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I: Remeandering of a Dutch lowland stream; description of the first results

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Sampling of a restored lowland stream and the potential effects of climate change on the restoration success

I: Remeandering of a Dutch lowland stream; description of the first results

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REPORT

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Over the past decade many stream restoration programmes have been implemented. The aim of the present study is to gain an understanding of the processes and factors that lead to successful restoration. To this end we monitored a sample project, 'de Geeserstroom', and investigated the effect of a large-scale remeandering on the ecology of the stream. The profile of the stream has been greatly altered but not the concentrations of nutrients, and there are various indications that the colonisation process by stream fauna is still very much in progress. Long-term monitoring will provide a more complete picture of the effects of a large-scale remeandering project than the results after just two years described in this report.

Keywords: stream restoration, diatoms, macrofauna, hydrology, nutrients, Drenthe, stream.

Contents

Foreword

The Water Framework Directive stipulates that surface waters should reach at least the standard "Good Ecological Condition" by 2015. Environmental policy also imposes a number of other ecological requirements on these waters. Over the past decade, many programmes for stream remeandering have been implemented. The aim of the present study is to gain an understanding of the processes and factors that lead to successful restoration. To this end, we monitored a sample project, 'de Geeserstroom', and investigated the effect of a large-scale remeandering project on the ecology of the stream.

This study was commissioned by the Ministry of Agriculture, Nature and Food Quality, Policy Support Research, Cluster Ecological Infrastructure, Theme BO-020007 Ecological objectives and standards for water management, projects 'Dispersion in aquatic ecosystems' ('Dispersie in aquatische ecosystemen') and 'Optimisation of restoration measures in aquatic ecosystems' ('Optimalisatie van herstelmaatregelen in aquatische ecosystemen', and the EUROLIMPACS project, contract no. GOCE-CT-2003-505540, financed by the European Union under Framework Programme 6, Theme 1.1.6.3 'Global Change and Ecosystems'. We would like to thank Gerhard Duursema and Gerrie Veldsink of the Velt and Vecht Waterboard (Waterschap Velt en Vecht), and Rebi Nijboer and Roos Loeb of Alterra, University of Wageningen, for their collaboration on this research and Native Speaker Translations for the translation of the original report.

Summary

According to the Water Framework Directive, surface waters should have reached at least "Good Ecological Condition" (GEC) by 2015. Environmental policy also imposes a number of other ecological requirements on these waters. Over the past decade many stream restoration measures have been implemented. Thus far, little is known about the effects of large-scale stream restoration projects. Few such projects have been carried out to date and there is often no long-term monitoring. However, the optimisation of measures requires long-term research into the effects of large-scale restoration projects.
This report contains a description of a large-scale stream restoration project carried out in the Geeserstroom catchment. Data from the first years following remeandering are now known and so the short-term effects of such a remeandering project can be described.
The aim of the present study is to gain an understanding of the processes and factors that lead to a successful restoration.

What is the abiotic situation after remeandering?
Before remeandering the stream was deeply incised, so that bank height was large and the water deep, while the width of the stream and the width between banks were small. Doe to the incision, there was also little variation in height between the different parts of the stream and the stream was characterised by its short length and limited fall. In its altered condition the stream is longer, with a greater fall, less pronounced incision and a shallower water body. The water level fluctuated from a few centimetres in April 2007 to nearly one metre during heavy rainfall in January 2007. It can clearly be seen that the water level follows the precipitation pattern. The average flow rate was 0.10 m/s in 2006, compared with 0.02 m/s in 2005 and 0.06 m/s in 2004. Interestingly, rainfall in the winter and in some summer months seemed to be accompanied by increased concentrations of nitrogen and phosphorus, which exceeded the GEC norms for R5.

Do the changes in abiotic factors influence the focal species to be expected in the stream?
The new profile leads to altered flow conditions. It is expected that typical lowland stream species will be able to benefit from the increased fall and the changed hydromorphology, with the associated increase in flow rate and decrease in depth. However, the remeandering process and the changing weather conditions in 2006 and 2007 led to major fluctuations in abiotic conditions. As a result, species that are resistant to disturbances have so far dominated in the stream after remeandering. Furthermore, the concentrations of nutrients in the stream have hardly changed. Nutrient-rich water from agricultural land has not yet been diverted, so that the nutrient levels of the water in the stream are too high for typical lowland flora and fauna to develop.

Which species disappeared due to implementation of the restoration measures?
Fifty-one taxa (25%) disappeared following remeandering. These were mainly non-flying taxa such as mites, bivalves, leeches, freshwater shrimps and worms, but also alder flies, and dragonflies. The habitat for many of these taxa is linked to nutrient-rich, vegetation-rich, still or regulated waters, which corresponds to the character of the Geeserstroom before remeandering.

Which species have returned?
The majority of the taxa (60 %) returned in 2007. In addition, 36 new taxa appeared. The new taxa that arrived after remeandering mainly use flight for locomotion (true bugs, chironomid midges and mosquitoes), but some worms and snails also appeared. There was no increase in the number of rheophilic species following remeandering. Species that were new or that increased in numbers were mostly typical colonists that are resistant to disturbances or that can survive in semi-permanent waters.

After how long and at what time did species return?
In 2006 the number of taxa and their abundances were very low. Thus, the majority of taxa only returned in 2007. The expected arrival of typical lowland stream species and focal species has not occurred yet. This can be explained by changing weather conditions and unchanged concentrations of nutrients.

The future
There are various indications that the colonisation process in the remeandered Geeserstroom is still very much in progress. Monitoring of the remeandering over a long period will probably give a different and more complete picture of the effects of a large-scale remeandering project than just the results after two years, which are described in this report.

1 Introduction

1.1 Restoration projects in the 21st century

Recent research (Nijboer et al, 2004, Nijboer & Bosman, 2006) has shown that many stream restoration projects do not achieve the desired aim. This is probably because, in many cases, the measures taken do not lead to the restoration of the correct abiotic conditions. Streams frequently still lack variation in flow rate and structures, and the failure to reduce the high nutrient content is a problem. Restoration projects often only tackle one problem, with the result that the desired species cannot return because there is still a bottleneck in the system. For example, this is the case in projects where the meanders of a stream are restored without ensuring that the water quality of the stream meets the norms. The scale of the restoration is also likely to be a determining factor for success. Restoring the entire stream can be expected to have a far more positive effect on the stream's ecosystem than if only a short stretch is restored.

So far little is known about the effects of large-scale projects. Few such projects have been carried out to date and there is often no long-term monitoring. Extended research into the effects of large-scale restoration projects is necessary to allow optimisation of the measures employed and to ensure that the results obtained cover the entire restoration period. This large-scale approach also fits in with the whole catchment approach, offering more insight into the possibilities of combining measures to realise greater effects.

1.2 Aim and relevance to policy

The aim of the present study is to gain an understanding of the processes and factors that lead to a successful stream restoration.
Specific research questions are:

- What is the abiotic situation after remeandering?
- Do changes in abiotic factors influence the focal species to be expected in the stream?
- Which species disappeared due to implementation of the restoration measures?
- Which species have returned?
- After how long and at what time did species return?

1.3 Sample project

The key aspects of restoration are the successful return of the intended indicator species and of the intended aquatic ecosystem. In order to keep track of this return, both the abiotic effects of the restoration measures and the actual return of indicator and focal species have been monitored in the test area – the Geeserstroom. The restoration measures for this area consisted of re-meandering, raising the water level,

raising the streambed and installing a fish ladder. The Geeserstroom project is very special because it involves remeandering the entire upper course system of a stream catchment.
At the start of the project we measured the null situation (2004-2005). In subsequent years, abiotic and biotic variables were monitored at selected set points. Data collected after the measures had been implemented were compared with data from the null situation to determine the effects of this remeandering project.

1.4 Guide to the report

This report contains a description of a large-scale stream restoration project carried out in the Geeserstroom catchment. Data from the first years following remeandering are currently known and so the short-term effects of such a remeandering project can be described.

- Chapter 2 gives a general description of the Geeserstroom remeandering project;
- Chapter 3 contains a description of the methods used;
- Chapter 4 describes the changes in abiotic conditions in the stream;
- Chapter 5 specifically describes the short-term effects of remeandering on abiotic conditions and on the ecology;
- Chapter 6 gives an overview of the current state of affairs, in which the results of Chapters 4 and 5 are discussed.

2 Geeserstroom

2.1 Reference description

In its natural state the stream valley consisted of a stream with swamp vegetation in the wettest parts and woods in the slightly drier parts. In some old meanders peat formation has occurred as a result of silting up. Along a natural stream course over loamy and clay soil there are woods of elder and ash, with oxlips. This wood type is frequently situated within oak and hornbeam woods where there is periodic flooding. The stream meandered and wound its way through the landscape and, due to a difference in flow rate between outside and inside curves, a mosaic of diverse habitats emerged. The cross section was asymmetric and rich in structures, with sandbanks, overhanging banks, areas of silt, detritus deposition, leaf accumulations, branches and tree trunks. The stream was (partially) shaded. The water was moderately acidic to neutral and mostly moderately to weakly eutrophic, and characterised by a slow flow rate with the possibility of the upper course of the stream drying out. The stream periodically burst its banks, thus flooding the old meanders, neighbouring elder and ash woods, and stream-side alder woods.
A great variety of fauna is to be found in a natural stream. A range of plants has developed which are characteristic of the flow regime. The composition of the fauna is very diverse. Most species live on solid substrates such as branches, leafy material and water plants, as well as on and in the sediment, the water column and the littoral. There are migration possibilities for fauna by means of connections with other streams and small rivers. Some characteristic flow-loving species are *Calopteryx virgo, Elmis aenea, Lebertia insignis, Notidobia ciliaris, Lype reducta, Baetis niger*, *Gomphus vulgatissimus* and *Lampetra planeri* (Verdonschot, 2000).
The natural stream type on which renovation of the Geeserstroom is targeted, is one with a slow-flowing upper and mid-course over sandy soil. The relevant reference water type from the Water Framework Directive (WFD) is R5: slow-flowing mid-course/lower course over sand/clay. The upper part of the stream may dry out. For this section, the natural stream type on which the renaturing is targeted can be that of an upper course that may dry out. For this upper course, the WFD type R4 – permanent slow-flowing upper course over sand – can be used.

2.2 Current situation

In the report "Ecological objectives and evaluation methods for flowing watercourses" (Torenbeek & Gijsen, 1990) the Geeserstroom was categorised as a canalised watercourse. Within this type the Geeserstroom was of good quality in the spring and autumn of 1984 and 1985. In the period 1991-1997 the natural function of the Geeserstroom was at medium level. At this level the ecosystem must be in good condition, discharges must not have any major influence on the system and the structure of the watercourse must be appropriate for the ecosystem. The natural value of the Geeserstroom was reasonable (10 focal species). However, for a good natural valuation there should be at least 20 focal species present (Duursema & Torenbeek, 1997). In 2002 macrofauna samples were taken at four points as part of the remeandering plan. The sampling point at the Koemaatsendijk and the sampling point in the Loodiep had limited natural value, with a lot of silt-related fauna in De Marsen. The samples at the Tilbrug and in the Bergstukken were of moderate quality, with a lot of stoneflies, amongst other things, in the Bergstukken (Working Group Geeserstroom, 2004).

