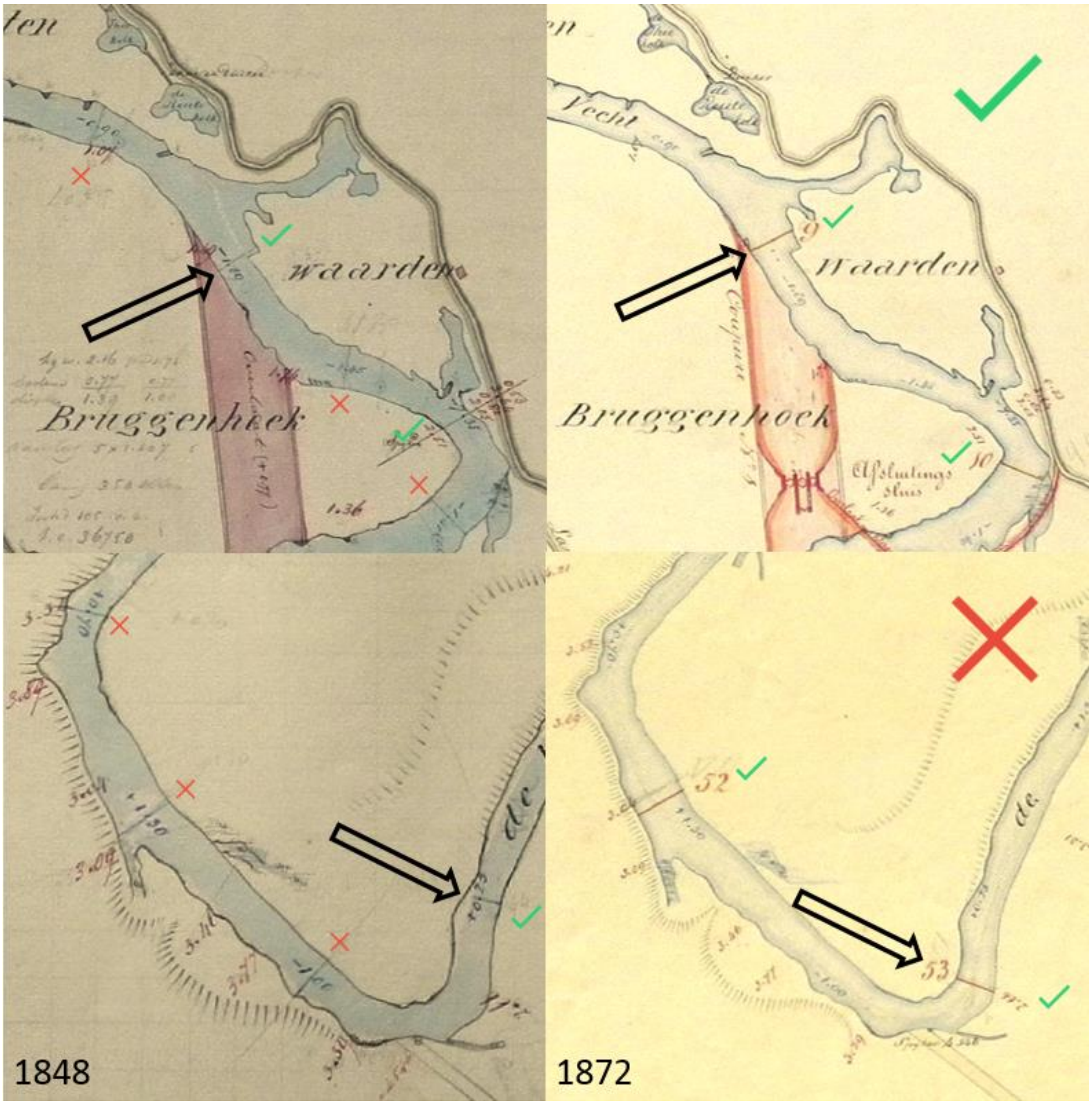


Figure 3.2 Example of when a measurement is accepted and when not. On the left side two examples of a map of 1848 is presented and on the right two examples of 1872. Check marks indicate when a measurement is available and a cross when this measurement is not available on an almost identical location. Therefore, these measurement were accepted for further analysis. Below it is visible that both measurement locations are relative close, but have different river width and are not in the same river situation. Measurement from 1848 is in straight river section and the measurement from 1872 in a river bend and are therefore not accepted.

Data was collected from the chosen measurement locations and recorded in an excel file. Example of how data is presented on the cross profiles is visible in figure 3.3. H_w is the height of the at that moment water line, A_w is the cross-sectional area of the river channel based on the water line height, E_m is the lowest river bed elevation of the river channel, D1, D2 etc are depth measurements, H_{bf} is the bankfull height and W_w is the width of the waterline. Unfortunately, in most profiles, the total width, total area and the average depth of the bankfull river channel are not known. Because scales are known, a ruler was accepted to be used to measure the missing data. In figure 3.3 W_l (width left) and W_r (width right) are the measured values and are indicated with red arrows.

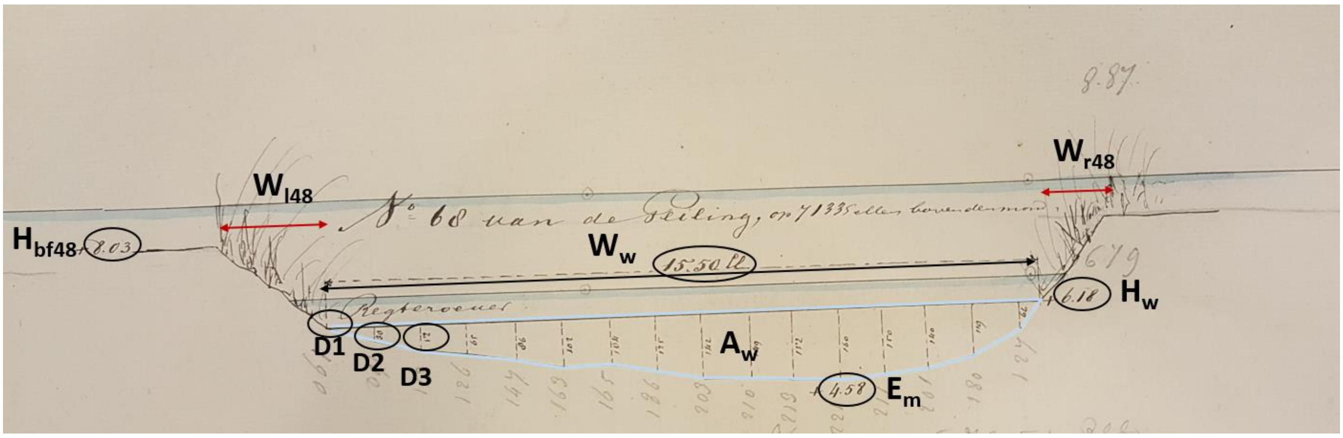


Figure 3.3 Example of a cross-profile of 1848 (N68). Within the profile the available data has been marked in black circles. The red lines present the measured width on the left and right side.

Lastly, the data presented by both different years was not uniform. Cross-profiles from 1872 did not show the whole cross-profile of the river, but showed it until a certain extent. This means that the bankfull height and the left and right end of the river channel of 1872 were unknown. In order to make a good comparison it was assumed that the left and right end of the river channel did not change in shape. Therefore, the left and right end of the river cross-profile of 1848 were projected on top of the 1872 cross-profile (figure 3.4).

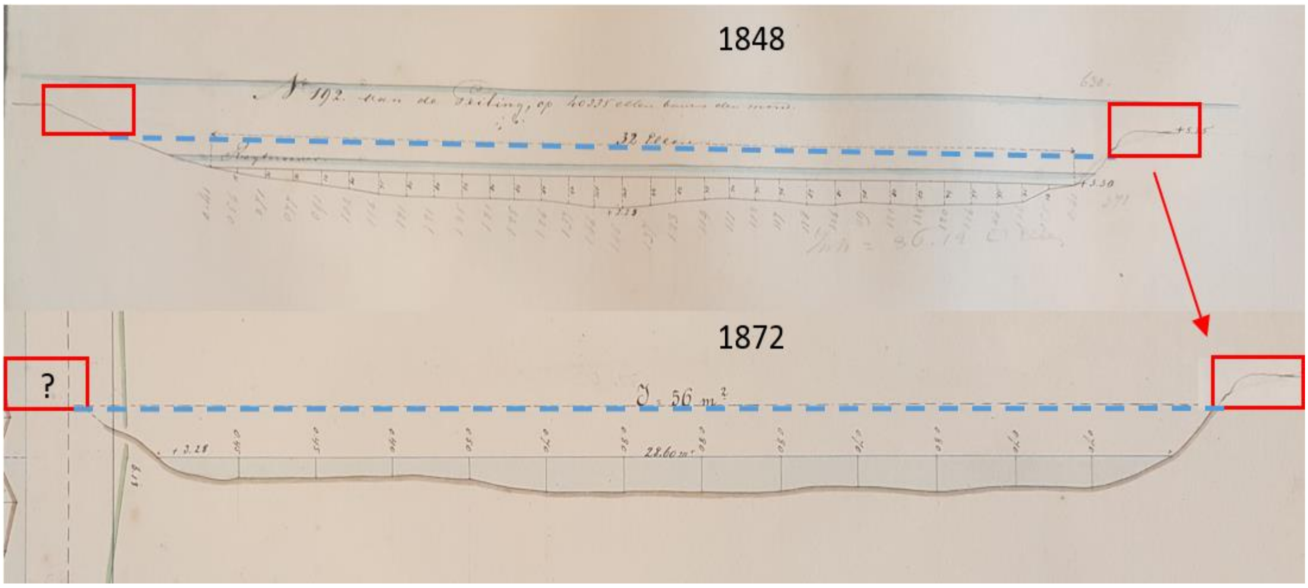


Figure 3.4 Projection of the left and right end from the 1848 cross-profile (top) on the 1872 cross-profile (bottom). On the left it is visible that in 1872 a part of the river cross-profile is missing. On the right is presented how the 1848 right end is projected on top of the 1872 cross-profile.

3.3 Data analysis

Changes in river morphology were analysed by comparing the channel dimensions of both years. For the analysis, the data from both years, are assumed to be on the exact same distance from the river mouth. This was accepted, because in the report "Afwatering van Twente" T. J. Stieltjes [16] stated that he could use the same distances as were used in the report from the "Overijsselse Wateren", due to little changes in river length [16]. Further, this makes comparing easier and focus can be put to the actual change.

3.3.1 Width

River width was calculated based on the given width (Ww) and the measured width from the map:

$$W_{48} = W_w + W_{r48} + W_{l48}$$

$$W_{72} = W_w + W_{r72} + W_{l72} + W_{r48} + W_{l48}$$

Where W_{48} and W_{72} are the bank full width (m) in 1848 and 1872, W_r and W_l the measured missing width (m) on the right and left extent of the cross-profile profile (figure 3.3) and W_{r48} and W_{l48} (m) are the missing right and left side of the profile measured in the 1848 profile (figure 3.5).

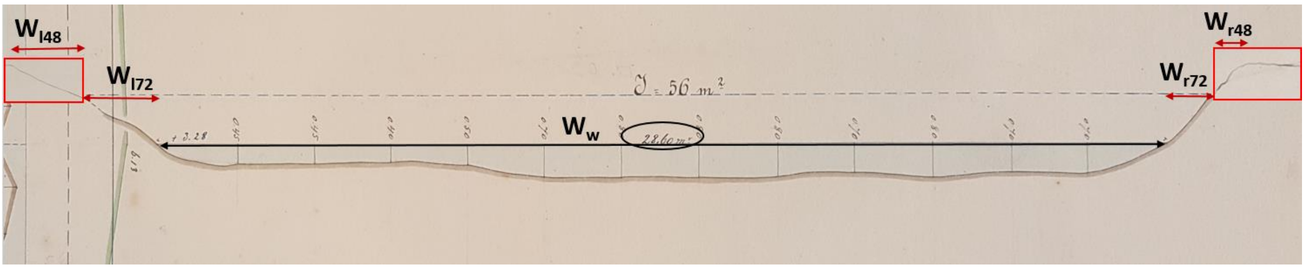


Figure 3.5 Profile of 1872 with in in de middle Ww and on the left and right side the measured Wl72 and the Wr72. The projected left and right side of the river cross-profile are indicated with red squares with corresponding 1848 widths (Wl48 and Wr48).

3.3.2 Average river bed elevation

The average river elevation E_a (m – NAP) was derived by subtracting the average depth from the H_{bf}. The average depth has been derived from the multiple depth measurements D (m), given in the cross-profiles (figure 3.3), and from calculating the average depth on the left and right extent of the cross-profile. Unfortunately, measurements D were not taken on the same interval size. Therefore, first an average interval size had to be calculated. The E_a was calculated following equation:

$$E_{a48}, E_{a72} = H_{bf} - \frac{Sum_m + \frac{H_{bf} - H_w}{2} * I_m}{I_w + I_m}$$

Sum_m is the sum of the depth measurements adapted to bank full height (individual D measurement + $H_{bf} - H_w$), ($H_{bf} - H_w$)/ 2 is the average depth in the left and right extent of the cross-profile, I_m is the amount of intervals in the left and right end of the cross-profile and I_w is the amount of intervals of the measurements D.

3.3.3 Sediment balance

The sediment balance was based on the differences in area A (m^2) of the cross-profile. The A per profile was calculated by adding the area below the waterline (A_w) with the area above the waterline and the area of the left and right extend of the cross-profile. The area above the waterline can be calculated using a rectangular shape and the areas on the left and right extent of the cross-profile are simplified as a triangle (figure 3.6). The A has been calculated using the following formulas:

$$A_{48} = A_w + \frac{(W_{r48} + W_{l48})(H_{bf48} - H_w)}{2} + W_w * (H_{bf48} - H_w)$$

$$A_{72} = A_w + \frac{(W_{r48} + W_{l48})(H_{bf48} - H_{bf72})}{2} + (W_w + W_{r72} + W_{l72}) * (H_{bf48} - H_{bf72})$$

A_{48} and A_{72} are the cross-profile areas of 1848 and 1872. A_{w48} is calculated by a summation of measurements D, dividing it by the amount of intervals and lastly, by multiplying it with the

W_w. A_{w72} is provided on the map itself. The second part of the equation is used to calculate the triangular shapes of the left and right end of the cross-profile and the third part is area calculation of the rectangular area above A_w. Calculating the A for 1848 is different from calculating the A for 1872.

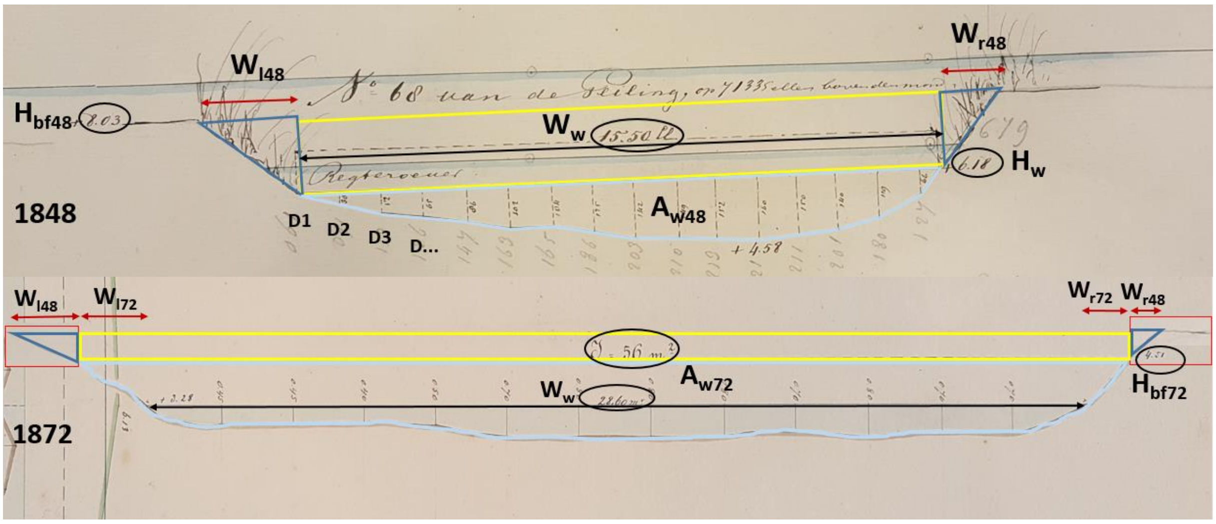


Figure 3.6 Area calculation of cross-profiles in 1848 (top) and 1872 (bottom). Light blue shape indicates the Aw, dark blue are the triangles, yellow indicates the rectangular shapes and the red squares in the 1872 cross-profile are the projected left and right end of the 1848 cross-profile.

The volume of sediment (m^3 per m) is then based on the on the subtraction of the different A's:

$$V_{ch} = A_{48} - A_{72}$$

Here is V_{ch} volume change of sediment for one meter of river stretch. Due to the fact that the Overijsselse Vecht is highly variable, we did not interpolate the sediment balance over the whole river channel, but kept it within one meter of distance.