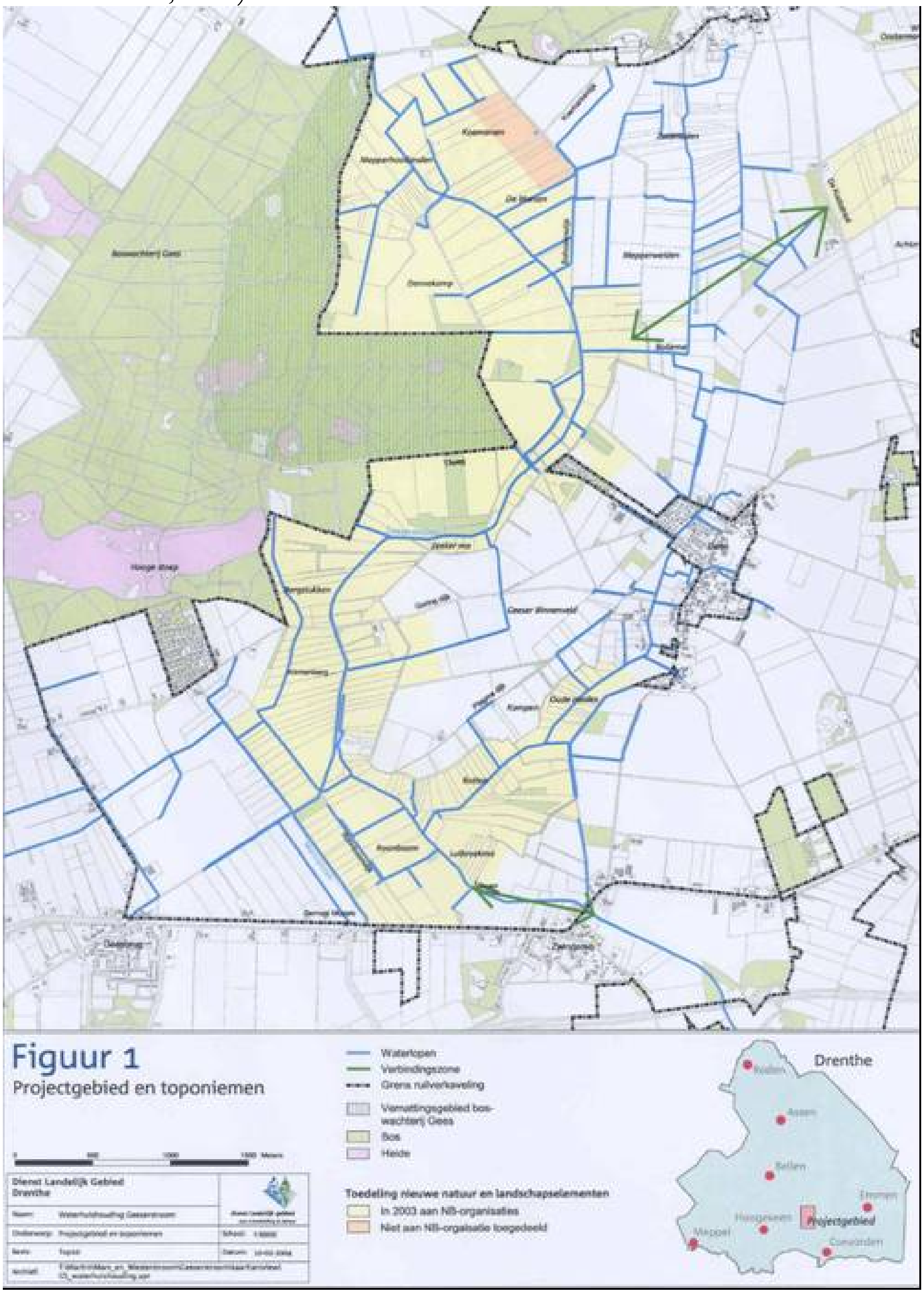

Figure 1. The former waterways of the Geeserstroom and surrounding waters (Working Group Geeserstroom 2004).

Research into nutrients in the surface water showed that the water system of the Loodiep and the Drostendiep south of the Verlengde Hoogeveense Vaart was of slightly lower quality than in the system to the north, which included the Geeserstroom. This was apparent particularly in the orthophosphate and ammonium content. The whole area often showed increased nitrate content during winter (Torenbeek, 1999).

2.3 Management and restoration

Before the current restoration project little had been done to relieve the disturbances in the Geeserstroom valley. Here and there more structure had been introduced into wooded banks and shelter belts in order to restore the old character of the area. The wastewater overflow at Meppen was provided with a storage sedimentation tank to reduce the contamination problem. However, this wastewater still discharges into the upper part of the system through the Broekstroom. The overflow of wastewater from Gees will only begin to operate less frequently when hardened surfaces are no longer connected to it. The anticipated effect is that a decreasing overflow frequency at Gees will make it possible to reduce the impact by approximately 18% (Working Group Geeserstroom, 2004). In the Gees forestry area, rewetting measures have been implemented since 2004 and these could have a positive effect on the seepage pressure in the stream valley.

2.4 Measures planned

The whole stream catchment of the Geeserstroom was restructured in 2005 and at the start of 2006. In order to approach the intended result of a natural stream valley, it was necessary to:

- restore the groundwater level and groundwater flows;
- restore natural stream hydrology and morphology;
- reduce excessive nutrient loading.

The following interventions were planned and implemented in order to achieve this (Working Group Geeserstroom, 2004) (Figure 2):

- Nearly all the waterways of the main drainage system were filled in. The stream to the east of the Klinkenberg was also filled in and in future the water will run over the fields to collect in the main stream.
- It is the intention to divert nutrient-rich water that drains from agricultural land as much as possible. However, the Bollema pumping station still discharges into the stream.
- In the fields upstream – Mepperhooilanden, Koemarsen and De Marsen – a trench has been dug in the lowest lying places to carry the water away.
- A new stream has been dug (from De Marsen to the level of the Luibroekma) with a slightly meandering (upper course) to meandering (lower course) channel in the lowest parts of the fields.
- To the east of the Hooge Stoep heathland a trench was dug for drainage
- The branch from Gees was given a narrow and shallow profile in the Oude Maden, which is slightly winding.

- In order to deal with a gradual transition from high water levels in the natural area to low water levels in the surrounding agricultural area, a weir with a fish ladder was installed and, in a strip between the Roonboomdijk and the agricultural area, a system with ditches was put in as a buffer zone.
- Downstream the stream valley was once again opened up (in line with its appearance around 1900) by felling the woods that had been planted during the 1970s.
- The landscape was made more attractive by restoring shelter belts and wooded banks and creating new ones upstream, and by erecting rustic fencing.

Based on the descriptions above and the restoration measures still to be taken it is forecasted that upstream (the upper fields) a groundwater-fed system will be created, which may dry out periodically. The flow rate will be moderate to limited. In the mid-course the water will consist of both groundwater and water from the Broerstroom (drainage from the Meppen overflow) and therefore the water quality may not be as good as in the upper course. The flow rate will be slow and the system will not go dry, but will experience significant fluctuations in water level. The lower course will have slightly better water quality due to the supply of groundwater and the tributary from Gees (if disconnected from the overflow). Downstream the stream has a large flood plain and the flow rate is low.

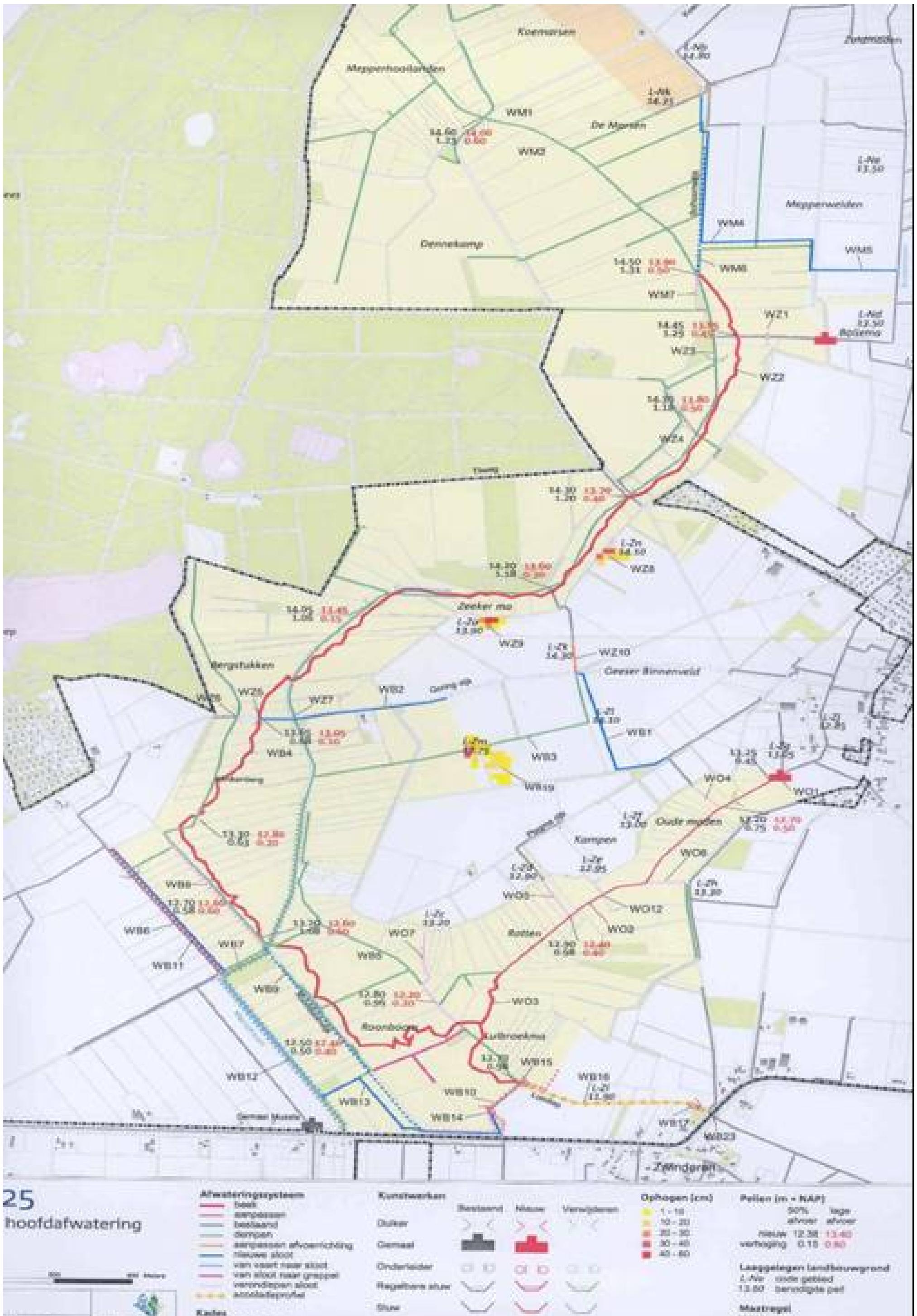

Figure 2. The map of measures for the Geeserstroom and the water flows as they will be in the future (Working Group Geeserstroom, 2004).

3 Methods

3.1 Locations

Monitoring was carried out at various locations in the stream. For this purpose the stream can roughly be divided into three parts:

- Upstream: stream from the spring to the Tilweg;
- Midstream: stream from the Tilweg to the Goringdijk;
- Downstream: stream from the Goringdijk to Loodiep.

3.2 Monitoring

Various samplings were carried out within the stream section under study (Table 1).

Table 1. Geeserstroom sampling data. Sampling points are indicated by numbers 1-16. Samples are divided into hydrology, water chemistry and biology. These sections are described in more detail in this chapter.

species group	**year**	**season**	**location**	**method**
macrofauna	2004	autumn	1,2,4,5,6,8	habitat samples
	2005	spring	1,2,4,6,8	habitat samples
	2005	autumn	1,3,4,6,7,8	multi-samples
	2006	spring	6,7,8,9,10,11	multi-samples
	2006	autumn	6,10,13,14,16	multi-samples
	2007	spring	9,10,11,13,14,16	multi-samples
	2007	autumn	9,10,11,13,14,16	multi-samples
diatoms	2005	spring	1,2,4	epiphyton
	2005	autumn	1,3,4,6,7,8	epiphyton
	2006	spring	6,8,9,10	epiphyton, sand, silt
	2006	autumn	6,10,13,14,16	epiphyton
	2007	spring	9,10,11,13,14,16	epiphyton
	2007	autumn	9,10,11,13,14,16	epiphyton
macrophytes	2007	autumn	1,9,10,11,13,14,16	Tansley
fish	2005	autumn		electric
chemistry	2004	monthly	agee 50, 99, amar20	water sample
	2005		agee 50,85,99, amar 20	water sample
	2006		agee 50,85,99, amar 20	water sample
	2007		agee 50, 86 amar40	water sample
fall	2005	spring		rotating laser
	2006	spring		rotating laser
	2006	autumn		rotating laser
	2007	spring		rotating laser
water level	2006	quarter hourly	fish ladder, wooden bridge	level troll

3.3 Hydrology

3.3.1 Profile

The fall of the entire stream length was measured. In June 2005 the fall of the main course of the original stream was measured and then, in December 2006 that of the new watercourse. The surveying was carried out using a rotating laser and the height of the water surface was measured every 50 metres in comparison to the top of the Koemaatsendijk. At this reference point, x 241321 y 532249, the stream runs under the dike. The stream length was also recorded. The fall was finally determined by dividing the height difference by the length (m/km).
At the same time as the stream height measurements, the bank height, stream depth, stream width and distance between the two banks were also measured.

- The height of the bank is the distance from the stream bed to the top of the bank. This was calculated by taking the average of the values for the left and right banks.
- The water depth was measured using a gauge at the deepest point of the stream. If the stream is more than 115 cm deep this is given as >115.
- The width of the stream is the wet width of the stream, i.e. the width of the water surface at the time of measuring.
- The distance between the banks is the channel width at the highest point of the bank. This is the maximum possible width of the stream before it bursts its banks.

Along straight sections with a regular fall, all these parameters were measured every 100 metres.

3.3.2 Water level and flow rate

The water height was continually measured at two locations in the stream, starting on 14 November 2006 at the wooden bridge and starting on 16 December 2006 upstream from the fish ladder. A Level troll 500 was used, which records the water height every 15 minutes. The principle of the Level troll is a barometrically compensated pressure sensor. The measurement data were downloaded a few times a year. The water heights at the two locations were compared with the monthly precipitation at the Zweeloo weather station. Every time the macrofauna was sampled, the flow rate was measured at the same point using a Sensa SC2.

3.4 Nutrients and water chemistry

Water samples were taken monthly by the Velt & Vecht Waterboard. The concentrations of the following anions and cations were determined: iron, hydrogen carbonate, total phosphate, sulphate, Kjeldahl nitrogen, orthophosphate, nitrite, nitrate, sodium, magnesium, potassium, chloride, calcium and ammonium. Investigations were made into whether differences in patterns could be found between the situations before and after remeandering. It was also investigated whether the chemical condition of the Geeserstroom met the Good Environmental Condition (GEC) or Very Good Environmental Condition (VGEC) norms for nutrients for the R5 water type. The R5 type is 'slow-flowing mid course/upper course over sand/clay'. The norm for this type for total phosphorus is 0.14 mg P/l and for total nitrogen 4 mg N/l (Heinis & Evers, 2007). Over the years the sampling locations have changed (Table 1).

3.5 Biology

3.5.1 Diatoms

Diatoms were sampled in 2005, 2006 and 2007 (Table 1). Diatoms were sampled by cutting off and taking away submerged live parts of aquatic plants. Diatoms use plants, among other materials, as substrates and make up part of the epiphyton (attachment of algae, bacteria and diatoms on the surface of the plant). In the laboratory the material was oxidised using hydrogen peroxide. The residue from this procedure contained the remaining siliceous shells, which were then prepared, identified and counted. For each sample 300 half shells were identified and counted, and the rest of the preparation was examined for additional taxa.
In order to get an idea of the changes that had occurred, seven indices were calculated. These 'Van Dam indices' are based on the characteristics of taxa relating to pH, chloride content, nitrogen metabolism, oxygen availability, saprobity, trophic state and desiccation (Van Dam et al, 1994). The indices were calculated for each sample using the following formula:

$$D = \frac{\sum (n_i * d_i)}{n_i}$$

where:
D = Van Dam index value (for PH, SA, NH, O2, SAP or TRO)
n_i = number of individuals from a taxon i in one sample
d_i = Van Dam index value (for PH, SA, NH, O2, SAP or TRO) for taxon i
Not included in this calculation are the index values for indifferent taxa (7 for trophic state and 6 for pH).

3.5.2 Macrophytes

In May 2002, June 2005 and October 2007 samples of the water vegetation were taken, for which the abundance of the individual species was recorded according to the Tansley scale. At each location (Table 1) a sample was taken from a representative test area, where the length of the test area depended on the heterogeneity of the water vegetation.

3.5.3 Macrofauna

For macrofauna sampling a standard macrofauna net was used with a mesh size of 500 μm and a net width of 25 cm. During sampling (Table 1) the net was moved in sudden jerks through the upper layer of the stream bed. All the habitats present were sampled for each location on the basis of how representative each habitat was.

The samples were kept cool at 4°C until they were examined. After 2005, habitat samples were combined. Macrofauna were separated in the laboratory into species groups while alive and then preserved in one of the following preservatives: ethanol (70%), Koenike (20% acetic acid, 50% glycerol, and 30% demi-water) or formalin (4%). If samples contained a lot of material they were subsampled. The material was identified in the laboratory, if possible to species level. Individuals that were too small or too young were only identified to genus or family level. After the identification of macrofauna taxa, estimates were made for the parts of samples that had not been selected and counted and the abundances of taxa were converted to a standard 5 m net sample. Abundances for partial samples were also converted into complete samples. In addition, adjustments were made for the taxa that occurred at diverse taxonomic levels. Adjustments need to be made to avoid pseudo-replication where taxa are identified at various levels.
For this research it is important above all to be able to differentiate between species. Therefore all levels above the species level are eliminated during adjustment. However, if a taxon is only identified at a higher level and no species can be distinguished, this taxon is retained at the appropriate level.

3.5.4 Analysis

3.5.4.1 Ordination

The previously processed sample data and a number of environmental variables were analysed simultaneously with the help of multivariate analysis techniques. Ordination was carried out using the CANOCO program package (CANOCO for Windows Version 4.53, Ter Braak, 1987; Ter Braak, 2004; Ter Braak & Smilauer, 1998).
With ordination one can choose between indirect detrended correspondence analysis (DCA) and direct ordination, detrended (canonical) correspondence analysis (DCCA). Using direct analysis, environmental variables are coupled to the position of the taxa and samples in the ordination diagram, with the help of regression. On the various ordination axes the environmental variables that explain the largest part of the variance are sought. With indirect ordination no connection is made with the environmental variables. Instead, the samples are positioned in the diagram on the basis of their taxonomic composition. A connection with the environmental variables can be given or calculated later.
DCA was additionally used for the research into the species groups of diatoms, macrophytes and macrofauna.

3.5.4.2 Options and parameters

The CANOCO program package includes various options. The choice of a particular technique, of particular preliminary processes, the way in which analyses are conducted and how the results are further processed are of importance for the final result. Before analysis, the values of the environmental variables were logarithmically transformed (log (x+1)) and taxa abundances were transformed into Preston classes (log2 (x+1); Preston, 1962). The option 'downweighting of rare species' was used. This option reduces the influence during the analysis of taxa that occur infrequently.

The most important parameters in the ordination are (Table 2):

- The percentage of variance explained: the measure of the amount of the total variance that is explained by the environmental variables for each individual axis.
- The eigenvalue: the measure for β-diversity, or heterogeneity. In this case measured as the total changes in taxa composition. It shows the degree of change in diversity between samples. A low eigenvalue means limited variation among samples in the taxa they contain and frequently a short environmental gradient. A high eigenvalue indicates a major shift in taxa between the samples.
- The cumulative percentage of variance explained: the measure for the amount of variance in the total data set that is explained by each of the axes.
- The sum of all canonic eigenvalues: a relative measure for the total amount of variance explained.
- The sum of all unconstrained eigenvalues: the sum of all eigenvalues from the entire analysis.

Table 2. Overview of the analysis options for ordination and the accompanying choice.

analysis option	**choice**
Monte-Carlo test, permutation number	499 (reduced model; unrestricted; set seeds)
method of detrending	by 2nd order polynomials
focus scaling on	inter-sample distances
scaling type	Hill's scaling
transformation of species data	no (because already log2 transformed)
species-weights specified	no
species made supplementary	no

3.5.4.3 Ordination diagrams

The results of the calculations were set out in ordination diagrams. The diagram shows the most important patterns in the data and contains the samples and the environmental variables. The technique indicates possible relationships but does not indicate any causal links.
The position of samples, grouped or ungrouped, tells us something about the relationships between them. The closer together the samples are, the greater their similarity. Samples in the centre of the diagram indicate average environmental conditions or sample compositions. Samples at the edge of the diagram often refer to exceptional environmental conditions or deviations in taxa composition.
The diagrams include only those environmental variables that actually help to explain the pattern discovered and thus have a high inter-set correlation.

3.5.5 Robust taxa and taxa disappearing or appearing following remeandering

In order somewhat better to understand the colonisation pattern following remeandering, taxa were selected according to a number of criteria. Firstly, 'robust taxa' were selected, which were those that did not appear to be disturbed by remeandering. These are taxa that occurred frequently during the whole sampling period. Secondly, 'taxa that disappeared' were selected, for which the remeandering had a negative influence on how frequently they occurred. These taxa, with high

frequency before remeandering combined with low frequency afterwards, were unable to withstand the remeandering process and (temporarily) disappeared. A third selection consisted of 'taxa that appeared', i.e. those that occurred infrequently before remeandering but were frequently present afterwards.
As when sampling macrofauna and interpreting the results the probability of finding many of the taxa is low, the selections only take into account taxa that were found three times or more in the total set of samples.

3.5.6 V-index and desiccation index

A flow index was calculated for each sample:
V-index per sample = the rheophilic value for each taxon * abundance of the taxon
A desiccation index was also determined: desiccation per sample = the desiccation value for each taxon* abundance of the taxon.
The results of the V-index of samples from different years were compared.

4 Abiotic factors

4.1 Hydrology

4.1.1 Profile

The area was greatly altered after remeandering as regards course length, height difference, fall, watercourse width, distance between the banks, water depth and bank height. The data are summarised in Table 3.

*Table 3. Data from the Geeserstroom for the situations before and after remeandering. *Fflood plains that remain wet over long periods are included in the width.*

	before remeandering	**after remeandering**
distance to fish ladder (m)	6005	8850
height difference to fish ladder (cm)	63	190
average fall (%)	10	21
average width (m)	7	9
maximum width (m)	12	85*
average bank width (m)	10	11
maximum bank width (m)	14	110*
average water depth (cm)	70	27
maximum water depth (cm)	115	110
average bank height (cm)	283	51
maximum bank height (cm)	365	235

4.1.1.1 Fall

The profile of the stream was altered after remeandering. First of all, the course length increased from 6 km to 9 km. The whole stream was raised as far as the fish ladder, with the result that the height difference increased from 63 cm to 190 cm and the fall increased from 0.1 m/km to 0.21 m/km (Figure 3.). The fish ladder was responsible for a very large height difference of 79 cm in 50m, which corresponds to a fall of 16 m/km.

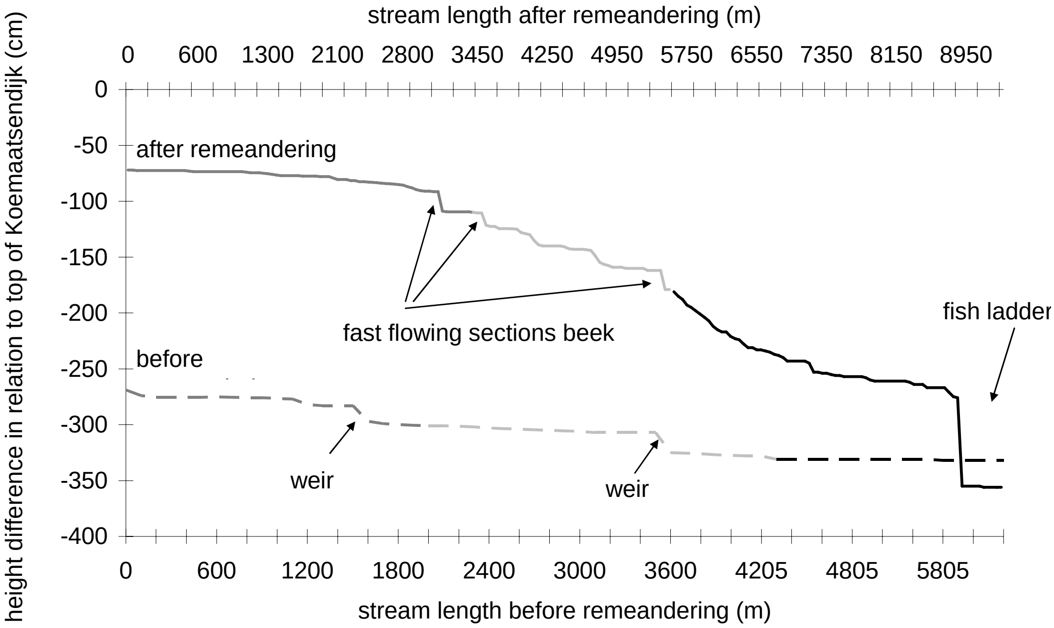

Figure 3. Stream bed height of the Geeserstroom in relation to the top of the Koemaatsendijk for the entire length of the stream. In each case the curve is divided into 3 sections, which can be recognised by the different colours (dark grey, light grey and black). The dashed line shows the situation before remeandering and the solid line gives the situation after remeandering of the stream. Notable structures are indicated (weirs, fast flowing sections and the fish ladder).

4.1.1.2 Width of the watercourse and bank

Before remeandering the stream's watercourse had an average width of 7.4 m. The width varied very little and reached a maximum of 11.5 m in the lower course. After remeandering the width was more varied with an average of 8.6 m and a maximum width of 85 m, which was measured in a flood plain in the upper course. It is noticeable that the upper course in particular varies in stream width and bank width, and that the mid-course section from the Tilweg is narrower than before, 6.9 m on average, and varies little in width, indicating a narrower profile. The peak in stream width near the fish ladder is connected with the shallow nature of the stream at that point. The stream overflows its banks at a low water depth, resulting in a water width measurement of 85 m at the time the measurement was made.