3.3.4 Data presentation

The first focus will be on the general trend in the whole river. All factors are plotted against distance to river mouth and are compared to see general trends of morphological change based on chronology. The focus in this research is river management, but in order not to miss interpreted results, the geomorphological setting (2.2.2) is included in the analysis. In addition, the Overijsselse Vecht will be split in a below and downstream section, due to the possible influence of the tributary the Regge. analysis. Furthermore, effects of river management measures might have an delayed effect and river morphodynamics might therefor not be in equilibrium.

3.3 River management influence

Historical archive research gives insight on how the Overijsselse Vecht has been managed and might explain changing river morphology. Based river management information found in the historical archive, two sections were chosen. The first section, Dalfsen – Lichtmiskanaal, has been chosen due to the abundance of information about river management practises and due to detailed letters between the municipality of Dalfsen and the province and the government about the Overijsselse Vecht. The second section, Ane – de Haandrik, has been chosen due to the construction of the canals and due to suggestions of poor functioning and the cause for a deteriorated state of the Overijsselse Vecht.

The two sections are cut out of the full Overijsselse Vecht trajectory and are presented with river management information. The river management information might explain changes in river width, river bed elevation and erosion and deposition in those sections.

3.4 Error propagation

In order to provide this research with proper values to analyse river morphology and to make a valid comparison between the cross-profiles from 1848 and 1872, an error propagation has been carried out. Stochastic Monte Carlo simulation has been used and all the above formulated formulas were run 10.000 times. The uncertainty of these parameters are based on measurement techniques described in the rapport 'de Overijsselse Wateren'[15] from Staring and Stieltjes. Unfortunately not all measurement techniques were explained, but the document 'Handleiding tot de Werkdadige Meetkunst' [45] provided information about historical measurement techniques in 1829. Lastly, because measuring directly on the cross-profiles was used as a data gathering technique, the drawing accuracy was estimated based on drawing technique. Poor accuracy estimation is accepted, because the contribution of the drawing error to the total error was rather small.

The measurements for 1848 and 1872 were not carried out on the same locations. In order make a valid comparison the differences in location has to be incorporated in the error propagation. This has been done by incorporating the relative difference in width visible on the maps provided by Staring and Stieltjes. This relative difference has been used for the error calculation for 1872 and is included in all the calculations. Additional information of the error propagation and the used uncertainties can be found in appendix B.

4. Results

This chapter starts with describing river management evolution in the Overijsselse Vecht area by explaining different management structures, responsibilities and river management. This is followed by the analysis of historical data from Staring and Stieltjes. Next the morphological changes within the sections Lichtmiscanal – Dalfsen and Hardenberg – Ane are explained by the results of the historical literature research.

4.1 River management

At the end of this chapter, figure 4.6 will summarize when the management organisations were active and recaps important events and findings from archive material research.

4.1.1 The marken

4.1.1.1 Organisation structure and responsibility

Most of the consulted archive material for the marken consisted of marken books. Time frame of the marke books was from 1750 till last notation record (date after first historical citation). Within these books, meetings were reported and were led by the marken director. These meetings were held annually or twice a year and the content that was discussed consisted mainly of problems and complaints. The problems and complaints that were discussed within the different marke had some similarities, but also different topics were discussed.

In Haerst they mainly discussed dike maintenance and about how and who should maintain the dike [46] (1670 – 1826). In the marke of Varsen they mainly talked about peat extraction with the additional problems and complaints [47] (1418 – 1887). In Arriën they also discussed peat extraction, but also the digging of canals to the Vecht was largely discussed [43] (1549 – 1826) [48] (1765 – 1835). A larger topic found in the marken Arriën and Haerst is the grazing of life-stock on the low lying meadows, which was also noted in pre-found literature. In Arriën the discussing about grazing was first discussed in 1775 where sheep were prohibited to graze on the meadows. Later again in 1804 they discussed grazing on the meadows, but now focussing on cows and horses. It took three years before the decision was made. Cows were allowed to graze on the meadows, but the amount of cows was limited. Horses were allowed ass well, but this depended on time of the year [43]. Furthermore, drift sands were reported and pine trees were planted a solution [48]. All the marken had the responsibility for bridges and divers.

In Haerst, after the flood of 1825, discussions of dividing the marken were reported. They insisted that implementing a new system would increase costs and would increase the load for the community. The province asked if the marke could provide the costs of dike maintenance, but as a response they replied that it was difficult to give a certain amount, due to the differences every year [49] (1827 – 1855).

4.1.1.2 Vecht Management

In the markenbooks little was reported about the Overijsselse Vecht and about the condition and state of the Overijsselse Vecht. In Arriën, erosion problems were reported once. As a solution the marke would investigate if groynes would help to stop the erosion [48]. This was in 1770, but the same problem was reported again in 1804 where they established a committee to investigate if groynes would help to stop erosion [48](figure 4.1).

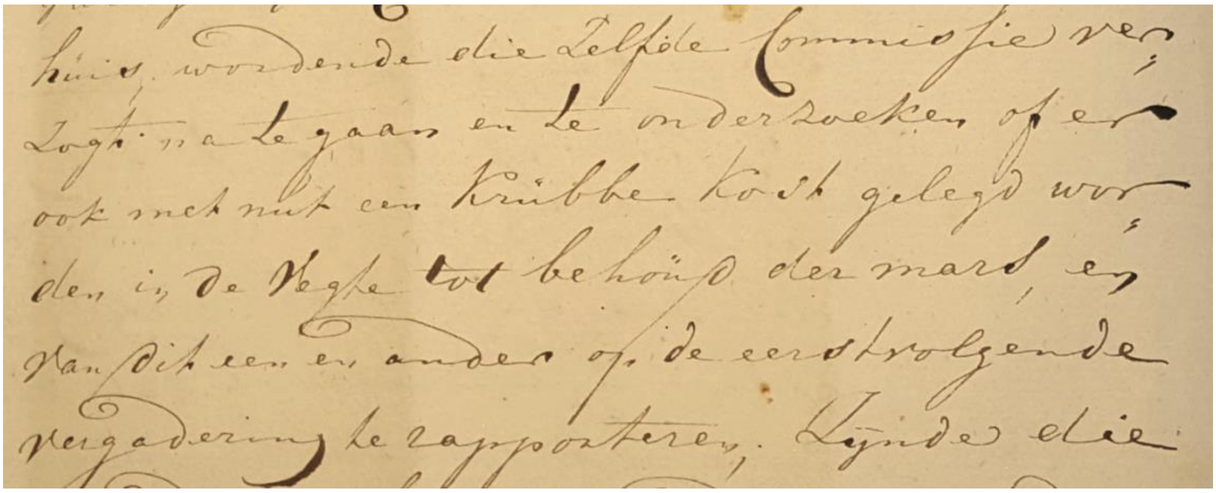

huis, wordende die zelfde Commissie ver=
zogt na te gaan en te onderzoeken of er
ook met nut een Krubbe kost gelegd wor=
den, in de Vegte tot behoef der marke, en
van dit een en ander op de eerstvolgende
vergadering te rapporteren. Zijnde die

Figure 4.1 Citation from the markenbook of Arriën describing the committee's task to investigate the use of groynes to protect erosion from the Vecht [48].

No information in between 1770 and 1804 regarding erosion and groynes has been found. Later, around 1823 groynes were discussed again [48]. Also in Varsen, where they once mentioned erosion of the Overijsselse Vecht at a particular location Grotenhuis (1766), they proposed a solution by digging a ditch on the other side. This should be constructed without financial support of the marke. Eventually, this leads to complaints and troubles for executing this idea [47]. Lastly in Haerst, where mainly dike maintenance was discussed, groynes were sometimes discussed in the form of reparations, but problems with the Overijsselse Vecht were not reported [46] [50]. In addition, reparations costs have all been noted [50].

4.1.2 Dike districts

4.1.2.1 Organisation structure and responsibility

After the dike districts took over the tasks of the marken they also recorded everything in minutes. The first thing that stands out is the higher quality of the records. The reports are better structured and the readability increases. Content consists of discussions and reports about problems and defects within the district with the focus on dike maintenance and elevation operations. The exact responsibilities were defined in dike regulation created by the province [51] (1836). When special works had to be carried out the dike committee had to ask permission from the provincial water state (article 12 in [51]). Stakeholders were mostly responsible for their own waterworks, but if they could not fund or carry out the necessary works, the dike district would take over. All reparations and improvements should be held as a public tender. In addition, cattle grazing is also a discussed topic. Cattle grazing on the dike itself is prohibited [51].

When water boards were finally established the dike districts did not agree with that decision. They state that it is not advisable to implement the new constitution on the existing districts. Furthermore they say that in the 45 years they were active they never felt the need to gain more legislature [52] (1873 – 1883).

In the notes of a meeting in 1936 it has been stated that during the takeover of the marken by the dike districts all the costs and expenses were taken over, but they never received their goods as was promised [53] (1936) (figure 4.2).

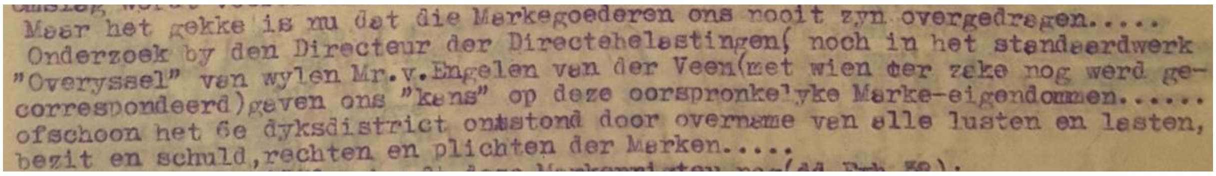

Maar het gekke is nu dat die Markegoederen ons nooit zyn overgedragen....
Onderzoek by den Directeur der Directebelastingen(noch in het standaardwerk
"Overyssel" van wylen Mr.v.Engelen van der Veen(met wien der zake nog werd ge-
correspondeerd)geven ons "kans" op deze oorspronkelyke Marke-eigendommen.....
ofschoon het 6e dyksdistrict ontstond door overname van alle lusten en lasten,
bezit en schuld,rechten en plichten der Marken....

Figure 4.2 Citation of a meeting of the water board 'Zuider Vechtdijken' where they discuss the fact that they did not received all goods from the marken [53].

4.1.2.2 Vecht management

No evidence has been found that the dike districts active participated in river management. Groyne construction were mentioned, but only in the form of reparations. The Overijsselse Vecht itself has been barely mentioned, including its problems, as were sometimes reported by the marke [54] (1836 – 1872) [55] (1836 – 1849) [56] (1849 – 1883) [57] (1836 – 1855).

4.1.3 Water boards

4.1.3.1 Organisation structure and responsibility

During the formation of the water boards a specific goal has been formulated: The water boards should defend all grounds from outside water and to regulate water discharge within its borders. Every association of common lands who has been put together to defend its ground against the water or to regulate the level and movement of water is a water board [58] (1879 – 1883). A water board can be created after the province has investigated and agreed that a water board is necessary. For every water board a special constitution has to be created. Those constitution give the rights and responsibilities for every individual water board. It can be recognised that the water boards have more legislature than the dike districts. More often they do not need to have permission form the province, but when costs are higher than 300 gulden, permission is needed (art 70 in [59]).

4.1.3.2 Vecht management

Also for the water boards as for the dike districts, no evidence has been found of active river management. In the special constitution for the water board the 'Noorder Vechtdijken' a description of the border has been given. This border does not include the Vecht itself, but is situated along the Overijsselse Vecht.

4.1.4 Government and provincial water state

4.1.4.1 Organisational structure and responsibility

The provincial water state has the task to maintain all the waterworks which have been made at the expense of the government. At time of exceptional danger, the inspectors of the provincial water state have to report that to the minister and measures can be taken. Further they make sure that measurements and field works are done to maintain the condition of the state and to keep track of the changing course of the rivers. And when there is a general concern measures can be taken [60].

4.1.4.2 Vecht management

That the river the Overijsselse Vecht was under attention of the government and the province has been clear by the multiple investigation reports of the Overijsselse Vecht. In 1809 J.E. Wildeman reported many shallow water levels and troublesome sand bodies. Ships were not able to travel or had to carry only one fifth of their total capacity. The sand bodies were merely found at locations with extreme width and low river banks. Furthermore, locations with extreme erosion were found. As a solution, J.E. Wildeman suggests that defensive groynes or the construction of weirs could be implemented [61]. Also in 1846, as an order of the province W. Staring got the assignment to investigate the watercourses of Overijssel [15]. And again after the decision on the 6th of November 1868, where T.J. Stieltjes got the assignment to investigate the drainage in Twente, the Vecht was again investigated [16].

In the archive material consulted for this research no more detailed info about this matter has been found in the early 19th century. It took until 1853, when letters were found about Vecht discussions between the minister and the province [62] (1853 – 1855, 1860 – 1863). In those letters they state that improvements should focus on the improvement of the river discharge with an eye on improving shipping across the Overijsselse Vecht.

Commissioned by the government an investigation was started to inspect the river Vecht and to come up with possible solutions province (executed by unknown, unreadable name). In addition, the province needed to investigate who was responsible for current maintenance of the Overijsselse Vecht. Little bit more than one year later the government changed their initial plan to improve the Vecht. The government states that due to the fact that to province does not want to contribute in the financials expenses, the government does not want to provide any financial support. The ongoing investigation must stop to prevent unnecessary costs. However, in 1855 the investigation was ready and the province came to the conclusion that almost nothing happened in river maintenance and only random measures were taken by land owners (figure 4.3) [62].

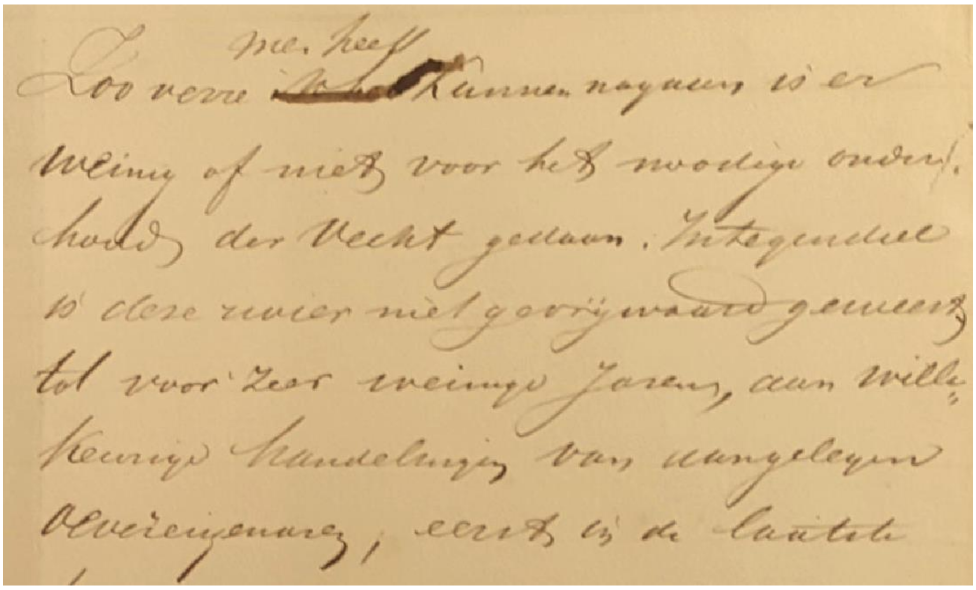

Zoo verre men heeft kunnen nagaan is er weinig of niets voor het noodige onderhoud der Vecht gedaan. Integendeel is deze rivier niet gevrijwaard geweest tot voor zeer weinige jaren, aan willekeurige handelingen van aangelegen Overeijenaars, eerst bij de laatste

Figure 4.3 Citation of the result of the investigation of the province. The province states that there was almost no river management and that random measures were taken by land owners [62].

In the report of the province propositions where made to improve the Overijsselse Vecht. For the proposition data from W. Staring and T.J. Stieltjes were used in order to give detailed explanation for every individual improvement. In this investigation the unknown executor states that the improvements focus on a better discharge and the shipping, but shipping seems to be less important due to the constructed weirs that are built on the river. On the other hand, Dalfen and Ommen might have a valid claim for improvements , due to their small shipping activities [62].

In 1859, the municipality of Dalfsen responded to a letter of the province about responsibility of the maintenance of the Overijsselse Vecht. Author of the letter, G.J. van Dedem, concluded that due to multiple inspections of the government at the river, the government appropriated the property (figure 4.4) and the maintenance of the Overijsselse Vecht [44] (1856 – 1866, 1905 – 1908).