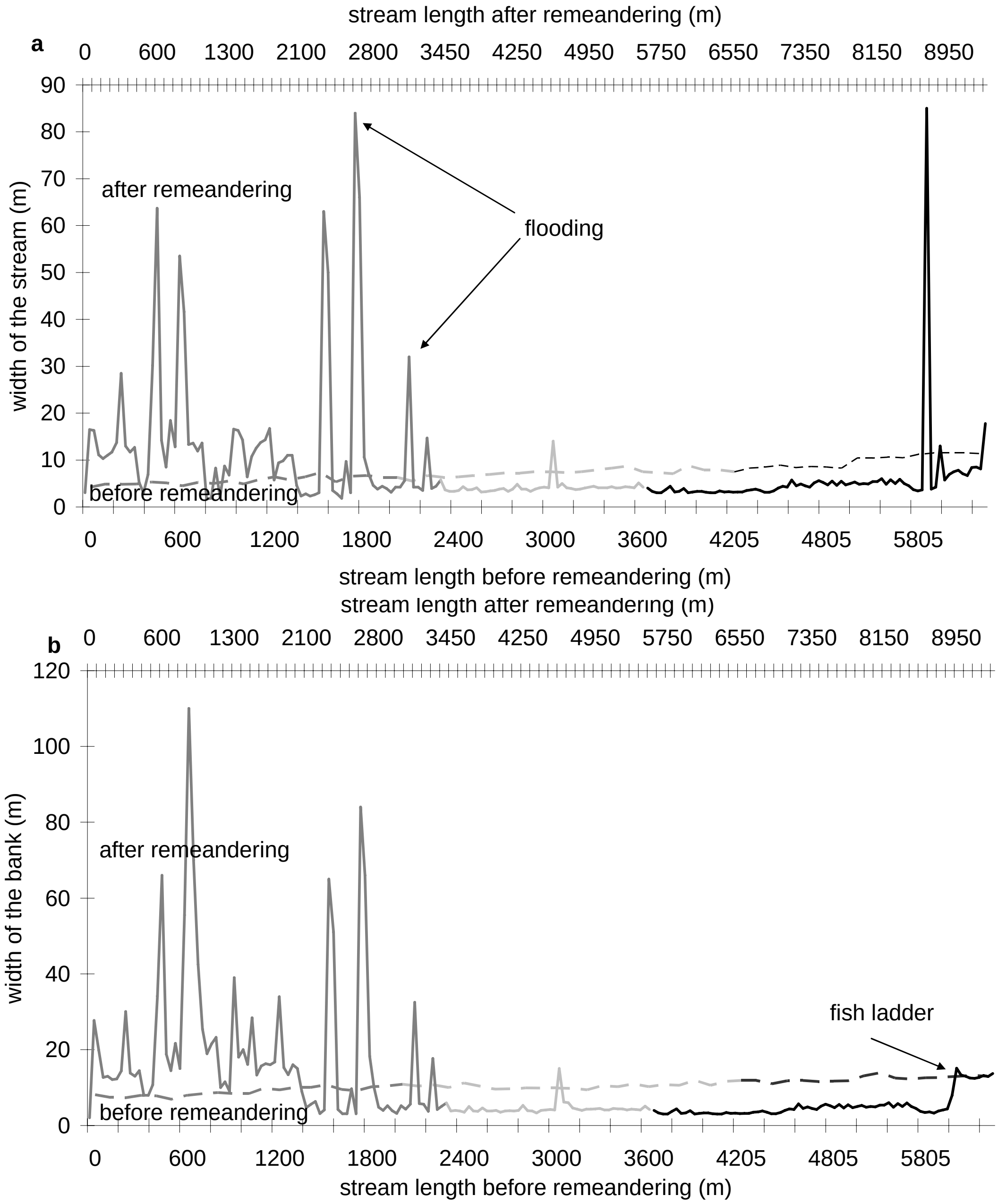

Figure 4. a: Width of the watercourse in metres. b: Bank width in metres. In each case the curve is divided into 3 sections, which can be recognised by the different colours (dark grey, light grey and black). The dashed line shows the situation before remeandering and the solid line gives the situation after remeandering of the stream.

4.1.1.3 Water depth and bank height

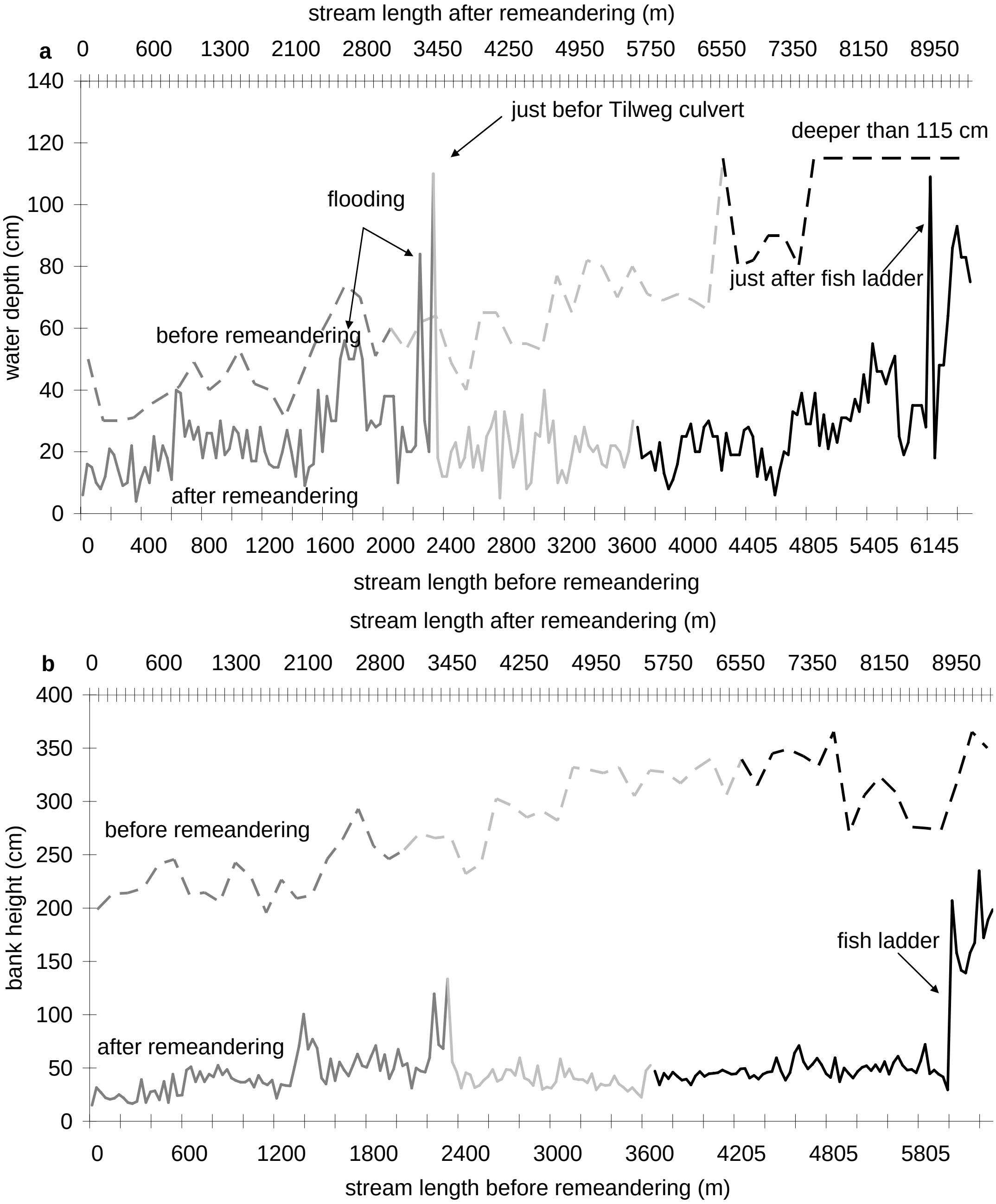

Figure 5. a: Water depth of the stream in metres. b: Bank height in metres. In each case the curve is divided into 3 sections, which can be recognised by the different colours (dark grey, light grey and black). The dashed line shows the situation before remeandering and the solid line gives the situation after remeandering of the stream.

Before remeandering the stream was deeply incised, with associated high banks and deep water. The water was 70 cm deep on average, with a bank height of 283 cm. After remeandering the stream is shallower, with an average water depth of 27 cm and a bank height of 51 cm. In the new situation several notable peaks in water depth can be seen. This is the case in the upstream flood plains, but considerable water depths were also measured before the culvert at the Tilweg road and after the fish ladder.

4.1.2 Water level

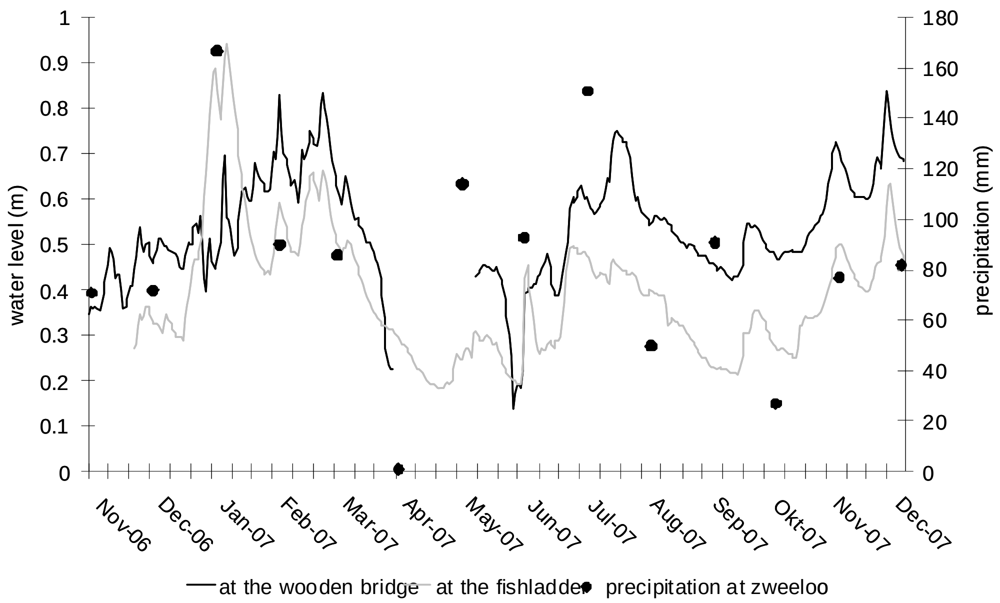

Figure 6. Water level measurements after remeandering, at the wooden bridge and upstream from the fish ladder: water height in metres. Precipitation is the total monthly precipitation measured at Zweeloo.

The water level in the stream at the two locations fluctuated from 14 cm in the dry period in April 2007 to nearly one metre during heavy rainfall in the winter. It can clearly be seen that the water levels follow the pattern of precipitation. Precipitation in January 2007, for example, led to an increase in the water level, as did precipitation in the wet summer month of July 2007, while the dry period in April 2007 led to a very low water level. An increase in water level is connected on the one hand to the increasing amount of precipitation in the stream and on the other hand to an increase in the amount of water from the pumping station. No comparison can be made with the situation before remeandering as measurements were only made after remeandering. Nor is it possible to make a comparison between the two sets of measurements as the water levels are not calibrated to the current Normal Amsterdam Water Level (Amsterdam Ordnance Datum).

4.1.3 Flow rate

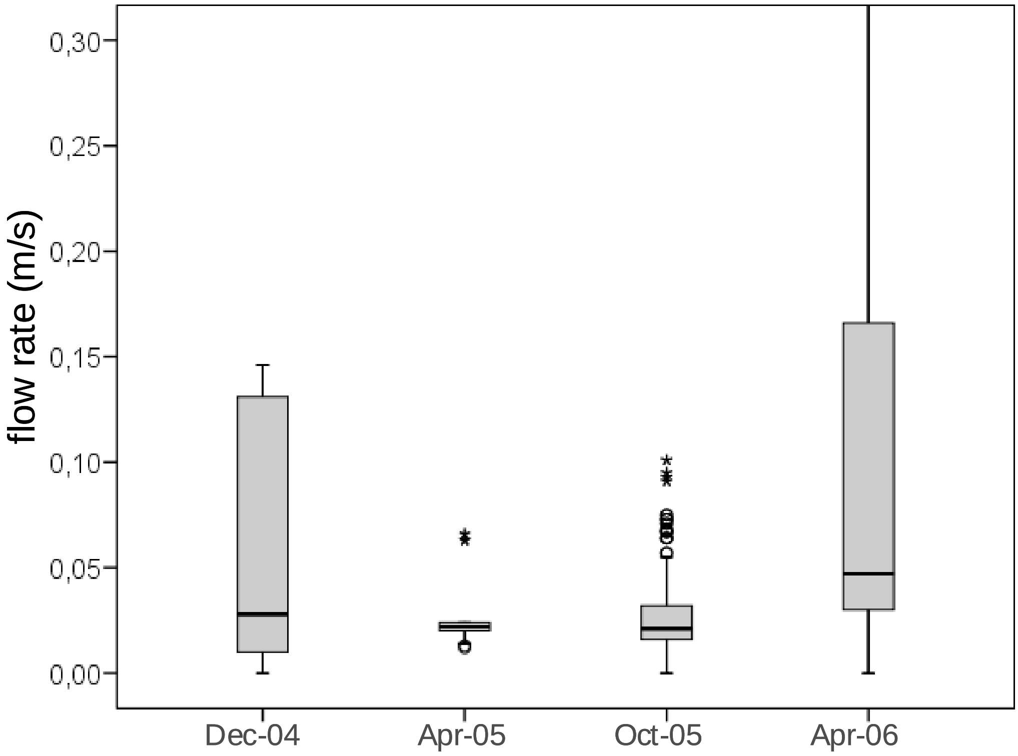

Figure 7. Flow rate measured on four different dates in 2004, 2005 and 2006.

Flow rate data are only available for four different dates in December 2004, April and October 2005, and April 2006. As the flow rate can fluctuate considerably from day to day and also over the course of a day, this is not a data set that can be used to reach firm conclusions. However, it is noticeable that the flow rate in 2006 was higher than in previous years. It averaged 0.10 m/s in 2006 compared with 0.02 m/s in 2005 and 0.06 m/s in 2004. The high values in 2006 can be attributed specifically to the flow rate at the location near the Tilweg road, where average rates of 0.28 m/s were recorded. It seems that the new watercourse at this location flows strongly. However, there are no data from other years, so that it could be a one-off event due, for example, to rainfall.

4.2 Nutrients

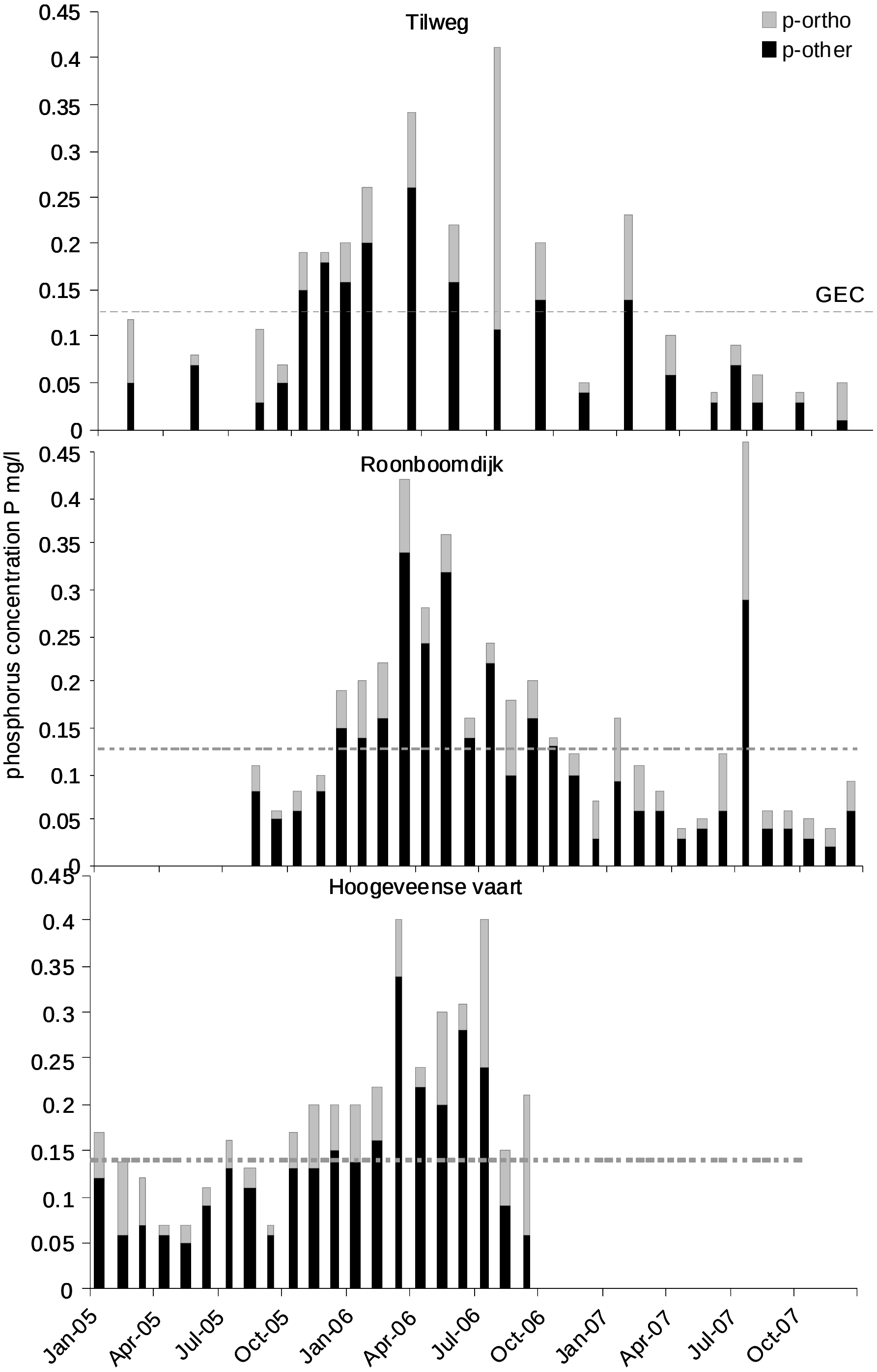

Figure 8. Phosphorus concentrations at various locations in the stream in the period January 2005 to December 2007. P-ortho is freely available phosphate, P-other are other phosphorus compounds. The two components together (total length of the bar) show the total phosphorus (P-total) concentration. GEC is the WFD norm for the reference natural type R5 of the Geeserstroom (0.14 mg P/l).

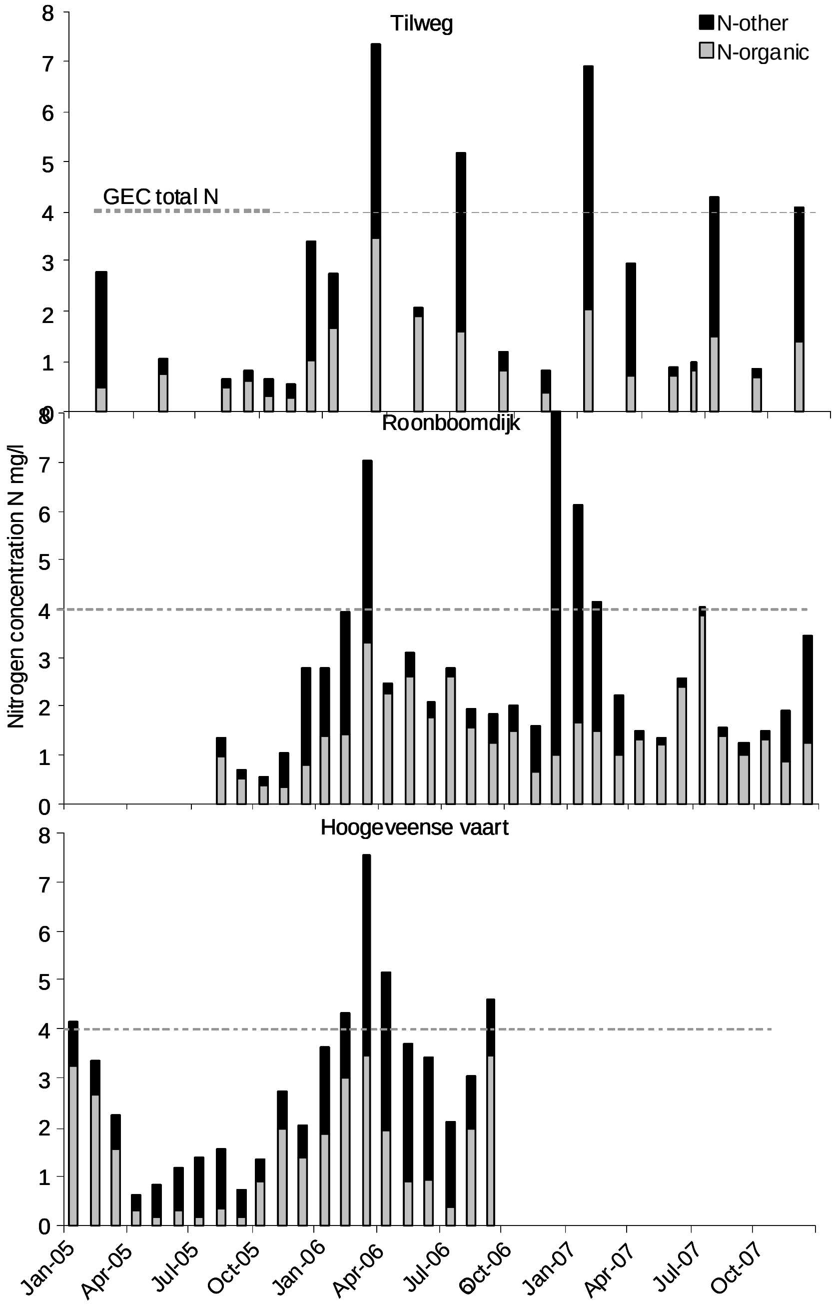

Figure 9. Nitrogen concentrations at various locations in the stream in the period January 2005 to December 2007. N-organic is organic nitrogen, N-other are other nitrogen compounds (the sum of nitrite, nitrate and ammonium). GEC total N is the WFD norm for the reference natural type R5 of the Geeserstroom for total nitrogen (4 mg N/l).

The Geeserstroom is a stream referable to the reference natural type WFD type R5 'slow-flowing mid course/lower course over sand/clay'. The norm for total phosphorus for this type is 0.14 mg P/l and for total nitrogen it is 4 mg N/l (Heinis & Evers 2007). A target value of 0.12 mg P/l, which belongs to the R4 type, is a suitable reference value for the upstream part of the watercourse.

There are three locations for which data from before and after remeandering can be compared. These are AGEE50 (Tilweg), AGEE 85/86 (Roonboomdijk) and AGEE99 (Hoogeveense Vaart). Data from the upper course of the stream are also available but measurements here were made over too short a period of time for it to be possible to see differences in the pattern of the various abiotic parameters. The nutrient concentrations fluctuated greatly, with concentrations of 0.04-0.46 mg P/l total phosphorus and 0.57-8.71 mg N/l total nitrogen having been recorded. The reference values for nutrients, specifically for total phosphorus, were frequently exceeded (Figure 8. Phosphorus concentrations at various locations in the stream in the period January 2005 to December 2007. P-ortho is freely available phosphate, P-other are other phosphorus compounds. The two components together (total length of the bar) show the total phosphorus (P-total) concentration. GEC is the WFD norm for the reference natural type R5 of the Geeserstroom (0.14 mg P/l).

, Figure 9). It is also noticeable that rainfall in winter and in some of the summer months appeared to be associated with increasing nitrogen and phosphorus concentrations, and increasing availability of orthophosphate, as was the case in March 2006, July 2006, December 2006, January 2007 and July 2007 *(*Figure 8. Phosphorus concentrations at various locations in the stream in the period January 2005 to December 2007. P-ortho is freely available phosphate, P-other are other phosphorus compounds. The two components together (total length of the bar) show the total phosphorus (P-total) concentration. GEC is the WFD norm for the reference natural type R5 of the Geeserstroom (0.14 mg P/l).

, Figure 9). Conversely, in dry periods the concentrations were lower, such as in the dry period in April 2007. This indicates that when there is reduced drainage there is greater influence from groundwater, with lower phosphorus concentrations. When there is more drainage, the influence of the phosphate-rich agricultural water from the pumping station increases.

4.2.1 Oxygen

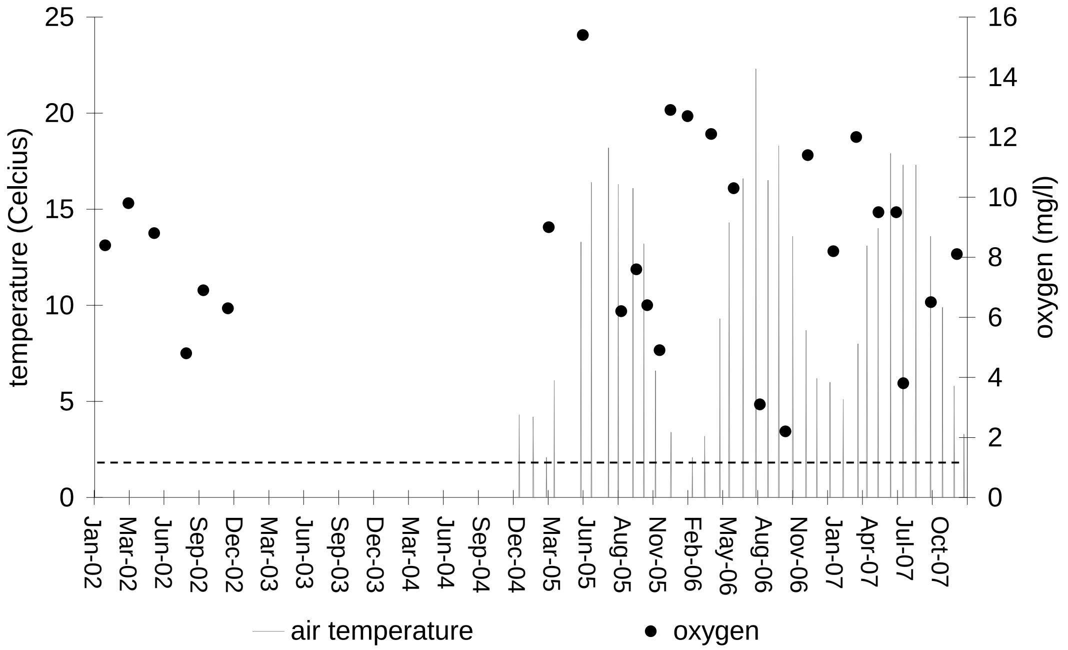

Figure10. Oxygen concentrations at Tilweg and average air temperature for each month measured at Emmen weather station.

Oxygen concentrations are very variable but never fall below the threshold of 2 mg/l to values that are lethal for most fish and macrofauna (Figure10). Some low values were measured in August and October 2006, and in July 2007. In August 2006 and July 2007 the monthly temperature was also high (Figure10). Concentrations in 2006-2007 did not differ from the situation in 2002-2004 (ANOVA P>0.05) and were on average approximately 8 mg/l.