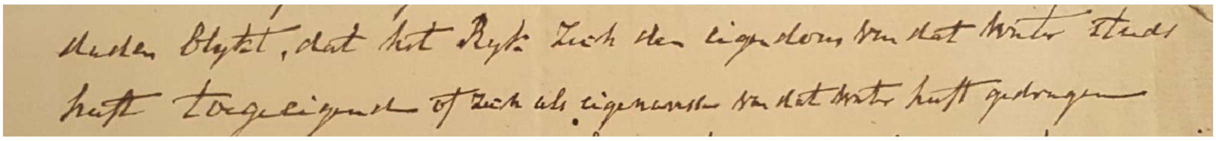

uitdien blijkt, dat het Rijk zich den eigendom van dat water steeds heeft toegeeigend of zich als eigenaar van dat water heeft gedragen

Figure 4.4 Citation from the municipality of Dalfsen stating that the government has appropriated the property of the Overijsselse Vecht [44].

In documents from 1861, the province discussed about a canal construction from Ommen to the Dedemsvaart (canal north of the Overijsselse Vecht, created between 1809 and 1854) and about improvements of the Overijsselse Vecht. In these documents the province agreed to improve the Vecht, if the government is going to provide a subsidy. In addition, first new research was needed [62].

Within two months supervisor van Wijngaarden replies that with the help of groynes the Overijsselse Vecht can get deeper, but when this is not sufficient artificial deepening can be used. He also implies that problematic areas are mostly found on areas with shallow and broad river banks. Furthermore, van Wijngaarden sheds light on the apparent many applications for creation of groynes by the municipality of Dalfsen [62].

In 1862, during the summer meeting, the province tends to decline the request of Dalfsen to establish groynes for improvement of the Overijsselse Vecht. The province will wait until a decision has been made about the whole Overijsselse Vecht improvement [62]. As a response, the municipality writes a letter to the province that they are disappointed that their request of improving the Overijsselse Vecht with groynes has so little interest. The municipality amplifies this by stating that the province badly invested the money intended for Dalfsen. Which is not the case compared with the investments for the harbour of Vollenhove and in the bridge of the municipality of Wierden. The municipality writes that in the past eight years, when the first groynes construction plan was created, the state of the Overijsselse Vecht became worse. Dalfsen remains as the last interested party, because Ommen, Hardenberg and Gramsbergen have left the quest. Ommen tries to save itself by asking for funding for the creation of a canal tot the Dedemsvaart. In this letter the municipality blames the weirs, which cause the use Vecht water for the constructed canals [44].

In addition of the letter to the province, the municipality writes a letter to the king. They felt they had no other option, because the province does not fulfil their promise to help. They write that the river is vital for Dalfsen and that no one is taking care of the maintenance of the Overijsselse Vecht (figure 4.5). The province was the first to ask, but they have little attention to their problem. When the problem was first discussed in 1857 the province postponed the problem to meetings in 1861. Furthermore, the province is responsible for construction of the weirs which obstruct shipping possibilities. In the letter the municipality of Dalfsen also elaborates on the proposed solution, which they have tested by monitoring a few constructed groynes. The chief-engineer expects large progress, but still the province asked for more investigation without telling which direction it will go [62]. A few months after the letter to the king the chief-engineer replies to the province that the municipality will get subsidy from the province when they further elaborate the plan. After the new plan is presented in 1865, subsidy is given and groynes are constructed at agreed locations between Dalfsen and the Lichtmiskanaal [44](sketches and locations in appendix C).

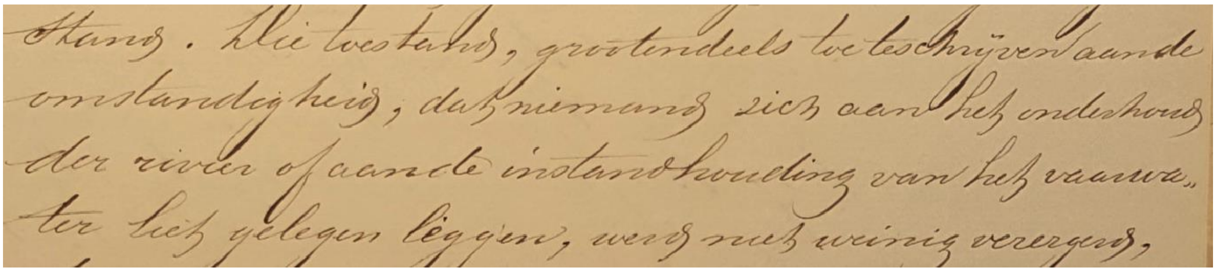

stand. Die toestand, grootendeels toe te schrijven aan de
omstandigheid, dat niemand zich aan het onderhoud
der rivier of aan de instandhouding van het vaarwa-
ter liet gelegen liggen, werd niet weinig verergerd,

Figure 4.5 Citation of the letter from Dalfsen to the King, stating that the condition of the Overijsselse Vecht can be ascribed due to the fact that no one takes care of the Overijsselse Vecht management [44].

In 1882 a complaint has been found about the use of the weirs for the canal the Dedemsvaart and the Overijsselse canals. They complain about extremely high waters on the Overijsselse Vecht which could harm their haylands. As a reply, the province admits that the functioning of weirs could have been better, but they refute that the extreme high water levels were caused by the weirs. The province states that the problem lies most probably between Hardenberg and Ommen. Furthermore, they make the suggestion that the foundation of a water board would solve these problems [60].

A few years later in 1886, chief engineer A. Deking Dura from the province, writes that the municipality of Dalfsen wrote a letter directed to the minister of the water state, trade and industry. Dalfsen complains about deteriorated state of the waterway and state that it should be improved by establishing groynes between the Lichtmiskanaal and Dalfsen. The engineer talks about that first, written in report of the province, the navigability increased, but that later in 1871 complaints started to arise again. The engineer says that the complaints are legitimate and are mainly the cause of the large width of the summer bed. In order to solve the problem he comes with two solutions: Normalisation by groynes or canalisation of the whole Overijsselse Vecht. Between 1865 and 1866 73 groynes were established between Dalfsen and the Lichtmiskanaal. Near those groynes larger depths have been found and the waterway has improved. But the engineer concludes that men made a large mistake by assuming that the task was done. They only improved several sections, but now the problem shifted to the other sections [44].

Based on the experiences A. Deking Dura concludes that normalisation with groynes between Dalfsen and the Lichtmiskanaal is the best solution. A. Deking Dura suggests that the construction and maintenance of the groynes should be the responsibility of the government, because we are dealing with an important river flowing from foreign territory with a larger discharge than was before assumed. Finally, in 1896 on the 15th of July, a constitution determines that the river Overijsselse Vecht will be maintained and supervised by the Dutch government [44].

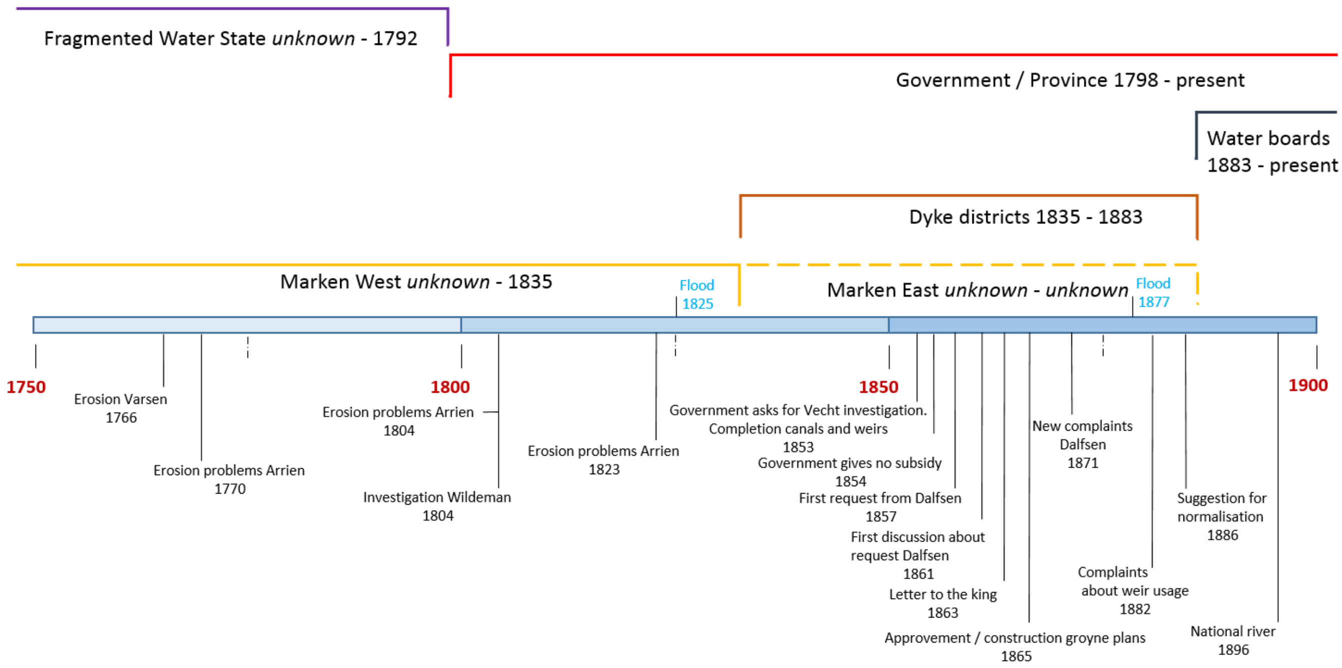


Figure 4.6 Timeline with management phases and a recap of important findings and events from archive material. When unknown is given in the figure its means that the exact start or end of the organisation(s) is unknown or too complex to express that in this figure.

4.2 River Morphology

From the measurements from W. Staring and T.J. Stieltjes in "De Overijsselse Wateren" (1848) and "Verslag over den tegenwoordige toestand der Afwatering in Twente" (1872) both periods were compared. After excluding incomparable measurements 38 locations per year remained for further analysis. Appendix D presents which profiles are used.

4.2.1 Average river bed elevation

In figure 4.7 the average river bed elevation (E_a) has been constructed and shows a steady decrease of river elevation from the German border. Both years have a similar slope of 0.0001. For the downstream part both slopes in 1848 and 1872 are 0.0001 and for the upstream part the slope in 1848 is 0.0001 and for 1872 0.00009. Comparing this with valley the slope, 0.00014, based on data of Staring and Stieltjes, calculated by H.P. Wolfert, we see that the channel slope is less. As an overall trend we cannot distinguish a significant change between both periods due spatial variation and the sometimes relative large error bars. Only in the very upstream part in section A there seems to be a deepening of the river channel. The average river bed elevation for the whole Overijsselse Vecht in 1848 is 3.14 ± 0.02 NAP (m) and in 1872 is 3.13 ± 0.05 NAP (m). The largest difference can be found at 26335 m from the river mouth and has a difference of 0.9 m. Only measurement Vechterweerd (1848), 20 (1872), at 10.300 m stands out with an extreme lower river bed elevation. Based on the map, this low river bed elevation might be explained by the influence of a harbour and short distance between the dikes. Narrower river channel causes larger flow velocities and therefore more erosion power and deepening.

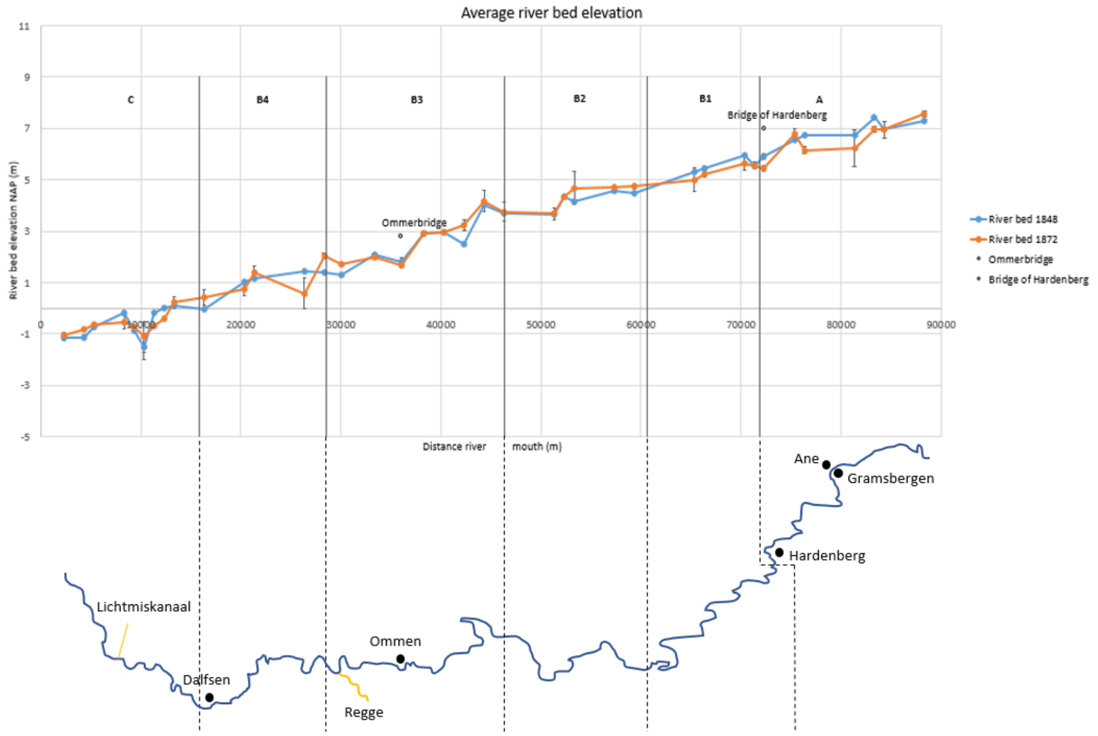


Figure 4.7 Average river bed elevation from 1848 and 1872.

4.2.2 Lowest river bed elevation

The lowest river elevation (E_L) has been plotted in figure 4.8. As can be seen is that the tendency of the E_a is the same as the E_L, but values are now amplified and are generally deeper than the E_a. As an overall trend no distinction can be made between both periods. The same as for E_a, there seems to be a deepening in section A. in addition, in section B3, the deepest locations of the river bed seem to be elevated. Furthermore, it is visible that the Regge might has an influence and that the lowest river bed elevation makes a clear jump down. The average E_L Overijsselse Vecht in 1848 is 2.09 ± 0.00 NAP (m) and for 1872 is 2.11 ± 0.02 NAP (m). Looking at the difference between up- and downstream it is visible that the Regge might has an influence that that the lowest river bed elevation makes a clear jump down. Downstream the average E_L in 1848 is -0.80 ± 0.01 NAP (m) and in 1872 -1.05 + 0.03 NAP (m). Upstream the average E_L in 1848 is 3.60 ± 0.01 NAP (m) and in 1872 3.76 ± 0.03 NAP (m). Based on the on average higher elevated lowest river bed elevation its seems that downstream the river has become deeper and that upstream, due to a decreased lowest river bed elevation, the river has become shallower

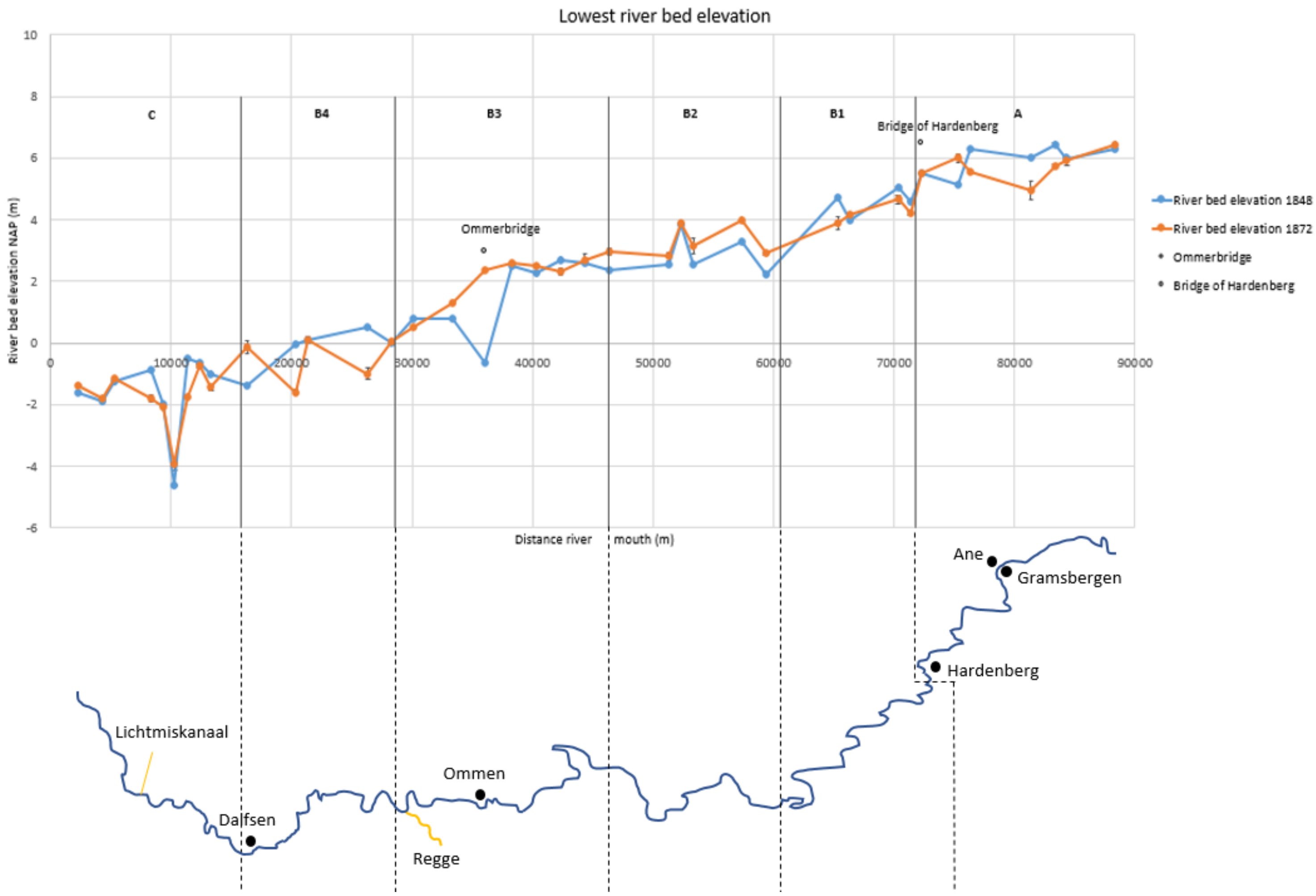


Figure 4.8 Lowest river bed elevation from 1848 and 1872.

4.2.3 Width

The reconstructed width-profiles show a clear widening towards the river mouth (figure 4.9). The differences between both years are well visible, but errors are large. This results in an average width of 39.59 ± 0.31 m in 1848 and an average width of 35.27 ± 0.57 m in 1872. Especially between the subdivision of the down and upstream Overijsselse Vecht differences are clear. Upstream the Overijsselse Vecht gets narrower due to the large sequence of narrowing locations. Downstream the tendency seems unclear and errors are larger. The average width upstream for 1848 is 33.63 ± 0.62 m and for 1872 is 27.07 ± 1.17 m. Variation between measurements in the same year are large. Especially from the river mouth till Dalfsen, but this might be explained by the presence of dikes which influence the natural levees. Furthermore, in T.J. Stieltjes indicates that in Hardenberg the bridge has remained the same and that in Ommen, between 1869 and 1870, the bridge has been renewed and has become wider [16]. This is nicely visible in the reconstructed width.

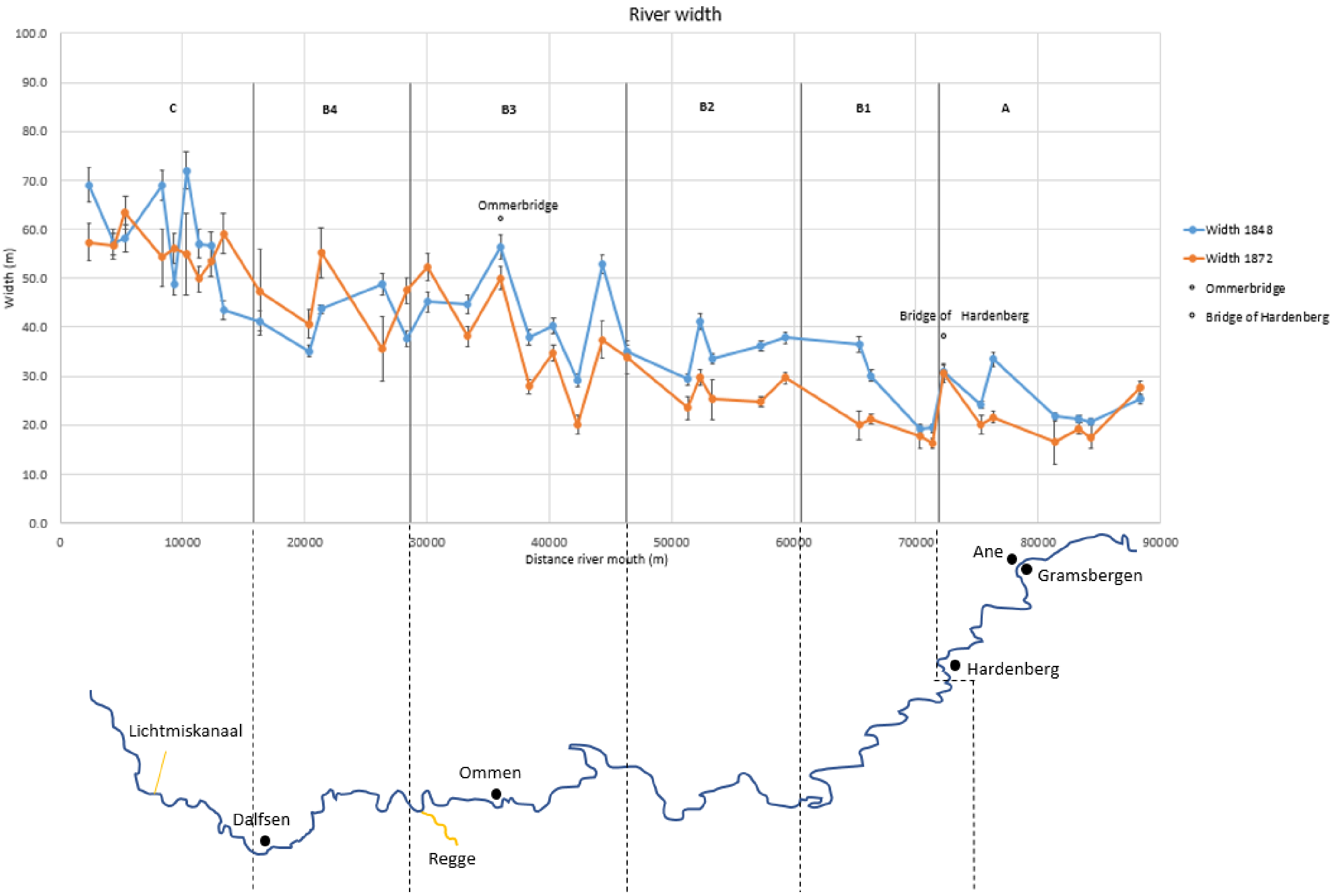


Figure 4.9 Reconstructed width from 1848 and 1872.

4.2.4 Sediment balance

In figure 4.10 the sediment balance has been presented. What is striking are the large error bars, which indicate the large uncertainty in predicting the sediment balance between 1848 and 1872. Despite the large error bars, the tendency in sections B3, B2 and B1 is visible. It seems that, within these section, sediment has accumulated. The average sedimentation in this this section is 19.62 ± 4.32 m^3/m. Also in the most downstream part, close to the river mouth there seems to be sedimentation. Only in section B4 between Ommen and Dalfsen there seems to be erosion with an average of -10.56 ± 1.98 m^3/m. In total the average sedimentation rate is 9.87 ± 3.07 m^3/m.

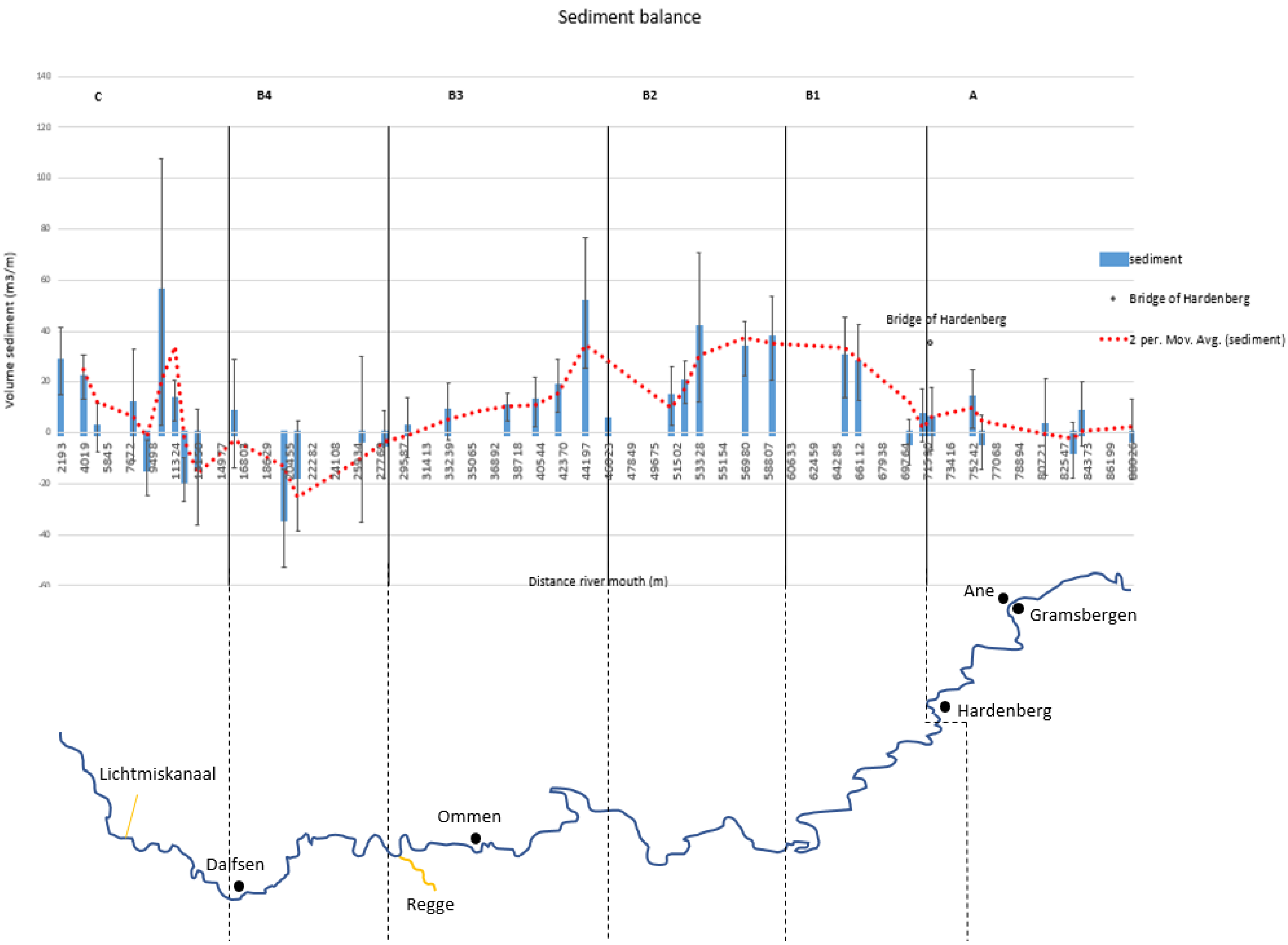


Figure 4.10 Volume of sediment that has been eroded or deposited on the particular measurement locations with a moving average.

4.3 River management case studies

Based on archive material, the impact of river management on river morphology is analysed. Furthermore, observations from archive material are checked to find out if they correspond with the reconstructed river morphology. From subchapter 4.1 we have learned that in the period 1848 – 1872 the contribution of the marken, dike districts and, later than 1872, water boards was little. Main influencers were the government and the province who executed most river investigations and were the main drivers behind the canal system construction and measures taken in the Overijsselse Vecht.

In the following paragraphs the chosen sections Ane – de Haandrik and Lichtmiskanaal – Dalfsen are analysed.

4.3.1 Canal system

In 1853, commissioned by the province, a canal system with its necessary weirs was constructed by Overijsselse Canal Company. They constructed a weir at the location Ane for the canal the Dedemsvaart and a weir at the location the Haandrik for the Overijsselse canal system. In figure 4.11 the weirs are shown together the morphological changes in that section.

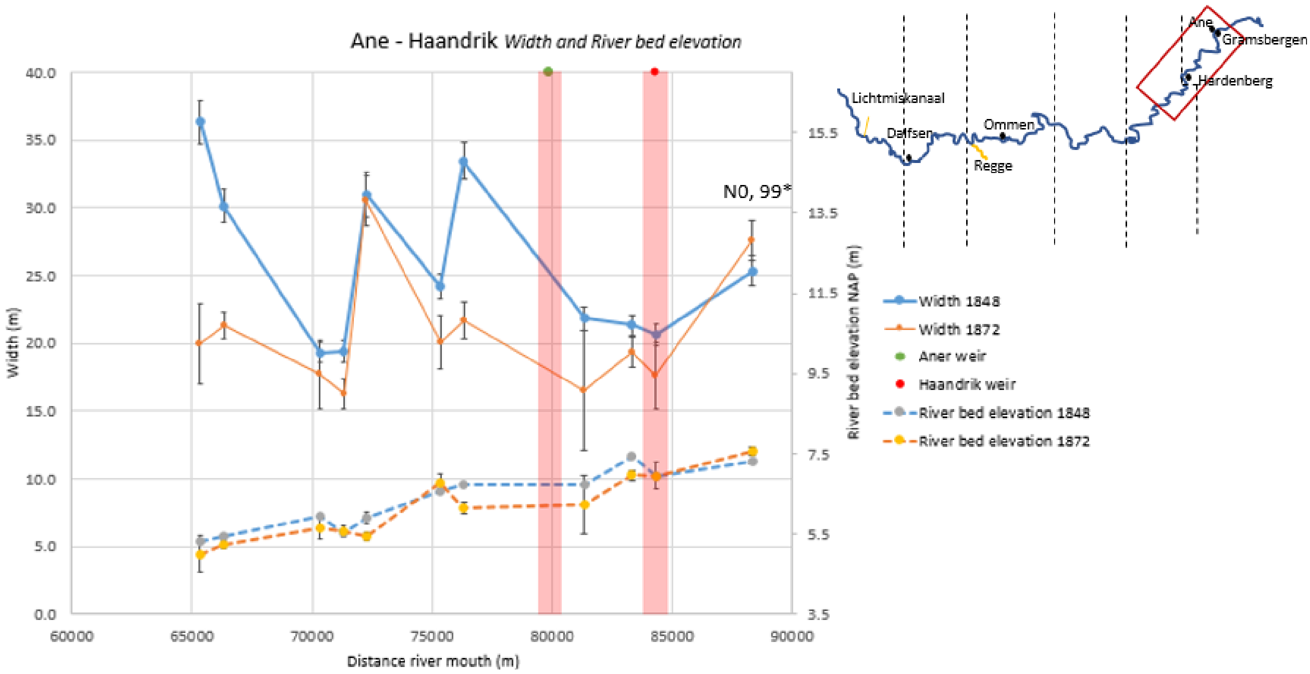


Figure 4.11 Changes in W and Ea in the section Ane – de Haandrik with the in 1853 constructed weirs indicated in red.

Variation in width and the changes between the two measurement locations are high. Overall the channel has become narrower and on most locations also deeper. This tendency, was also visible in sections B1 (chapter 4.2). For section Ane – de Haandrik the average decrease in W was -6.21 ± 0.38 (m) and the average decrease in river bed elevation was -0.20 ± 0.05 (m). At the last measurement location N0 (1848), 99* (1872), the tendency seems to change to a deepening and widening river channel, but error bars are large and upstream information is lacking to confirm this.

The weirs had the purpose to push the water to higher levels in order to supply the canals to retain sufficient water levels. The impact on the waters levels is presented in figure 4.12. Data came from Staring and Stieltjes who included water levels in their report ‘Afwatering in Twente’. These water levels are described as normal water and is interpreted as average water levels resulting from annual average discharge.