4.2.2 Other chemical factors

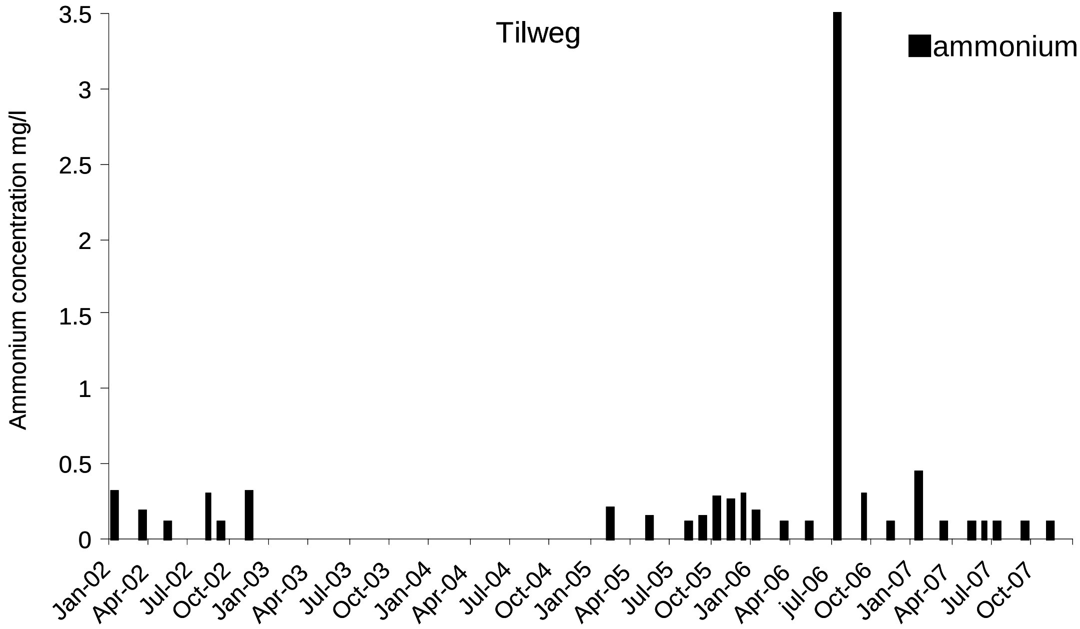

Figure 11. Ammonium concentrations measured at Tilweg.

Concentrations of other ions also fluctuated greatly, without there being any clearly visible differences between the periods before and after remeandering. Besides a fluctuating pattern, all parameters showed a few clear peaks. Interestingly the concentrations of potassium, sodium, chloride and ammonium, as well as EGV, showed a peak at the end of July 2006 (Figure 11). Three days before this measurement, 34 mm of rain fell in Zweeloo in a single day. This may have led to high concentrations as a result of these substances being washed out from the surrounding area.

5 Biotic factors

5.1 Diatoms

Multivariate analysis of the diatom samples did not produce any clear patterns. Seven ecological indices (pH, salinity, nitrogen, oxygen, saprobity, trophic state and humidity, Van Dam et al, 1994) were calculated for each sample. (Appendix 3). The result of these indices indicated little variation over space and time. Indices varied more from one location to another within the same year than between years and as a result, these indices did not reveal any clear patterns. The average indices (Table 4) showed that a community emerged at a pH of around 7 and higher, at chloride concentrations <500 mg/l, consisting mainly of autotrophic taxa that tolerate elevated concentrations of organic nitrogen, requiring average oxygen concentrations (50-75% saturation), eutrophic and α-mesosaprobic, and which occur both in permanent waters and boggy areas.

Table 4. VD Van Dam Index: O_2 oxygen; NH nitrogen metabolism; SA salinity; SAP sapbrobity; TRO trophic state; AE humidity; PH acidity;

	Average	SD	2005	2006	2007
VDPH	3.24	0.09	2.9	3.3	3.5
VDSA	1.98	0.01	1.9	2.0	2.0
VDNH	2.20	0.05	2.1	2.2	2.2
VDO2	2.41	0.10	2.3	2.5	2.4
VDSAP	2.55	0.07	2.5	2.8	2.4
VDTRO	4.67	0.14	4.2	4.9	4.9
VDAE	2.51	0.08	2.7	2.4	2.4

The three most dominant taxa, which together made up 49% of the shells found in all samples, were *Achnanthidium minutissimum*, *Cocconeis placentula* and *Gomphonema parvulum*. These three taxa are very common, with *C. placentula* and *G. parvulum* occurring frequently in nutrient-rich systems. In addition they are known as early colonisers (pioneers) because they are characteristic of artificial substrates (Biggs et al, 1998). The abundance of these taxa in the samples was very variable, from absence in some samples to strong dominance in others. For the less dominant taxa there is likewise no clear relationship between the taxa composition and the sampling point, the date or the time of sampling.

The numbers of taxa varied from 5 to 49. The lowest number of taxa were found in the samples at locations 10, 11 and 16 in the autumn of 2007 (the total numbers of taxa were 5, 5 and 13). The diatom community of these samples was dominated by *C. placentula* at 99%. A possible explanation is the extremely dry period of April 2007, during which various parts of the stream system ran dry and the colonisation process began anew. Furthermore, *C. placentula* is a species that frequently dominates in the autumn. Because of its shape this species lies flat on the substrate, which means that grazers see it as a less attractive food source and it can thus achieve dominance in the autumn.

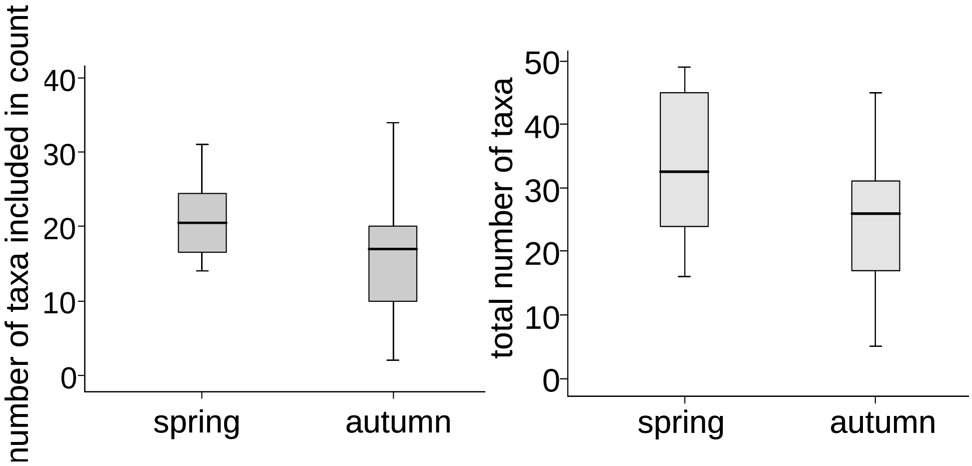

Figure12. Number of diatom taxa included in the count and total number of diatom taxa found in spring and autumn samples.

Although the taxon distribution between the samples appeared to be independent of the sample location, the year and the time of sampling, there was a difference in the numbers of taxa in the different seasons. In spring an average of 21 taxa were found among those included in the count and 12 taxa among those not included in the count, whereas in autumn these numbers were 15 taxa included in the count and 10 taxa not included in the count (Figure12, Table 5).

Table 5. ANOVA results of diatom taxa in different seasons.

number of taxa	included in count	not included in count	total
spring average	21	12	33
autumn average	15	10	25
F	4.3	1.2	3.9
P	0.048	0.289	0.058

The absence of a clear trend in the development of the diatom community between 2005 and 2007 leads to the conclusion that the remeandering of the Geeserstroom has so far not led to an observable improvement in the composition of the diatom community. Up to 2008 the diatom community of the Geeserstroom continued to be in a very unstable condition. At many locations within the stream system the diatom community is dominated by pioneer species and the consequences of the periods of drought are clearly visible. The diatom community is the one that is most closely related to the availability of nutrients in the system. As there have not yet been any changes in nutrient concentrations (see 3.4), any improvement in the composition of the diatom community cannot be expected until such time as fewer nutrients are available.

5.2 Macrophytes

A multivariate analysis (direct DCA) showed that there was not much difference in the plant records for 2002, 2005 and 2007, or between different locations in the

Geeserstroom. The only clear difference that emerged was that between a few locations in the stream's source and all other locations. At these few locations the number of plant species was small and included Marsh Pennywort *Hydrocotyle vulgaris* and Bulbous rush *Juncus bulbosus*. There was also a slight difference between some samples in the lower course before remeandering. These samples featured species such as Curled Pondweed *Potamogeton crispus,* Perfoliate Pondweed *P. perfoliatus,* Water dock *Rumex hydrolapathum,* Greater Water Parsnip *Sium latifolium,* Yellow Flag *Iris pseudacorus,* yellow pond-lily *Nuphar lutea,* narrow-fruited watercress *Rorippa microphylla,* unbranched burweed *Sparganium emersum,* Arrowhead *Sagittaria sagittifolia*, and Reed Sweet-grass *Glyceria maxima*. These species probably disappeared temporarily as a result of remeandering. So far the remeandering work has not had any clearly positive effect and it is to be expected that water plants characteristic of flowing water will win out over water plants typical of a still-water and food-rich situation. As the data are only from one year after remeandering, and as the stream has dried out and has also stopped flowing in the last few years, it is to be expected that this will only happen at a later stage. The stream has not yet been cut off from water derived from agricultural land, and therefore the effect of a less nutrient-rich environment on plants will not be visible for some time.

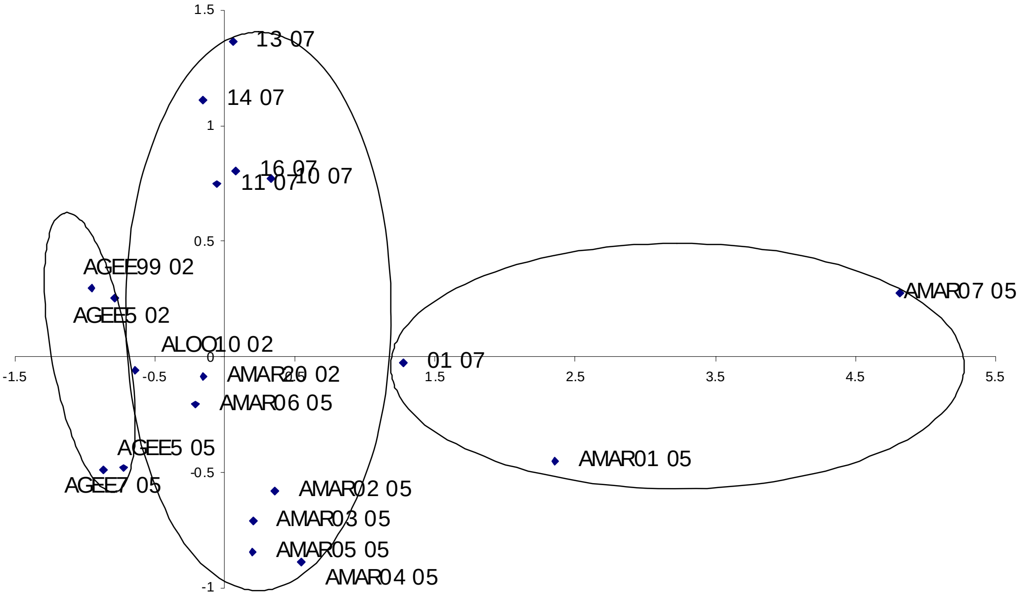

Figure13. Clusters of plant samples. The names of locations are given in Appendix 1 together with the relevant year 02=2002, 05=2005 07=2007.

5.3 Macrofauna

5.3.1 Number of taxa and abundance

In four years a total of 366 taxa were found with a total abundance calculated at 14,000 individuals. Of these, 163 taxa only occurred once or twice. One focal species

was found, which is also on the red list. These were the larvae of the caddis-fly species *Notidobia ciliaris*, of which four individuals were found on one single occasion in October 2005.
The number of taxa varied from one year to the other (ANOVA, F=5.1 P=0.005). In the first year after remeandering (2006) there were significantly fewer taxa (32 on average) than in 2005, the year of remeandering (62 on average)Figure 14) (Hochberg GT2 P=0.003). The same pattern can be seen in the number of macrofauna individuals (Kruskal Wallis, Chi square=19.2 P=0.000). In 2006 there were an average of 1050 individuals, fewer than in 2004, 2005 and 2007 (Figure 15). (Mann Whitney-U P=0.001 P=0.000 P=0.000, an average of 1050 individuals in 2006, compared to 7820, 6719 and 4790 in 2004, 2005 and 2007).

This could perhaps be a result of the dry period at the start of the first year following remeandering. Another possible explanation could be that remeandering brings about major changes and involves a lot of earth-moving, which initially causes a lot of macrofauna taxa to die out.