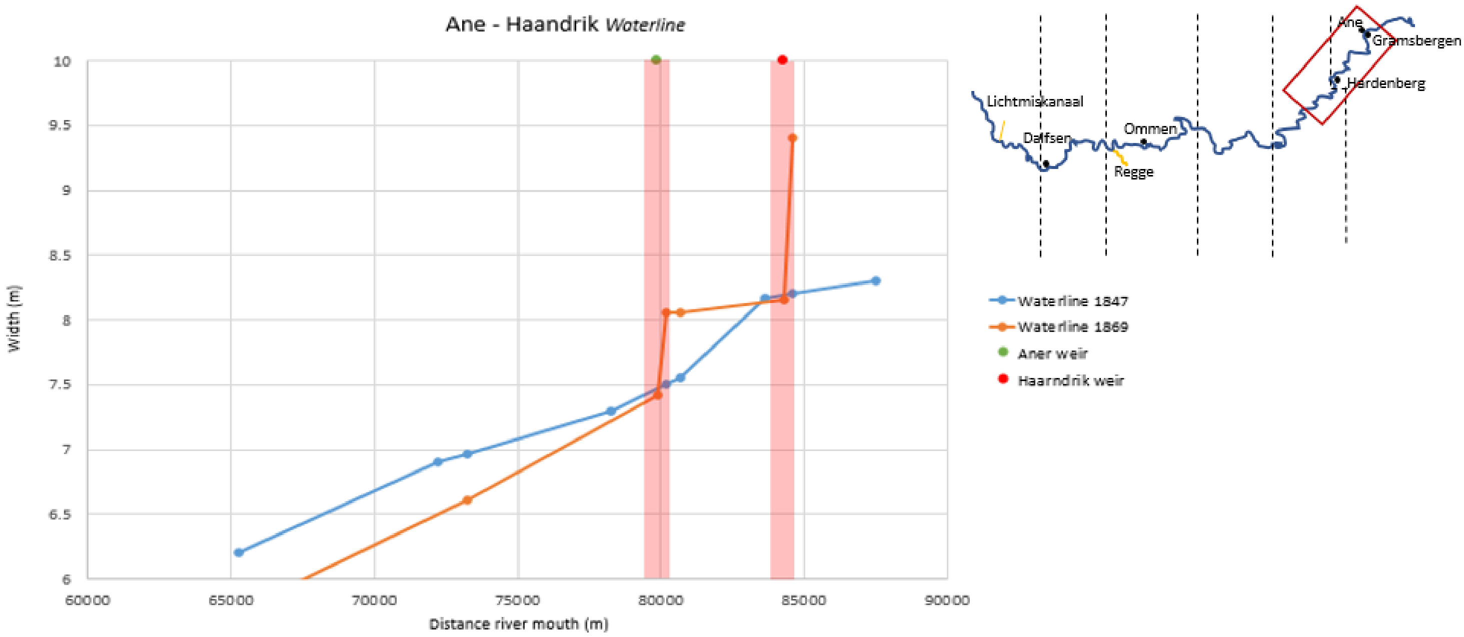
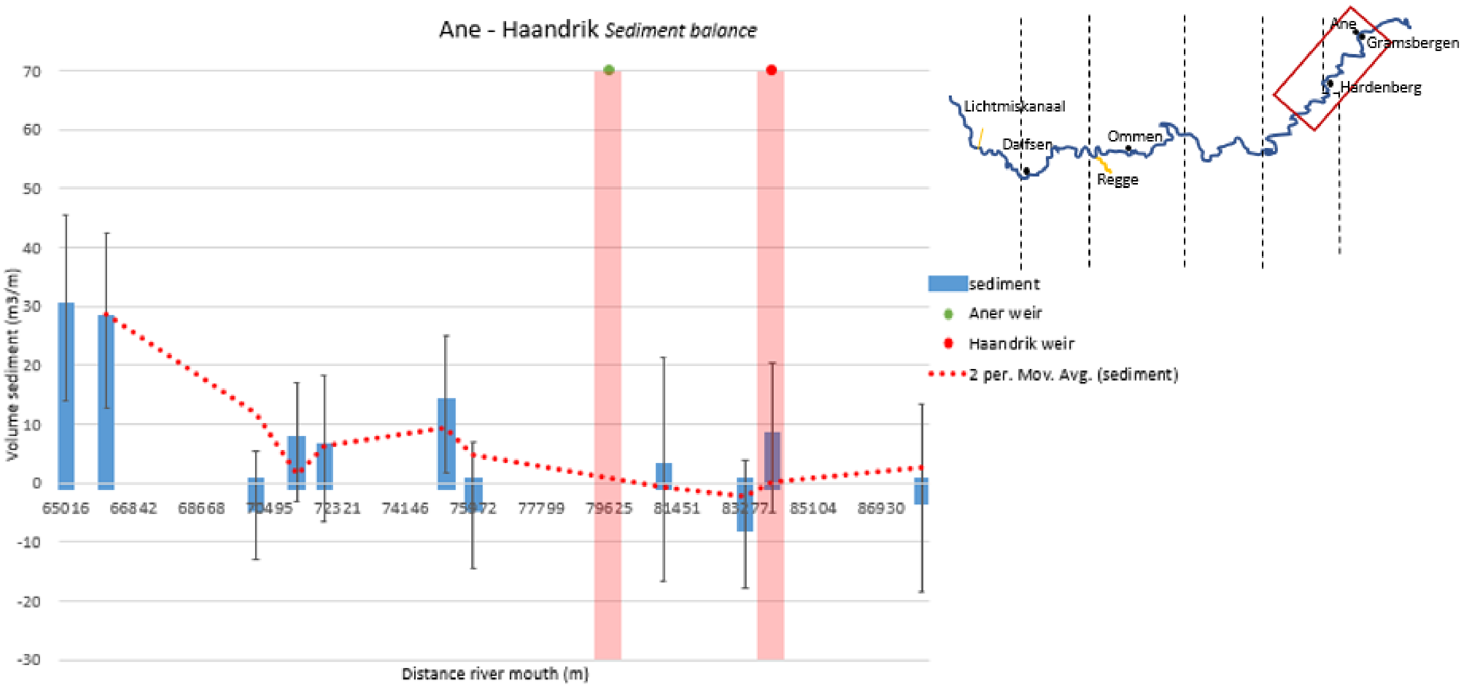


Figure 4.12 Changes in waterline in the section Ane – The Haandrik with the in 1853 constructed weirs indicated in red.

In figure 4.12 the effect of the canals is clearly visible. Water has been clearly pushed and has been used to maintain sufficient water levels in the canals. Not only water levels are higher, also the slope has decreased. The opposite is happening downstream of the weirs where water levels have significantly decreased and slope has increased. This suggest an incising river channel.

The reconstructed sediment balance (figure 4.13) shows that upstream sedimentation or erosion tendency is not clear. Going more downstream of the canals there seems to be sedimentation.



More downstream, 63 km from the Aner weir, the municipality of Dalfsen blamed the weirs Figure 4.13 Sediment volume change in the section Ane – de Haandrik with the in 1853 constructed weirs indicated in red.

to be the main cause for the low quality of the river. The municipality states that due to the weirs water levels dropped and ships endured navigation problems over the river. In figure 4.14 the average normal waterline before and after the construction of the canals are presented together with extreme low summer levels.

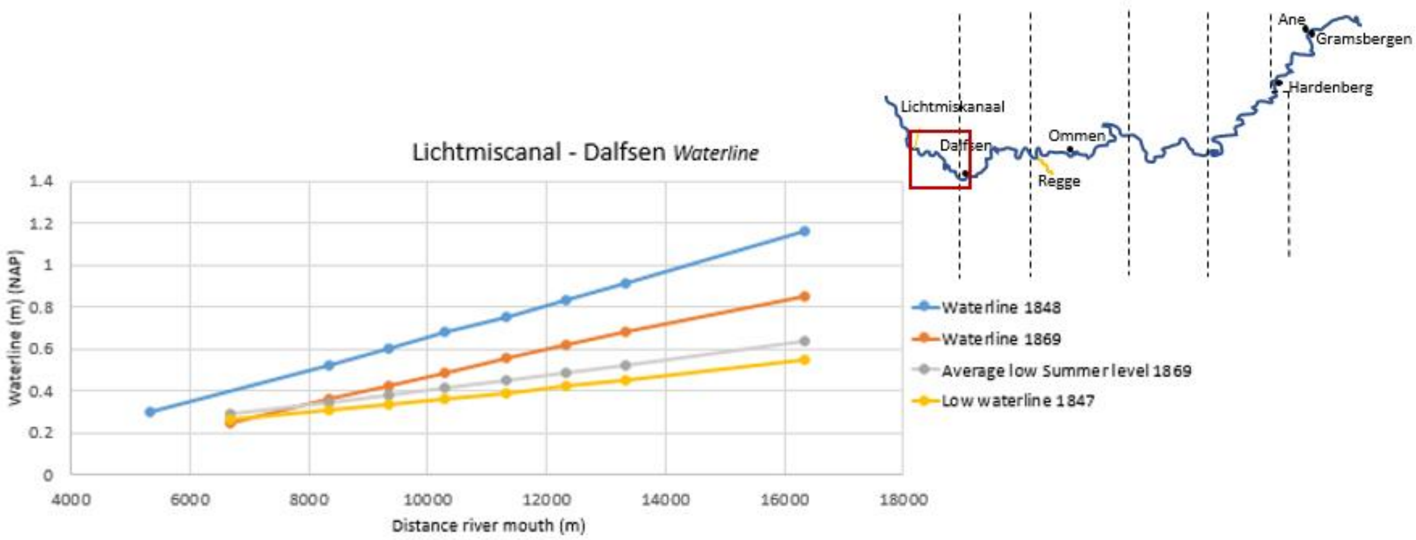


Figure 4.14 Normal and extreme summer low waterline before canal construction (1847), normal (1869) and extreme summer low (average 1854 – 1886) waterline after canal construction.

In time there are definitely changes in water level. Especially, there has been a decrease of normal water levels between 1848 and 1869. The normal water level decreased at Dalfsen with 0.3 m. For summer levels the difference is rather small, showing even a small increase water level. Beside for the fact that there are differences, the difference gets smaller towards the river mouth. This can be explained due the larger distance of the weirs and the growing influence of the sea.

The changed water levels with changes in in river bed elevation can show the effect on shipping possibilities. 1.30 meter is the desired depth for shipping and can be used as a threshold for shipping possibilities [44]. Figure 4.15 shows the water depth resulting from the subtraction of river bed elevation from the water line height.

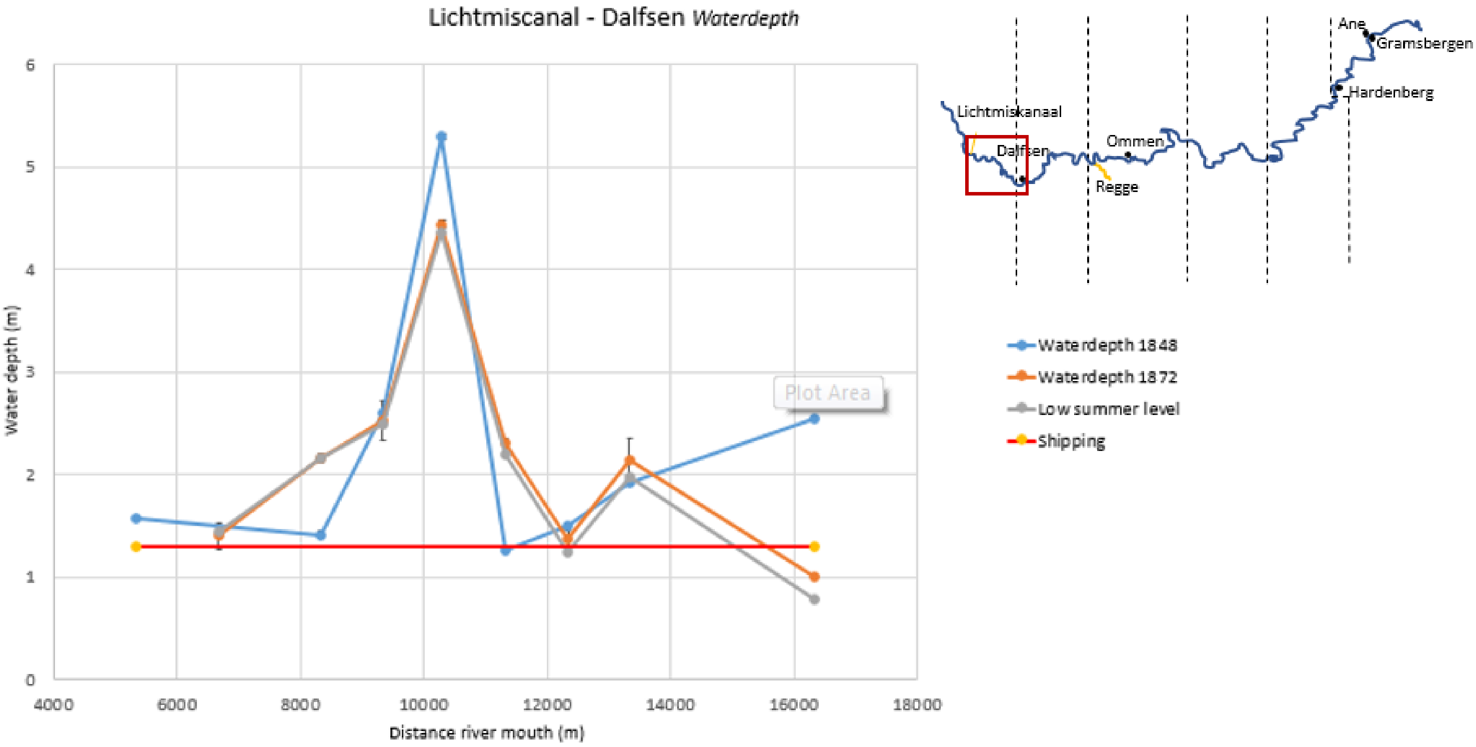


Figure 4.15 Water depth before and after the canal construction including the extreme summer lows after canal construction. Red line indicates shipping threshold of 1.30 m.

Most of the locations are above the shipping threshold. Only close to Dalfsen the water depth decreased with 1.53 m and resulted in a water depth below the shipping threshold. 0.30 m is explained by a drop of water level and 1.23 m is explained by an increase of river bed elevation. Overall differences between the threshold are not large, which means that local sand bodies directly influence shipping possibilities.

4.3.2 Groyne construction

Due to complaints and problems of the municipality of Dalfsen, eventually 73 groynes were implemented in the section between Dalfsen and the Lichtmiskanaal. Dalfsen stated that groynes would solve the problems by increasing river depth. Also engineer A. Deking Dura concluded that larger depth near the constructed groynes were found. From archive material [44] the exact locations of the groynes are known and are presented in figure 4.16 with the changing width and river bed elevation.

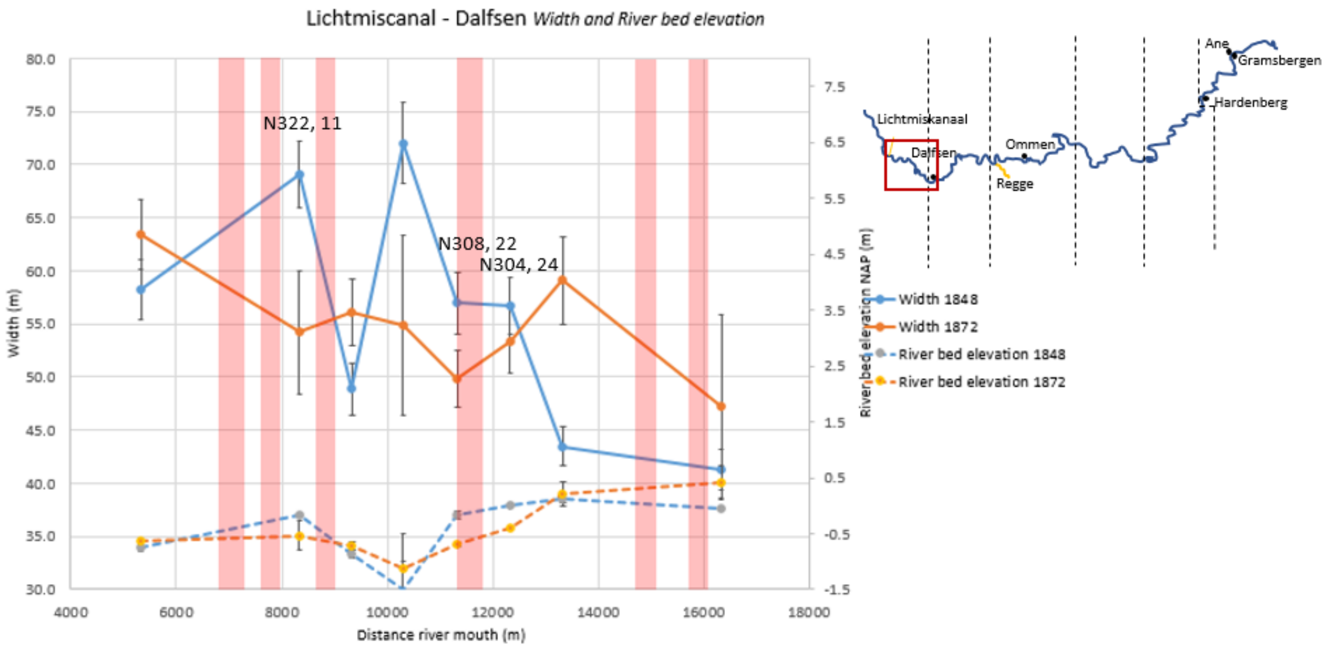


Figure 4.15 Water depth before and after the canal construction including the extreme summer lows after canal construction. Red line indicates shipping threshold of 1.30 m.

In this river section error bars and variation are large, especially between the width. Including the fact that the measurement locations are not close to the groynes makes it difficult to make reliable conclusions. Only location N308 (1848), 22 (1872) in this figure is within the groyne section and location N322 (1848), 11 (1872) is closely surrounded by groynes. The changes on these measurement locations suggest indeed influences from groynes due to narrowing and deepening of the river channel. Location N304 (1848), 24 (1872) shows the same tendency.

5. Discussion

This chapter starts with discussing river management responsibilities and the overall importance of the Overijsselse Vecht. This is followed with a discussion about changed river morphology by river management.

5.1. River management responsibilities

From Neefjes et al. (2011) [10] and historical archives cited in Wolfert et al. (1996) [5] it was clear that marken were concerned about the Overijsselse Vecht. They maintained dikes and tried to overcome erosion by groynes. The marke Beerze used groynes to stop erosion and in Mariënberg open fields were protected [17]. This has also been found in the historical literature that has been consulted for this research. Within the marken, groyne constructions were sometimes mentioned and incidentally erosion problems were discussed. This indicates that the Overijsselse Vecht indeed caused problems and that the marken tried to overcome associated erosion implications. However, these discussions were rather limited. Within the archive material, the Overijsselse Vecht has barely been mentioned and river management responsibilities were not discussed. In the marken Haerst dikes were discussed, but the responsibilities were not directed to the marken board itself. Maintenance duty was directed to the concerned farmlands and had the responsibility to maintain the dike for a proper defence. This was called 'Hoefslagplicht'. The marken itself, at least twice a year, checked the dikes if the they were still in a good condition. If not, they would fine the farmers who were responsible [11].

After the marken were divided the Dike districts took over and later, in 1881, these dike districts were transformed to water boards together with the remaining river borders. As has been suggested by Neefjes et al. (2011) [10], that no clear river management was operative, has been supported by findings within this research. But in the report 'de Afwatering van Twente', Stieltjes states that the establishments of water boards are crucial to improve the Overijsselse Vecht [16]. But his advice has never been implemented.

In Neefjes et al. (2011) [10] is has been stated that the government had a restrained attitude towards river management. This come to expression when the government asks the province in 1853 to investigate who was responsible for the management of the Overijselse Vecht [62] and shows that government and the province itself were not concerned with the management. Based on the multiple reports (Krayenhoff (1775), Wildeman (1809), Staring and Stieltjes (1848), Stieltjes (1872)) the government and the province showed their interest, but real action was lacking. That the government and the province did not know who was responsible for river management, is surprising. Also that river management was not included in the laws of water boards suggests little knowledge about river management responsibilities and shows disinterest in the condition of the Overijsselse Vecht.

5.2 The Overijsselse Vecht as unimportant river system

Within this research little river management responsibility has been found. Therefore, in the following sub chapter the importance of the river Overijsselse Vecht for the management organisations and its loss of its important transportation status are going to be discussed.

5.2.1 Marken, decision making and land use

For the marken, the Overijsselse Vecht had value as a transportation route for excavated peat and other goods. But archive material, that has been consulted for this research, shows no evidence that the Overijsselse Vecht has extensively been used. As has been discussed in the previous paragraph, it was clear that the marken suffered from river implications as erosion, but surprisingly the Overijsselse Vecht has barely been mentioned. Problems were reported incidentally and decision making about these matters was time consuming. It could take years before decisions were made. Also the decisions were rather ineffective. This can be seen in the marke Arriën, who investigated the same problem multiple times in 1770, 1804 and 1823 and proposed the same solution [48]. The fact that the marken were mostly concerned about safety and land protection, suggests the Overijsselse Vecht had little importance to them and explains the little discussion.

The marken were mainly concerned about their own lands by preventing erosion. But still it is surprising that the discussion about erosion prevention was rather little. Especially with the fact that the floodplains near the river were from high value [63]. They were used as hayland and produced food for their animals in winter [64], as meadow for cow grazing or they were swampy soils called '*broekgronden*'. Cows were generally the only cattle permitted on these soils, because cows have higher demand for food quality, which could not be provided by the heather. Grazing other cattle was forbidden and could lead to fines [65]. This topic was a recurring discussion within the investigated markenbooks. Figure 5.1 shows the soil distribution. These floodplains were regularly flooded, especially during winter, and were supplied with fresh nutrients [63] [66]. These soils are called 'greenlands'. Concerning this importance it is expected that the marken would defend their lands and would benefit if these lands would expand. The meanderbelt of Junner koeland grew a lot in size and extended into the lands of the marken of Stegeren and Arriën. C. Quik suggested that this meander migration might have been enhanced deliberately [66]. Evidence of this suggestion has not been found within the information concerning the marke Arriën. Only the greenlands within the marke itself were mentioned and had to be protected by groynes. An explanation might be that the eroded lands from Arriën and Stegeren consisted of the lower value heathlands and were therefore for less importance. Unfortunately the markenbook of June has never been found to find possible evidence. The marke Varsen was investigated in this research and had greenlands within a meanderbelt, but also here no evidence has been found that suggested intended meandering.

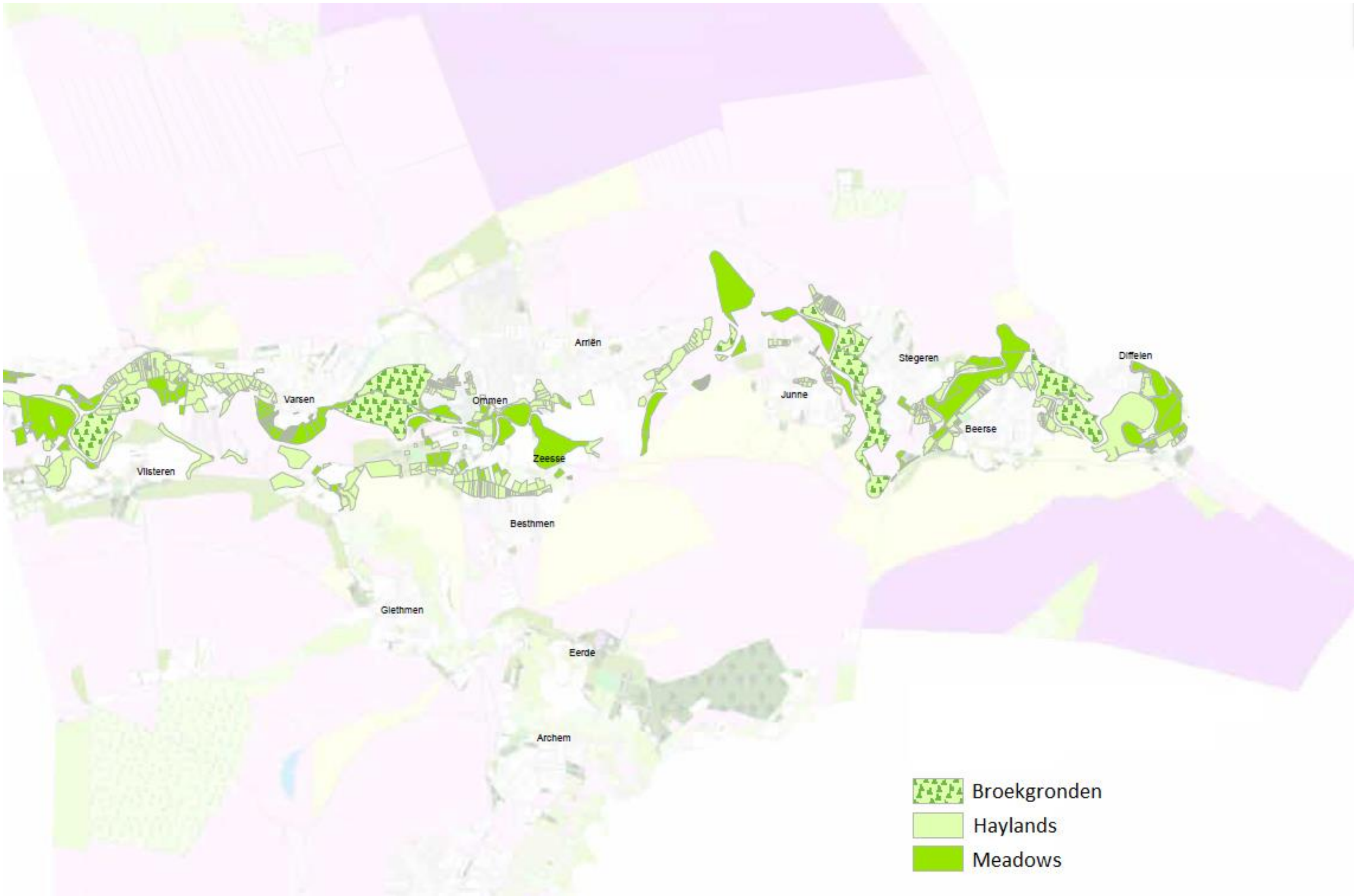


Figure 5.1 Greenlands next to the Overijsselse Vecht with its corresponding categories [63]: OAT Kadaster 1832

5.2.2 Canals as an alternative

The deteriorated state of the Overijsselse Vecht caused problems for transport. Together with growing interest in peat more and more individuals started to dig small canals to transport peat. The best example is the Dedemsvaart which is located northerly of the Overijsselse Vecht and is a canal which connects Hasselt and Ane. Because of the increased industry near the Dedemsvaart (figure 5.2) and because in Twente the textile industry grew, the province started to think in 1826 of the construction of canals in order to improving shipping possibilities. But due to high costs, financial risks and the fact that the canals would get insufficient supply of water from neighbouring rivers, it did not work out [42]. When eventually in 1845 the option of train connections was too expensive too they had to go back to their old plans of canals. In 1849 the plan was approved and eventually the last part of the Overijsselse canals, canal from Deventer to Dalmsholte, were completed in 1858 (figure 5.3).

Neighbouring rivers as the Overijsselse Vecht and the Regge were used as water supply to keep stable levels in the canals [42]. Especially in the summer, when discharge was high, water from the Vecht was used maintain water levels on the canals. The economic interest shifted to the canals and suggest that the Overijsselse Vecht was subordinate to the canals.

Figure 5.2 An example of an industry that flourished next to the Dedemsvaart. Calcium ovens were a direct result of the peat extraction industry and were used for agriculture [10].

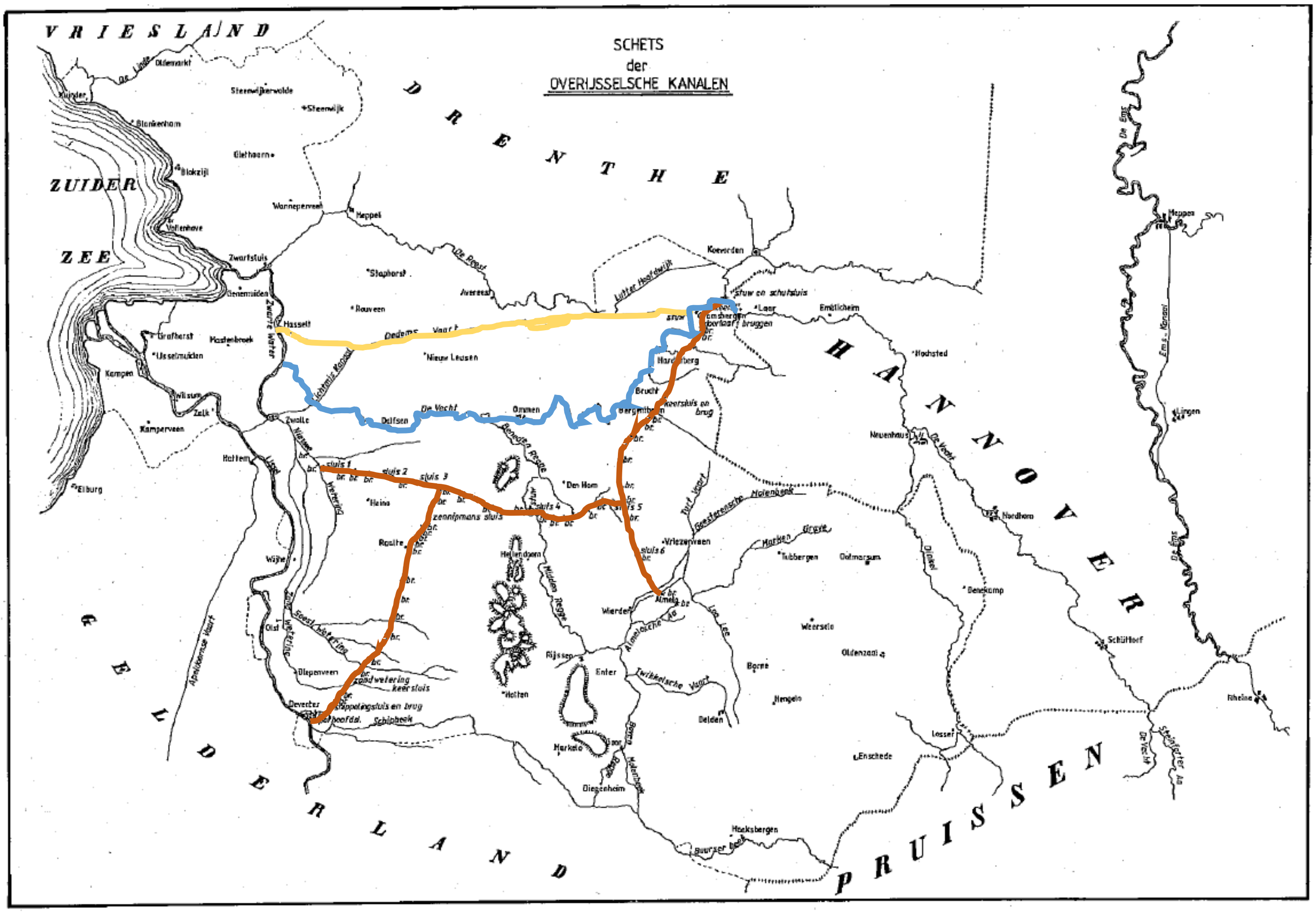


Figure 5.3 figure Overview of the Overijsselse canal system. In blue the Overijsselse Vecht (Dutch part), in yellow the Dedemsvaart and in orange the Overijsselse canals [42].

Literature and reported water levels (figure 4.14) show the impact of constructed canals. Normal water levels dropped and caused multiple problems for cities situated at the river border. Dalfsen complained that transport was of vital importance, but that due to the canal system transport was almost impossible [62] [44]. Multiple times the municipality of Dalfsen expressed their concerns and complaints to the province, but their complaints were shifted to following meetings and suggestion were rejected, because in their opinion more research was needed [62]. However, multiple investigation and possible solutions were already available. Staring and Stieltjes wrote an extensive report and also the municipality of Dalfsen tested and monitored groyne constructions. Also the willingness to pay was low. The government withdrew their cooperation, because the province was not willing to pay either [62]. The reserved attitude towards river improvements shows that the river the Overijsselse Vecht had little important meaning for the province. This drove the municipality of Dalfsen desperate by eventually writing a letter to the king about this matter.

5.2.3. Bentheimer Sandstone, fall of transportation value

With no interest in the Overijsselse Vecht as a river system it raises the question if there was any interest in the years before 1750. From the 11th century sandstone from Bentheim in Germany (Bentheimer sandstone) had been extracted and used for statues [19]. Around 1400, cities around the Overijsselse Vecht started to appreciate the Bentheimer sandstone as a construction material. The Overijsselse Vecht was being used as a transportation route to the Netherlands [10]. Especially in the 17th century the transportation activity on the Overijsselse Vecht has been large. The Bentheimer standstone has been used in many constructions in the Netherlands (example figure 5.4). After 1700, when the interest of Amsterdam in the sandstone decreased, trade dropped and therefore also the transport. In the 19th century the transport decreased totally [10]. With almost no transportation on the Overijsselse Vecht and the rise of new transportation methods the economic value of the Overijsselse Vecht decreased. In years after the decrease of transportation reports of Krayenhoff (1775) [13], Wildeman (1809) [14] and Staring and Stieltjes (1848) [15] showed a deteriorated state of the Overijsselse Vecht. The loss of transportation value might have released the pressure of maintaining the river and led to problems in the 18th and 19th century.

Figure 5.4 Bentheimer sandstone in the St. Janskathedral in s'Hertogenbosch (left) and in the church of Delden (right) [19].

5.3 Morphological changes

This paragraph is addresses the changes in river morphology and the influence of river management and discusses possible explanations for the changed morphology.

5.3.1 Canals as alternative, its morphological consequences

Construction of weirs, to feed the canals, affects flow regime [67] and decrease discharge volume. This is clearly visible in the decreased average water height on the Overijsselse Vecht. Directly after the weirs, water level clearly dropped and also near Dalfsen, normal water levels were significant lower. Complaints from Dalfsen about troublesome shipping possibilities can be confirmed based on the reconstructed river bed elevation and decreased water levels (figure 4.15). Especially near Dalfsen itself, but also other locations in the Dalfsen – Lichtmiskanaal section show water depth just above the shipping threshold. Local sand bodies and variation around this water level will immediately give problems for shipping. On the other hand the canals did not have a significant impact on lower summer water levels. There is not enough data to confirm impact on summer water levels, but frequency of low water levels in the summer might have increased. After continuous complaining by the municipality of Dalfsen groynes were established between Dalfsen and the Lichtmiskanaal. Based on the results, it can be concluded that groynes had an effect by river channel narrowing and deepening. However, due to limited data it is hard to conclude if the groynes improved the river channel on all locations.

Previous research, conducted by Candel et al. [8] and Wolfert et al. [5] found the sequence of river channel narrowing in the 19th century. This corresponds with the results of this research and falls together with the weir and canal constructions. The reconstructed decrease in channel narrowing from previous research resulted in the decrease of bankfull discharge. Bankfull discharge is an approximation of channel forming discharge with an occurrence rate in every 1 or 2 years [68] [69]. This suggests that the canals and weirs caused a decrease in bankfull discharge. P.E. Grams (2002) showed that when dams are constructed in a river, discharges are controlled, peak discharges decrease and river channels will narrow [70]. Weirs are not dams, but the drop in water levels in the Overijsselse Vecht show that the weirs also control river discharge. In addition, it can be assumed that annual peak discharges decreased, because water can also be discharged on the canals for a certain extent and can explain the river channel narrowing.