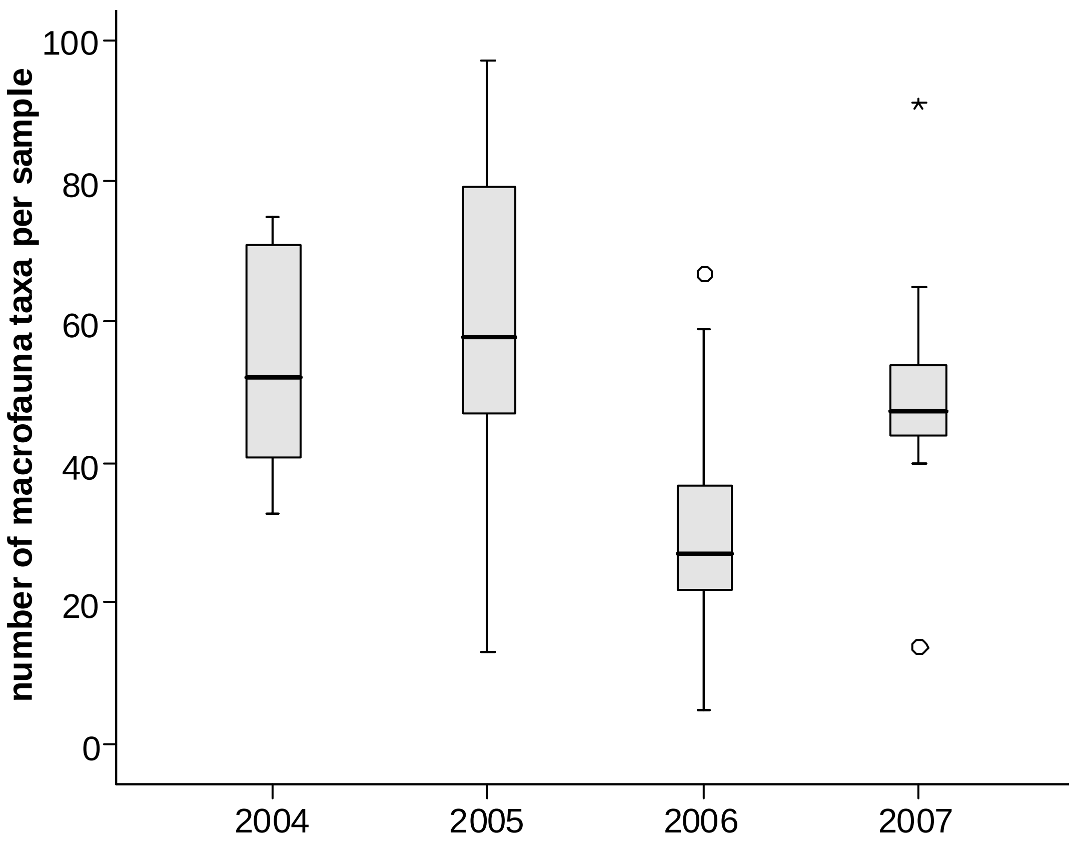

Figure 14. Number of macrofauna taxa in 2004, 2005, 2006 and 2007

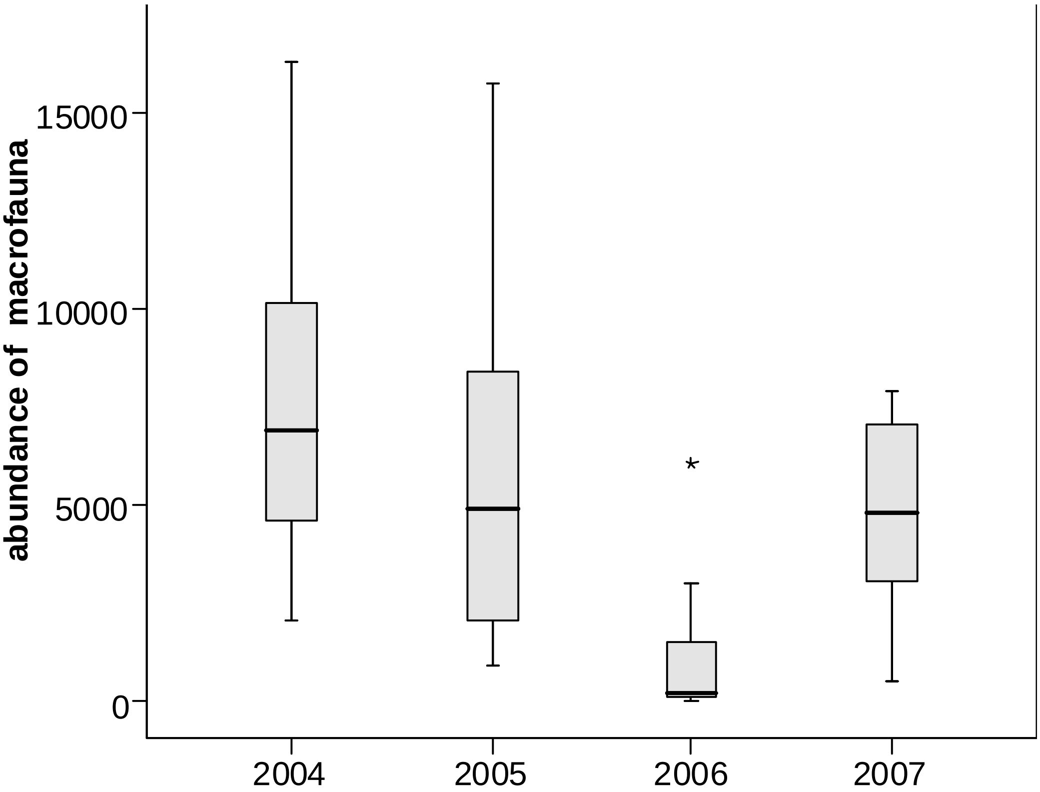

Figure 15. Macrofauna abundance: a mean of 1050 individuals in 2006 compared to 7820 in 2004, 6719 in 2005 and 4790 in 2007.

5.3.2 Ordination analysis of macrofauna samples

The DCA gradient length is 2.917. Given this length it is, normally, just as valid to apply a DCA with unimodal detrending as to use a linear technique (Ter Braak & Verdonschot 1995). Using a unimodal technique leads to higher eigenvalues on the second axis indicating that, in the rest of the analysis, detrending with 2nd order polynomials should be preferred.

In the DCA carried out, remeandering is the variable most strongly correlated with the first axis (0.69), however, part of the variation appears to be explained by the sampling method and the sampling season and sampling location. The correlation with the second axis is highest for Remeandering (Remeandering 0.55), Location 1 (Lo1 0.55) a location from upstream in the source region, and the sampling method (Multi 0.56).

The seasonal and location influences are not of interest in the current enquiry and therefore the effect of remeandering was also tested in a partial DCA using location as a covariable. The covariable 'location', or rather the influence of all locations, explain 9.3% of the variation in the macrofauna data. The factor 'remeandering' then explains 5.3 % of the remaining variation. The remeandering effect is unclear because the variables 'season', 'location' and 'method' have such strong effects on the occurrence of macrofauna taxa. The samples from 2006 clearly always tend to be outliers. This is due to the low numbers of taxa and individuals that were found in most of the samples taken in 2006. After remeandering (e.g. compared to 2004 and 2005), many taxa were absent or present in lower numbers in 2006.

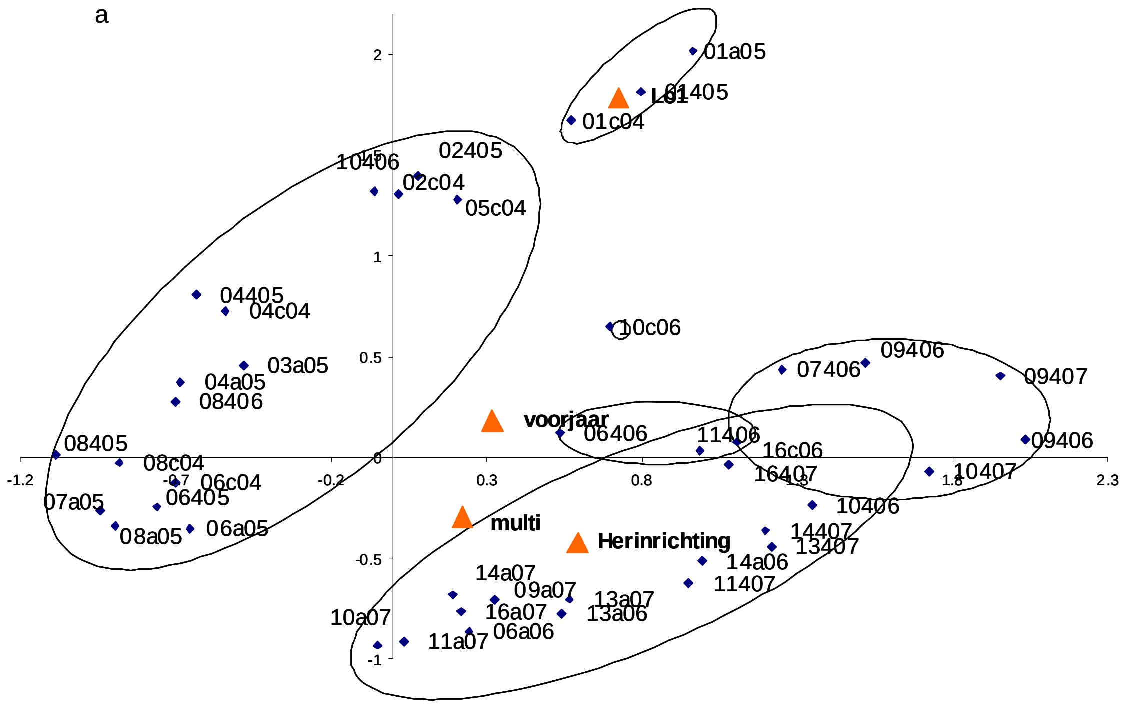

Figure 16. a DCA of all macrofauna samples from the Geeserstroom and the position of clusters. The first two digits in the sample code indicate the location (Appendix 1). The last two digits give the year and the digit in front of that the month: 4 April a October c December. Variables Lo1 location 1; voorjaar spring; Multi multi-samples; herinrichting after remeandering. b partial DCA.

Table 2. Overview of the most important ordination results.

Axes	1	2	3	4	Total inertia
Eigenvalues :	0.391	0.309	0.141	0.110	3.605
Gradient lengths :	2.917	2.818	2.551	2.297	
Variation explained :	10.8	19.4	23.3	26.4	
2^{nd} poly:					
Eigenvalues :	0.391	0.344	0.197	0.139	3.605
Variation explained :	10.8	20.4	25.9	29.7	
Partial DCA					
	0.238	0.175	0.126	0.107	3.605
Variation explained :	11.7	20.4	26.6	31.9	
Partial DCCA					
Eigenvalues :	0.107	0.233	0.167	0.132	3.605
Variation explained :	5.3	16.8	25.0	31.5	

5.3.3 Robust taxa and taxa disappearing or appearing

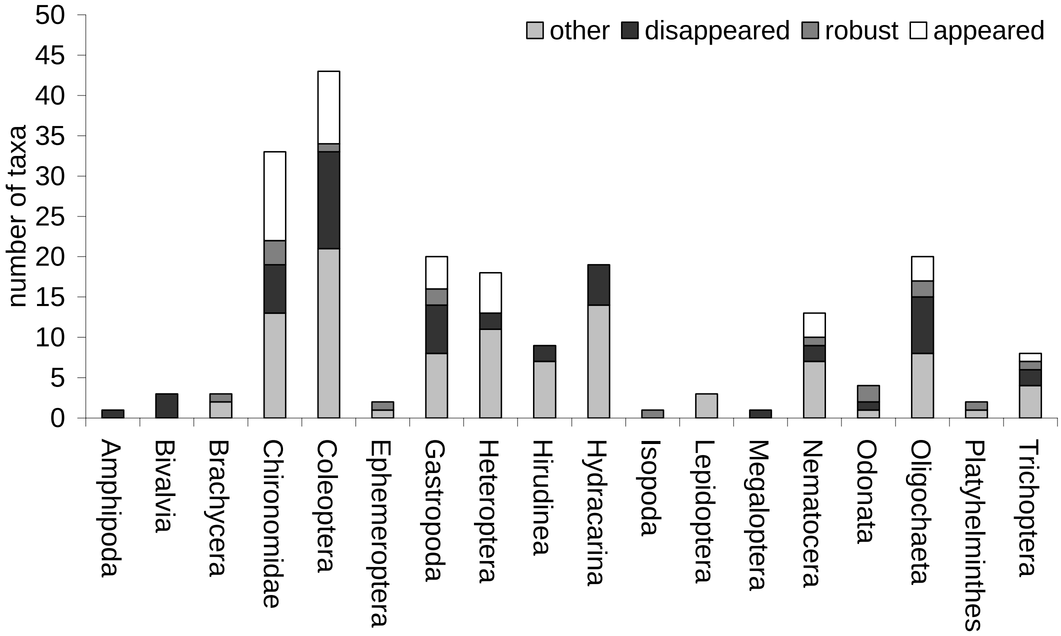

Figure 17. Distribution of taxa over the different orders. Division into taxa that disappeared or appeared following remeandering, robust taxa (those that were equally abundant after remeandering as before) and other taxa.