Beside the fact that weirs control river discharge, evidence from archive material suggest extreme peak discharge events over the Overijsselse Vecht. When water levels were too high, water would be discharge over the Overijsselse Vecht and led to multiple complaints [60]. In addition, also farmers from Hardenberg protested after a flood induced by discharging the surplus of water over the Overijsselse Vecht and the community of Marle was also flooded due to the same cause [42]. Unfortunately, the frequency of these peak discharge events is unknown. But, due to the narrowing river channel and decrease in bank full discharge it is suggested that these events happened sporadic.

However, extreme water discharge events have a lot of power to erode and transport sediment [71]. The sudden opening of the weirs might have caused large sediment transport events through the Overijsselse Vecht system. From the morphological data it is visible that the Overijsselse Vecht channel narrowed with large sedimentation deposition. Directly downstream of the weirs, sedimentation is absent and the river seems to incise, but that can explained by higher stream power [72]. Further downstream, velocity can decrease due to river channel widening and might therefore induced the decrease in sediment transportation power. Wildeman, in his report, stated that the Overijsselse Vecht was too wide and resulted in flow deceleration and sedimentation [14]. The last part of the 19th century some river channels were still meandering, but due to the decrease of bankfull discharge there was too little power to meander [8]. The extreme discharge events might have induced enough power for meandering. However, it can be questioned how far downstream these peak discharges could have an effect. In addition, extreme peak discharges in the combination with intensive greasing on the floodplains might have decreased bank stability and enhanced meandering [73] [74] [5].

Sedimentation in the Overijsselse Vecht more overly happened in section B (figure ...) and especially in subsections B1, B2 and B3. In section B1 sedimentation volume increased going more downstream and in section B3 sedimentation volume decreases when going more downstream. Subsections B2 and B3 are characterised by extreme meanders. These extreme meanders decrease the speed of water velocity and therefore also the transportation power. Also in the research of P.E. Grams meandering reaches narrowed more than other sections [70]. Section B4 is actually also characterised by meanders, but just upstream of that section the Overijsselse Vecht tributary the Regge debouches into the Overijsselse Vecht. This results in a large increase of discharge (figure 5.5). The increase of discharge increases transportation power and therefore the decrease of sedimentation. In section C there also seems to be sedimentation. Groynes, constructed in the section Dalfsen – Lichtmiskanaal could have contributed to this sedimentation.

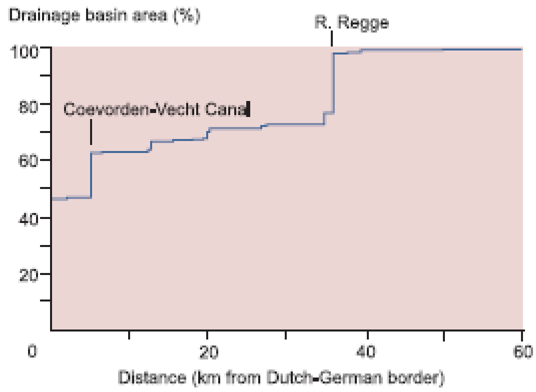


Figure 5.5 changes in discharge along the Overijsselse Vecht. Distance to river border is based on its current river length [3].

5.3.2 Economic cause or an ongoing problem

A possibility is that sedimentation problems have always been large, but that due to dropping economic interests, as a result of decreasing sandstone transport, waterways maintenance dropped. No effort is being taken anymore to retain quality waterways. This could have led to more obstructive sand bodies.

Another possibility is that problems around the Overijsselse Vecht were something that already occurred for centuries. This might explain the little discussion about erosion in the markenbooks. Erosion problems might have been common sense that occurred already for centuries. Since the Overijsselse Vecht has been used as a transportation route it was known that water levels were shallow with many obstructive bodies and that large peak discharges occurred. Ships that sailed on the Overijsselse Vecht were called ‘potten’ and later ‘zompen’ (figure 5.6) and were characterised by flat bottoms and were built for shallow waters [10]. From literature we know that particular techniques were used to overcome shallow waters. In 1858 Staring described a technique about the creation of small water traps in the river channel. Sailors would built small sand traps to capture enough water to generate a wave which had enough volume to transport boats further downstream [75]. The technique was forbidden since 1772, because this technique could generate new obstructive sand bodies [10]. Further other techniques like lifting, moving sand with their feet and pulling the boats over the sand bodies [76] and by digging away the sand bodies [77]. Next to those obstructions lodges formed, where sailors could get food and drinks. Staring suggested that these lodges benefited from the obstruction and maintained them. These techniques and the prohibition of Zwolle, shows that sailors were busy with displacement around the river and suggests higher interest.

Figure 5.6 The last ‘zomp’ that sailed the Overijsselse Vecht. In 1939 it was taken out of practise [10].

That the Overijsselse Vecht had a relative low base flow and high peak discharges can be explained by land use change. Within the catchment of the Overijsselse Vecht peat reclamation started in the 12th and 13th century [78] [79] and increased the following centuries [80]. When lands are reclaimed the sponge effect disappears and results in a short response time to precipitation [81] [82]. These peat reclamations are mentioned as one of the causes that might explain channel pattern change from laterally stable to a meandering river system [8]. This suggests that problems in the Overijsselse Vecht initiated after the start of the meandering phase and that river management between 1750 and 1900, or almost no river management as discussed here, did not contribute that much to the deteriorated state of the Overijsselse Vecht.

6. Conclusions and Recommendations

This research shows that historical literature provides valuable information of historical river management. It can be concluded that the marken were not focussed on river management, but more on their own lands. The later established dike districts and water boards had no responsibilities for river management as well. The Overijsselse Vecht itself has barely been mentioned with in the consulted archive material. Overall, it can be concluded that it was unclear who was responsible for river management and that the higher authorities were restrained in taking river improvement measures. The reconstructed river morphology shows river channel narrowing and sedimentation deposition in especially meandering river sections. No clear trend in changing river bed elevation can be distinguished, however water depths have decreased due to a lower water levels as a result of weir constructions. Therefore, problematic shipping possibilities of Dalfsen were confirmed. The weirs regulated water discharge over the Vecht and might therefore decreased peak discharges. Controlled discharge normally leads to river channel narrowing and the decrease in bankfull discharge. On the other hand, large peak discharges, generated by uncontrolled sudden opening of the weirs might have forced enough power to transport large amounts of sediment into the river system.

It is shown that between 1750 and 1900 river management was limited and that shipping possibilities decreased due to lowered water levels. Despite this conclusion, this research could not conclude that the lack of river management was the cause for the deteriorated state of the Overijsselse Vecht. However, multiple suggestions have been that might explain the deteriorated state. In order to confirm these suggestions, future research is needed. Therefore, I would recommend a study that focusses on the period of the Bentheimer sandstone transport era. Focus should be on identifying differences in river management from 1750 – 1900, in finding practises of river improvement and see if and how sailors would increase navigability on the river.

7. References

1. Glitz, D., *Künstliche Gerinne: die Altarme von Morgen.* Garten und Landschaft, 1983. **83**(2): p. 109-111.
2. Brookes, A., *Restoring the sinuosity of artificially straightened stream channels.* Environmental Geology and Water Sciences, 1987. **10:1**: p. 33-41.
3. Wolfert, H.P. and G.J. Maas, *Downstream changes of meandering styles in the lower reaches of the River Vecht, the Netherlands.* Netherlands journal of geosciences, 2007. **86**(3): p. 257-271.
4. Duursma, G., *Achtergronddocument kaderrichtlijn water.* Waterschap Vechtstromen, 2014.
5. Wolfert, H.P., G.J. Maas, and G.H.P. Dirkx, *Het meandergedrag van de Overijsselse Vecht : historische morfodynamiek en kansrijkdom voor natuurontwikkeling.* DLO-Staring Centrum, 1996, Rapport 408.
6. Wolfert, H.P., *Toekomst van de Vecht als een halfnatuurlijke laaglandrivier : bouwstenen bij de grensoverschrijdende Vechtvisie.* Alterra, 2009.
7. Viveen, W., G.J. Maas, and J.M. Schoorl, *Sedimenthuishouding in het stroomgebied van de Nederlands-Duitse Vecht : potenties voor herstel van natuurlijke rivierdynamiek.* Alterra, 2009.
8. Candel, J.H.J., Makaske, B. Quik, C. Wallinga, J. Kleinhans, M. G. Hoek, W. Z., *Late holocene channel pattern change from laterally stable to meandering - A palaeohydrological reconstruction.* Earth Surface Dynamics, 2018. **6**(3): p. 723-741.
9. Rijksdienst voor het Cultureel Erfgoed, S., *Handboek Beken en Erfgoed.* 2018.
10. Neefjes, J., R. van Beek, and R. Elfring, *Cultuurhistorische atlas van de Vecht : biografie van Nederlands grootste kleine rivier.* WBOOKS, 2011.
11. Wieringa, H. and H. Schelhaas, *Waterstaat in Overijssel.* Provincie Overijssel, 1983.
12. Coster, W., *Omtrent de Vechtlanden : waterschapsgeschiedenis in Noordoost Overijssel.* Waanders, 1999.
13. Steen, G. and W. Veldsink, *De geschiedenis van Ommen*. 1948.
14. Algemeen Rijks Archief, *Archieven van de Inspecteurs en commissies van de watersaat in Nederland voor 1850. Inv.nr. 275: Rapport van J.E. Wildeman over de bevaarbaarmaking van de vecht, Regge en Schipbeek.* 1809.
15. Staring, W. and T.J. Stieltjes, *De Overijsselse Wateren.* 1848.
16. Stieltjes, T.J., *Verslag over den tegenwoordige toestand der Afwatering in Twente.* 1872.
17. Rijks Archief Overijssel, *Statenarchief. Inv.nr. 5002: Stukken betreffende de schouw van de Vecht en Zwartewatersdijken.* 1650 - 1787.
18. Overijssel, R.A., *Statenarchief. Inv.nr. 5002: Stukken betreffende de schouw van de Vecht en Zwartewatersdijken (betreft stuk uit 1772).* 1650 - 1787.
19. Nijland, T.G., C.W. Dubelaar, and R.P.J.v. Hees *Bentheimer zandsteen: oliereservoirgesteente en bouwsteen*. 2003. **57**, 21-25.
20. Meinardi, C.R., C.G.J. Schotten, and J.J.d. Vries, *Grondwateraanvulling en oppervlakkige afstroming in Nederland : langjaarlijkse gemiddelden voor de zand- en leemgebieden.* Stromingen: vakblad voor hydrologen, 1998. **4**(3): p. 27-41.
21. Janssens, M., *Frequentieonderzoek afvoer Overijsselse Vecht, deel 1*. 1991, Rijkswaterstaat, Ministerie van Verkeer en Waterstaat.

22. Ter Wee, M., *Geologische kaart van Nederland 1:50.000, Toelichtingen bij het kaartblad 16 Steenwijk Oost, Technical report.* Geologishe Stichting , Afdeling Geologische Dienst, 1966.
23. Kuijer, P.C. and H. Rosing, *Bodemkaart van Nederland : toelichting bij kaartblad 21 Oost Zwolle.* Wageningen : Staring centrum, 1994.
24. Dirkx, G.H.P., D.G.v. Smeerdijk, and H.v. Haaster, *Historische ecologie van het Reestdal : een onderzoek naar historische referentiebeelden voor natuur*. 1998, Assen [etc.]: Stichting 'Het Drentse Landschap' [etc.].
25. Huisink, M., *Changing river styles in response to Weichselian climate changes in the Vecht valley, eastern Netherlands.* Sedimentary Geology, 2000. **133**(1): p. 115-134.
26. Ente, P.J., et al., *De bodem van Overijssel, de Noordoostpolder en Oostelijk Flevoland.* Stichting bodemkartering, 1965.
27. Bakker, J.A., *The TRB West Group: studies in the chronology and geography of the makers of Hunebeds and Tiefstich pottery*. 1979: Sidestone Press.
28. Beek, R.v. and W. van Es, *Nederzettingssporen uit de Laatromeinse Keizertijd bij Dalfsen (Ov.)*. 1964, Westerheem.
29. Bruins, H. and R. van Beek, *Wijthmen, gem. Zwolle. Een Sallandse buurtschap in Romeinse tijd en Middeleeuwen*. 1984, Westerheem.
30. Vos, P., et al., *Atlas van Nederland in het Holoceen.* Landschap en bewoning vanaf de laatste ijstijd tot nu, 2011.
31. Visscher, W., *Een wereld van turf: de Overijsselse turfindustrie en de veenondernemingen in de hoge venen van Overijssel.* H&K Uitgevers, 2003.
32. Fockema Andreae, S.J., N.E. Algra, and H.R.W. Gokkel, *Fockema Andreae's rechtsgeleerd handwoordenboek.* Tjeenk Willink, 1948.
33. Blécourt, A.S.d., *Kort begrip van het oud-vaderlands burgerlijk recht, 7de druk.* 1969: p. 113.
34. Kuile, G.J.t., *Oorkondenboek van Overijssel regesten 797-1350.* Tjeenk Willink, 1963.
35. Doorninck, J.I. and N. Uiterdijk, *Bijdragen tot de Geschiedenis van Overijssel, Tweede Deel.* 1875.
36. Historisch Centrum Overijssel, *0157 Marken in de provincie Overijssel, Inv.nr. 717, Besluiten van de Gouverneur van de Provincie Overijssel betreffende de bevordering van de verdeling van de markegronden*. 1837.
37. van Engelen van der Veen, G.A.J., *Marken en Waterschappen, in: Overijssel.* 1931: p. 199-202.
38. Historisch Centrum Overijssel, *0157 Marken in de provincie Overijssel, Inv.nr. 104, Ingekomen stukken bij de commissie tot verdeling van de marke.* 1895 - 1897.
39. Historisch Centrum Overijssel, *0157 Marken in de provincie Overijssel, Inv.nr. 657, Stukken betreffende een proces, rakende de verdeling van de marke, afkomstig van mr. R.E. Hattink te Almelo, advocaat van de marke.* 1897 - 1904.
40. Historisch Centrum Overijssel, *0157 Marken in de provincie Overijssel, Inv.nr. 1427, Vonnis van de arrondisisementsrechtbank te Zwolle, houdende het bevel over te gaan tot verdeling van de marke, met aanwijzing van Mr. P.C.A. Sichterman tot rechter-commissaris bij de verdeling.* 1903.
41. van Deventer, J. and W.T. Sandberg, *Memorie betreffende de dijks- en polderdistricten in de provincie Overijssel.* 1958.

42. Smolders, A., *De geschiedenis van de Overijsselse kanalen : geschiedenis van de N.V. Overijsselsche Kanalisatie Maatschappij en haar rechtsopvolger de N.V. Maatschappij Overijsselsche Kanalen (1850-1989).* Rijkswaterstaat-serie, 1989.
43. Historisch Centrum Overijssel, *0157 Marken in de provincie Overijssel, Inv.nr. 29, Markeboek.* 1549 - 1826.
44. Historisch Centrum Overijssel, *0624 Gemeente Dalfsen, gemeentebestuur, Inv.nr. 1023, Stukken betreffende het onderhoud aan en de verbetering van de bevaarbaarheid van de Vecht, met tekeningen.* 1856 - 1866, 1905 - 1908.
45. Nanning, G. and P. Frederik, *Handleiding tot de werkdadige meetkunst.* P. de Groot, 1828.
46. Historisch Centrum Overijssel, *0157 Marken in de provincie Overijssel, Inv.nr. 424, Markeboeken.* 1670 - 1826.
47. Historisch Centrum Overijssel, *0157 Marken in de provincie Overijssel, Inv.nr. 1368, Markeboeken.* 1418 - 1887.
48. Historisch Centrum Overijssel, *0157 Marken in de provincie Overijssel, Inv.nr. 33, Markeboeken.* 1765 - 1835.
49. Historisch Centrum Overijssel, *0157 Marken in de provincie Overijssel, Inv.nr. 425, Markeboeken.* 1827 - 1855.
50. Historisch Centrum Overijssel, *0157 Marken in de provincie Overijssel, Inv.nr. 443, Stukken betreffende het onderhoud van en herstellingen aan de in de marken gelegen kribben in de Vecht.* 1738 - 1791.
51. Historisch Centrum Overijssel, *WS-20 Derde Dijkdistrict van Overijssel, Inv.nr. 17, Stukken betreffende vaststelling en wijziging van het Reglement op het beheer der dijken, kaden, polders en waterleidingen.* 1836 - 1875.
52. Historisch Centrum Overijssel, *WS-20 Derde Dijkdistrict van Overijssel, Inv.nr. 4, Registers houdende notulen van het dijksbestuur.* 1873 - 1883.
53. Historisch Centrum Overijssel, *WS-15 Waterschap De Zuider Vechtdijken (Zesde Dijkdistrict van Overijssel), Inv.nr. 36, Memories ter gelegenheid van het honderjarig bestaan van het waterschap.* 1936.
54. Historisch centrum Overijssel, *WS-20 Derde Dijkdistrict van Overijssel, Inv.nr. 3, Registers houdende notulen van het dijksbestuur.* 1836 - 1872.
55. Historisch Centrum Overijssel, *WS-15 Waterschap de Zuider Vechtdijken (Zesde Dijkdistrict van Overijssel), Inv.nr. 1, Register van notulen van de vergaderingen van het verenigd college en het dijkbestuur.* 1836 - 1849.
56. Historisch Centrum Overijssel, *WS-15 Waterschap de Zuider Vechtdijken (Zesde Dijkdistrict van Overijssel), Inv.nr. 2, Register van notulen van de vergaderingen van het verenigd college en van het dijkbestuur.* 1849 - 1883.
57. Historisch Centrum Overijssel, *WS-15 Waterschap de Zuider Vechtdijken (Zesde Dijkdistrict van Overijssel), Inv.nr. 147, Bestekken en akten van aanbestedingen van werkzaamheden aan de dijken en kaden en de krib- en pakwerken.* 1836 - 1855.
58. Historisch Centrum Overijssel, *WS-20 Derde Dijkdistrict van Overijssel, Inv.nr. 18, Stukken betreffende de vaststelling van het Grondreglement voor de waterschappen in Overijssel.* 1879 - 1883.
59. Historisch Centrum Overijssel, *WS-20 Derde Dijkdistrict van Overijssel, Inv.nr. 19, Stukken betreffende het concept-reglement voor het waterschap de Noorder Vechtdijken.* 1883.

60. Historisch Centrum Overijssel, *0025 Provinciaal Bestuur van Overijssel, Inv.nr. 18062, Circulaires en beschikkingen van de minister van waterstaat inzake de waterstaat.* 1824 - 1870.
61. Historisch Centrum Overijssel, *0140.1 Rijkswaterstaat in Overijssel, Inv.nr. 333, Rapport aan het Departementaal Bestuur van Overijssel van een inspectie van de Vecht, de Regge en andere watergangen in de provincie.* 1804.
62. Historisch Centrum Overijssel, *0140.1 Rijkswaterstaat in Overijssel, Inv.nr. 676, Stukken betreffende de verbetering van de rivier.* 1853 - 1855, 1860 - 1863.
63. Borsen, O., *Landschapsopbouw en landgebruik van de groenlanden langs de middenlopp van de Overijsselse Vecht tussen 1800 en 1950*, in *Landschapsgeschiedenis*. 2012, Groningen University.
64. Elerie, J.N.H., *Weerbarstig land : een historisch-ecologische landschapsstudie van Koekange en de Reest*. 1998, Wageningen University.
65. Dirkx, G.H.P., *...ende men sal van een erve ende goedt niet meer dan een trop schaepe holden... : historische begrazing van gemeenschappelijke weidegronden in Gelderland en Overijssel.* DLO-Staring Centrum, 1997, Rapport 499.
66. Quik, C., *Historical morphodynamics of the Overijsselse Vecht : extreme lateral migration of meander bends caused by drift-sand activity?*, in *Environmental Sciences*. 2016, Wageningen University.
67. Walker, K.F., *A review of the ecological effects of river regulation in Australia.* Hydrobiologia, 1985. **125**(1): p. 111-129.
68. Dury, G., *Magnitude-frequency analysis and channel morphology.* Fluvial geomorphology, 1973: p. 91-121.
69. Wolman, M.G. and J.P. Miller, *Magnitude and Frequency of Forces in Geomorphic Processes.* The Journal of Geology, 1960. **68**(1): p. 54-74.
70. Grams, P.E. and J.C. Schmidt, *Streamflow regulation and multi-level flood plain formation: channel narrowing on the aggrading Green River in the eastern Uinta Mountains, Colorado and Utah.* Geomorphology, 2002. **44**(3): p. 337-360.
71. Richards, K.S., *Rivers : form and process in alluvial channels.* University paperbacks ; 771, 1982.
72. Bull, W.B., *Threshold of critical power in streams.* GSA Bulletin, 1979. **90**(5): p. 453-464.
73. Beschta, R.L. and W.J. Ripple, *The role of large predators in maintaining riparian plant communities and river morphology.* Geomorphology, 2012. **157-158**: p. 88-98.
74. Trimble, S.W. and A.C. Mendel, *The cow as a geomorphic agent — A critical review.* Geomorphology, 1995. **13**(1): p. 233-253.
75. Staring, W., *Voormaals en thans.* 1858.
76. Nationaal Archief, *Hulpdepot Schaarsbergen, confidentieel copieboek N.H.M., Nijverdal.* 1836.
77. Schutten, G.J., *Varen waar geen water is: reconstructie van een verdwenen wereld: geschiedenis van de scheepvaart ten oosten van de IJssel van 1300 tot 1930.* Broekhuis, 1981.
78. Gerding, M.A.W., *Vier eeuwen turfwinning. De verveningen in Groningen, Friesland, Drenthe, en Overijssel tussen 1550 en 1950*. 1995, Wageningen University.
79. van Beek, R., G.J. Maas, and E. van den Berg, *Home Turf: an interdisciplinary exploration of the long-term development, use and reclamation of raised bogs in the Netherlands.* Landscape History, 2015. **36**(2): p. 5-34.

80. Borger, G.J., *Draining — digging — dredging; the creation of a new landscape in the peat areas of the low countries*, in *Fens and Bogs in the Netherlands: Vegetation, History, Nutrient Dynamics and Conservation*, J.T.A. Verhoeven, Editor. 1992, Springer Netherlands: Dordrecht. p. 131-171.
81. Conway, V.M., *The hydrology of some small peat-covered catchments in the N. Pennines.* Journal of the Institute of Water Engineers, 1960. **14**: p. 415-424.
82. Holden, J., P.J. Chapman, and J.C. Labadz, *Artificial drainage of peatlands: hydrological and hydrochemical process and wetland restoration.* Progress in Physical Geography, 2004. **28**(1): p. 95-123.

Appendix

[A] Archive descriptions

0157 Marken in de provincie Overijssel

Age: 1300 – 1942
Size: 28 m, 6 photo's
Access: Mensema, A.J., Inventory of the archives of the Marken in the province Overijssel (1978)
Publicity: Public
Category : - General board
- Property, ownership and taxes
- Agriculture, cattle breeding and fishing

Inv.nr.	424
Marke:	Haerst
Title:	Markeboek
Age:	1670-1826

Inv.nr.	425
Marke:	Haerst
Title:	Markeboek
Age:	1827-1855

Inv.nr.	443
Marke:	Hearst
Title:	Stukken betreffende het onderhoud van en herstellingen aan de in de marke gelegen kribben in de Vecht.
Age:	1738-1791

Inv.nr.	1368
Marke:	Varsen
Title:	Markeboek
Age:	1418-1887

Inv.nr.	29
Marke:	Arriën
Title:	Markeboek
Age:	1529-1826

Inv.nr.	33
Marke:	Arriën (Zuid)
Title:	Markeboek
Age:	1765-1853

WS-15 Waterschap de Zuider Vechtdijken (zesde Dijkdistrict van Overijssel)

Age: 1836 – 1962
Size: 3.60 m
Access: Raat, T. de, Inventory of the Archives of the disestablished water boards within the water board South of the Vecht (1983)
Publicity: Public
Category: **-** Traffic and Water State

Inv.nr. 1
District: 6^{de} district de Zuider Vechtdijken
Title: Register van notulen van de vergaderingen van het verenigd college en het dijksbestuur
Age: 1836-1849

Inv.nr. 2
District: 6^{de} district de Zuider Vechtdijken
Title: Register van notulen van de vergaderingen van het verenigd college en van het dijkbestuur
Age: 1849-1883

Inv.nr. 36
Water board: de Zuider Vechtdijken
Title: Memories ter gelegenheid van het honderdjarig bestaan van het waterschap
Age: 1936

Inv.nr. 147
Water board: de Zuider Vechtdijken
Title: Bestekken en akten van aanbesteding van werkzaamheden aan de dijken en kaden en de krib- en pakwerken
Age: 1836-1855

WS-20 Derde Dijkdistrict van Overijssel

Age: 1836 – 1883
Size: 2.25 m
Access: Witmer, C.J.W., Inventory of the archive of the third dike district and of the archive of the Waterboard the Noorder Vechtdijken, inv.nrs 1-156 (1995)
Publicity: Public
Category: - Traffic and Water state

Inv.nr. 3
District: 3^{e} district de Noorder Vechtdijken

Title:	Registers houdende de notulen van het dijksbestuur
Age:	1836-1872

Inv.nr.	4
District:	3e district de Noorder Vechtdijken
Title:	Registers houdende de notulen van het dijksbestuur
Age:	1873-1883

Inv.nr.	17
District:	3e district de Noorder Vechtdijken
Title:	Stukken betreffende de Vaststelling en wijziging van het Reglement op het beheer der dijken, kaden, polder en waterleidingen
Age:	1836-1875

Inv.nr.	18
Water board:	de Noorder Vechtdijken
Title:	Stukken betreffende de vaststelling en wijziging van het Grondreglement voor de waterschappen in Overijssel
Age:	1879-1883

Inv.nr.	19
Water board:	de Noorder Vechtdijken
Title:	Stukken betreffende het concept-reglement voor het waterschap de Noorder Vechtdijken
Age:	1883

0025 Provincial Board of Overijssel

Age:	1813 – 1920 / 1948
Size:	1482 m
Access:	Wigger, J.H. and Folkerts, J., Inventory of the archives of the Provincial Board of Overijssel, Zwolle (1995)
Publicity:	Public
Category:	- General governance and politics

Inv.nr.	18062
Title:	Circulaires en beschikkingen van de minister van de waterstaat inzake de waterstaat
Age:	1824-1870

0140.1 Rijkswaterstaat in Overijsel

Age:	(1770) 1804 – 1974 (1985)
Size:	54 m
Access:	Central Archive selection service, Inventory of the archives of the Rijkswaterstaat Overijssel, Winschoten (1987)
Publicity:	Public
Category:	- Traffic and Water State

Inv.nr.	676
Title:	Stukken betreffende de verbeteringen van de rivier
Age:	1853-1855 / 1860-1863

0624 Municipality Dalfsen, Municipality board

Age:	(1806) 1811 – 1927 (1934)
Size:	57.75 m
Access:	Doxis, Inventory of the Archive of the Municipality Dalfsen, Leidschendam (2000)
Publicity:	Public
Category:	- General governance and politics

Inv.nr.	1023
Title:	Stukken betreffende het onderhoud aan de verbetering van de bevaarbaarheid van de Vecht, met tekeningen
Age:	1856-1866 / 1905-1908

[B] Measurement names

Table B Selected measurement locations with measurement names from 1848 and 1872. In the last column the distance to river mouth is shown.

Measurement name 1848	Measurement name 1872	Distance to river mouth (m)
N 344	5	2335
N 336	9	4335
N 332	11	5335
N 320	16	8335
N 316	18	9335
Vechterweerd	20	10300
N 308	22	11335
N 304	24	12335
N 300	26	13335
N 288	32	16335
N 272	40	20335
N 268	42	21335
N 248	51	26335
N 240	55	28335
N 233	58	30085
N 220	6*	33335
Ommerbridge	Ommerbridge*	36021
N 220	15*	38335
N 192	19*	40335
N 184	23*	42335
N 176	27*	44335
N 168	31*	46335
N 148	40*	51335
N 144	42*	52335
N 140	44*	53335
N 124	52*	57335
N 116	56*	59335
N 92	67*	65335
N 88	69*	66335
N 72	77*	70335
N 68	79*	71335
Bridge at Hardenberg	Bridge at Hardenberg*	72280
N 52	85*	75335
N 48	87*	76335
N 28	92*	81335
N 20	94*	83335
N 16	95*	84335
N 0	99*	88335

[C] Locations groynes Dalfsen - Lichtmiskanaal

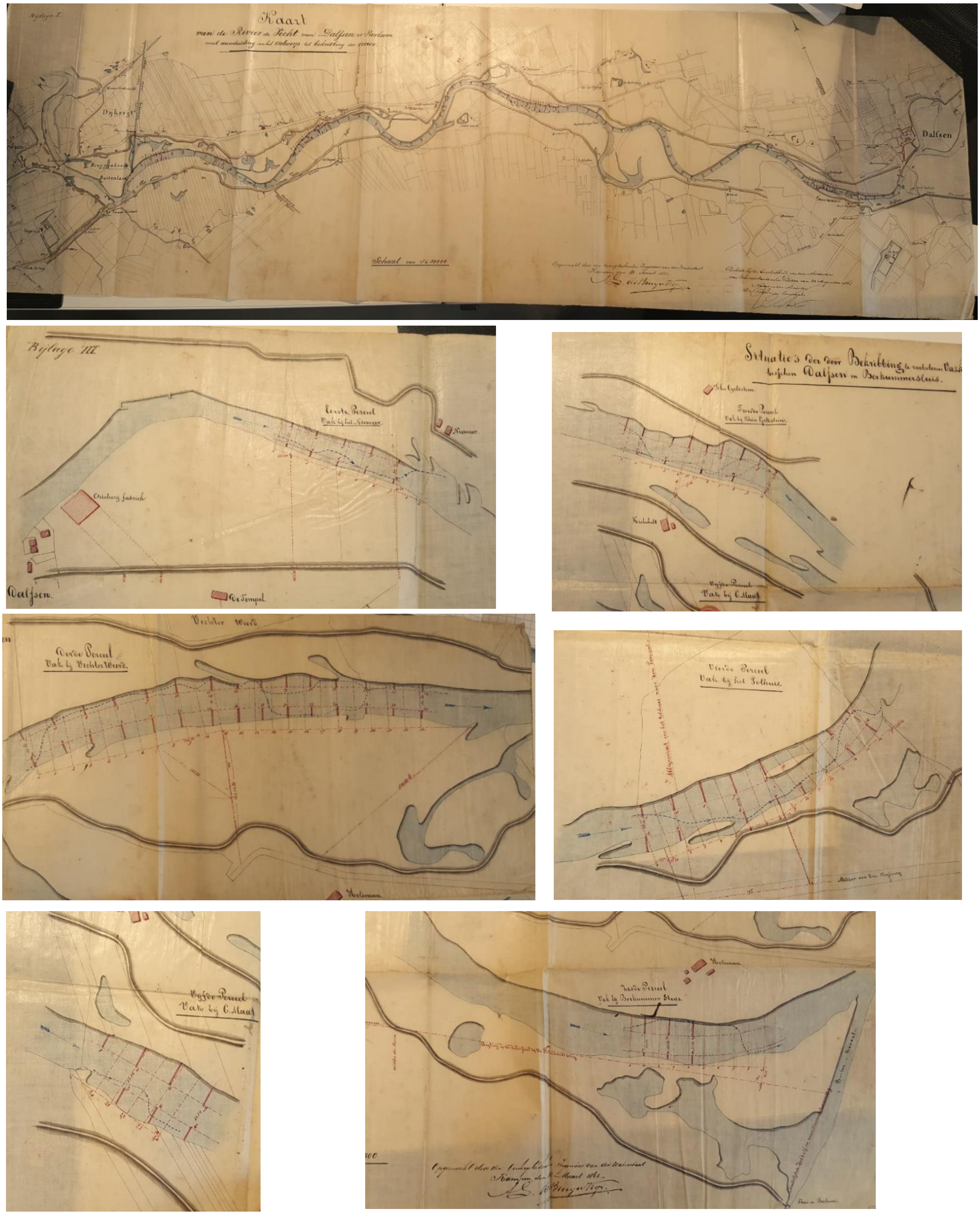


Figure C Locations of groynes in the section Dalfsen – Lichtmiskanaal. Figure on the top are all the groynes through the whole section. Other figures are all groynes in particular subsections.

[D] Parameter uncertainty

Table D Uncertainties per parameter with source or reasoning.

Parameter	Uncertainty (m)	Source
H_w, H_{bf}	0.0127	'de Overijsselse Wateren' and is based on the Gravatt's Dumpy Level
Sum_m	0.025 (per depth measurement)	Based on Handleiding tot de Werkdadige Meetkunst.
α (angle)	0.5 degree	Based Trigonometry used to estimate error in W_m, For this research an angle of 45 degrees has been taken due to unknown method.
AB (triange side)	5 %	Based Trigonometry (Handleiding tot de Werkdadige Meetkunst) used to estimate error in W_w.
Wr, Wl	0.1	Multiple redrawing of cross suggest accurate drawing.
D_m	0.03	Based on depth measurement uncertainty (0.025) and height measurement uncertainty (0.0127).
Wl	0.03	Based on depth measurement uncertainty (0.025) and height measurement uncertainty (0.0127).
Different locations	$\left\lvert \frac{W\ map\ 1872}{W\ map\ 1848} - 1 \right\rvert$	Based on relative difference between width on the actual measurement locations. Measured with adobe illustrator 2018 (accuracy 0.73 m).