5.3.3.1 Robust taxa

There are three taxa that were not disturbed by the major impact of remeandering. These were the flatworms belonging to *Polycelis* sp., the mosquito larvae belonging to *Chironomus* sp. and the mayfly *Cloeon dipterum.* A number of taxa were temporarily absent but occurred in large numbers again in 2007. These were Ephydridae (Brachycera), *Procladius* sp*., Psectrotanypus varius* (Chironomidae), *Haliplus* sp. (Coleoptera), *Gyraulus albus*, *Planorbarius corneus* (Gastropoda), Asellidae (Isopoda), Ceratopogonidae (Nematocera), Coenagrionidae, Libellulidae (Odonata), Lumbriculidae, *Stylaria lacustris* (Oligochaeta), and *Triaenodes bicolor* (Trichoptera).
The robust taxa mainly contain those identified at a supra-specific level, such as the family Odonata. The leads to the possibility that the frequency of occurence of such groupings can remain the same even if there are changes in the constituent species-level taxa. Some robust taxa are very common, the caddis fly *Triaenodes bicolor,* for example, is one of the commonest species in the Netherlands. Many robust taxa are also negative indicators for the WFD Water Type R5, namely *Chironomus* sp*., Psectrotanypus varius, Cloeon dipterum, Gyraulus albus,* and *Stylaria lacustris.*

5.3.3.2 Disappearing taxa

There are taxa that were no longer found or that were found much less frequently after remeandering. Taxa that occurred frequently and that were very abundant under the conditions before remeandering, and that had completely disappeared in 2007, were *Sialis lutaria* (Megaloptera), *Limnodrilus claparedeianus, Ilyodrilus templetoni* (Oligochaeta), *Limnesia undulata* (Hydracarina), *Natarsia* sp. *(*Chironomidae), *Anacaena limbata* and Scirtidae (Coleoptera).

Other taxa that disappeared were *Marstoniopsis scholtzi, Acroloxus lacustris, Hippeutis complanatus, Segmentina nitida* (Gastropoda)*, Unio pictorum* (Bivalvia)*, Erpobdella testacea* (Hirudinea)*, Potamothrix hammoniensi* (Oligochaeta)*, Forelia liliacea, Brachypoda versicolor, Arrenurus cuspidator,* (Hydracarina) *Aeshna grandis* (Odonata)*, Ranatra linearis, Hebrus ruficeps* (Heteroptera), *Laccophilus hyalinus, Hydroporus memnonius, Hydroporus nigrita, Hydroporus erythrocephalus, Agabus sturmii, Ilybius ater, Hydraena testacea, Helochares punctatus, Dryops luridus* (Coleoptera)*, Ptychoptera* sp. (Nematocera)*, Chironomus luridus* agg*, Paralimnophyes hydrophilus, Psectrocladius platypus, Natarsia* sp.*, Zavrelimyia* sp. (Chironomidae) and *Athripsodes aterrimus* (Trichoptera).

Taxa that occurred a lot less, of which the frequency of occurrence was halved and the abundance decimated, were *Gammarus pulex* (Amphipoda)*, Arrenurus globator* (Hydracarina), *Apsectrotanypus* sp./*Macropelopia* sp. (Chironomidae), juvenile Tubificidae with trichomatous setae*,* juvenile Tubificidae without trichomatous setae*, Quistadrilus multisetosus, Limnodrilus hoffmeisteri* (Oligochaeta), *Pisidium* sp.*, Sphaerium corneum* (Bivalvia) *Valvata piscinalis, Bithynia* sp. (Gastropoda) *Graptodytes pictus* (Coleoptera) *Erpobdella octoculata* (Hirudinea), Limoniidae (Nematocera) and *Limnephilus* sp. (Trichoptera)

The large number of taxa that could not fly was striking. These included the Mollusca (Gastropoda and Bivalvia), Oligochaeta, Hydracarina and Hirudinea. In addition, many taxa were typical inhabitants of nutrient-rich, vegetation-rich, still or regulated waters, for example the beetles *Anacaena limbata, Graptodytes pictus* and *Helochares punctatus,* the true bugs *Hebrus ruficeps* and *Ranatra linearis*, and the alder fly *Sialis lutaria.* These taxa enjoyed an appropriate habitat in the Geeserstroom as it was before remeandering.

Indicators for the reference situation that were present before remeandering but subsequently disappeared were the beetles *Hydroporus nigrita* and *Hydroporus memnonius*, the chironomid midge *Zavrelimyia* sp.*,* the caddis fly *Athripsodes aterrimus,* the freshwater shrimp *Gammarus pulex* and the mite *Forelia liliacea.*

The negative indicators *Erpobdella octoculata* (leech), *Arrenurus globator, Limnesia undulata* (mites)*,* and *Limnodrilus hoffmeisteri* and *Potamothrix hammoniensis* (worms) also disappeared.

5.3.3.3 Taxa that appeared

A number of taxa were not present before remeandering but were frequently found in samples afterwards. Particularly noticeable were the taxa that were found in more than three samples in 2006 and 2007, whereas they were not found during sampling in 2004 and 2005.

These were *Physella acuta, Planorbis planorbis* (Gastropoda)*, Chaetogaster diaphanus* (Oligochaeta)*, Hygrotus impressopunctatus* (Coleoptera), *Dixella aestivalis,* (Chironomidae) (all only in 2007)*, Callicorixa praeusta, Gerris thoracicus,* (Heteroptera)*, Hydroporus planus, Gyrinus substriatus,* (only in 2006)*, Berosus* sp. (Coleoptera)*, Dixella amphibia., Simulium* sp.*,* (Nematocera) and *Callicorixa praeusta* (Heteroptera).

There are also taxa that were found in more than three samples in 2006 and 2007, but were found in one sample in 2004 and 2005:
Paratanytarsus sp., *Micropsectra* sp., *Glyptotendipes* sp., *Cryptochironomus* sp., *Ablabesmyia* sp., *Chironomus riparius* agg., *Corynoneura* sp., *Psectrocladius obvius, Parachironomus* in the *P. arcuatus* group (Chironomidae) *Rhantus* sp., *Laccobius minutus, Dytiscus* sp. (Coleoptera), *Corixa punctata* (Heteroptera), *Dero* sp. (Oligochaeta) and *Oecetis furva* (Trichoptera).
Finally, there are taxa that occurred twice as frequently and in numbers 10 times greater after remeandering than before. These were *Radix auricularia*, *Galba truncatula* (Gastropoda), *Hydroglyphus geminus*, *Hygrotus inaequalis* (Coleoptera), *Metriocnemus* sp., *Orthocladius* (*Orthocladius*) sp. (Chironomidae), *Sigara semistriata* and *Sigara striata* (Heteroptera).

The taxa that were new after remeandering were mainly those that can fly (Heteroptera, Coleoptera and Chironomidae), but a few non-flying Oligochaeta and Gastropoda also newly arrived after remeandering. Some of these are typical colonisers that can resist disturbance or that can survive in semi-permanent waters, such as the beetles *Hygrotus impressopunctatus* and *Hydroglyphus geminus*, and the negative indicators *Glyptotendipes* sp. and *Cryptochironomus* sp. (Chironomidae), the snail *Planorbis planorbis* and the true bugs of the genus *Sigara.* In addition a few flow indicator species appeared, such as the mosquitoes *Simulium* sp. and *Micropsectra* sp., together with fairly rare taxa, such as the beetle *Berosus signaticollis*. The arrival of *Simulium* sp. may indicate that the newly structured conditions offer a habitat for stream organisms that were previously not present.

If the number of taxa that appeared and disappeared within each order are compared, it is noticeable that the taxa that appeared after remeandering were mainly taxa of flying groups, such as true bugs and mosquitoes, while those that disappeared were the predominantly non-flying mites, bivalves, leeches, freshwater shrimps, alder flies, dragonflies and worms (Figure 18).

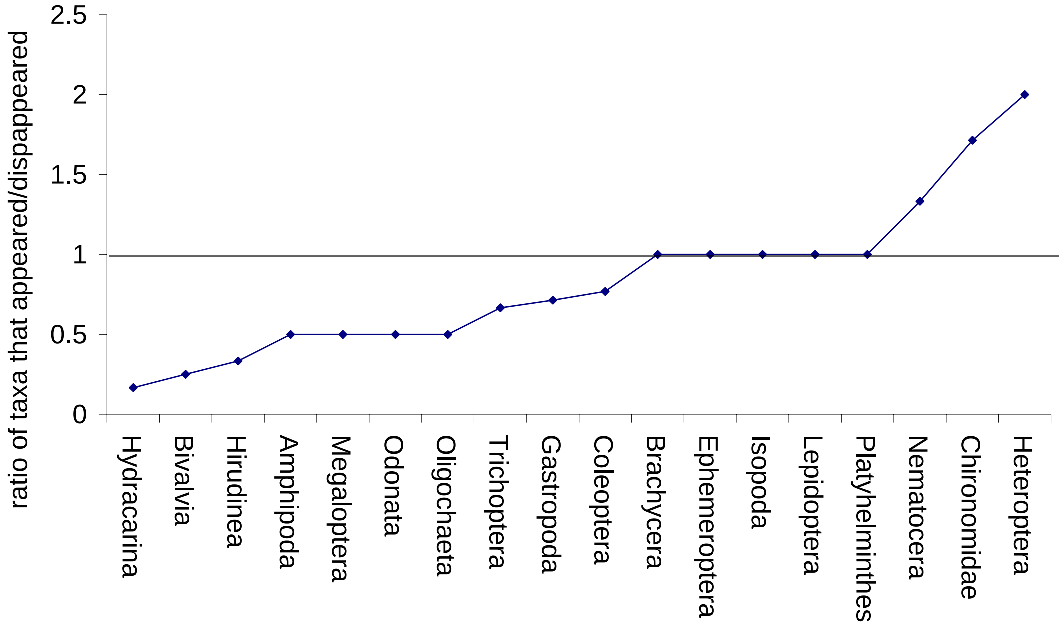

Figure 18. Relationship between taxa that were new after remeandering and those that disappeared due to remeandering, by species group.

5.3.4 V-index and desiccation index

Autoecological information from the taxa encountered was used in order to obtain a picture of the current situation in the Geeserstroom.
Rheophilia is one characteristic of taxa highly desired in the new stream situation. It is expected that the new profile in the remeandered stream will offer a habitat for these flow-loving taxa. In addition, in the intervening period, the stream can be a suitable habitat for colonists and taxa that are resistant to periods when the stream runs dry. For these reasons the above characteristics were investigated first.

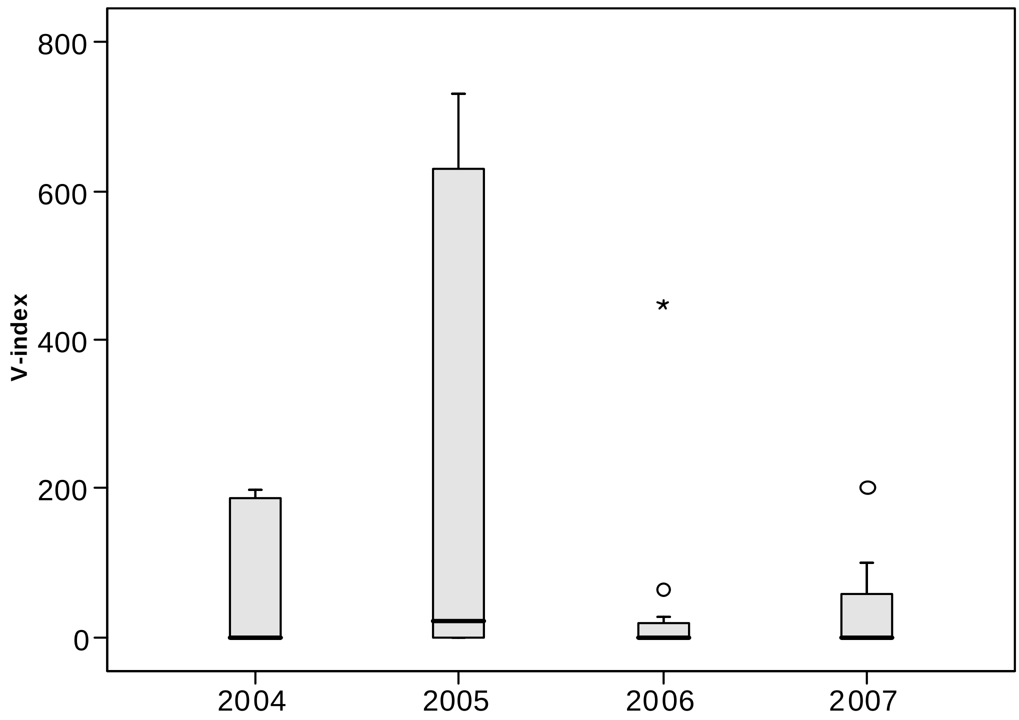

Figure 19. V-index for each sample in the years 2004, 2005, 2006 and 2007.

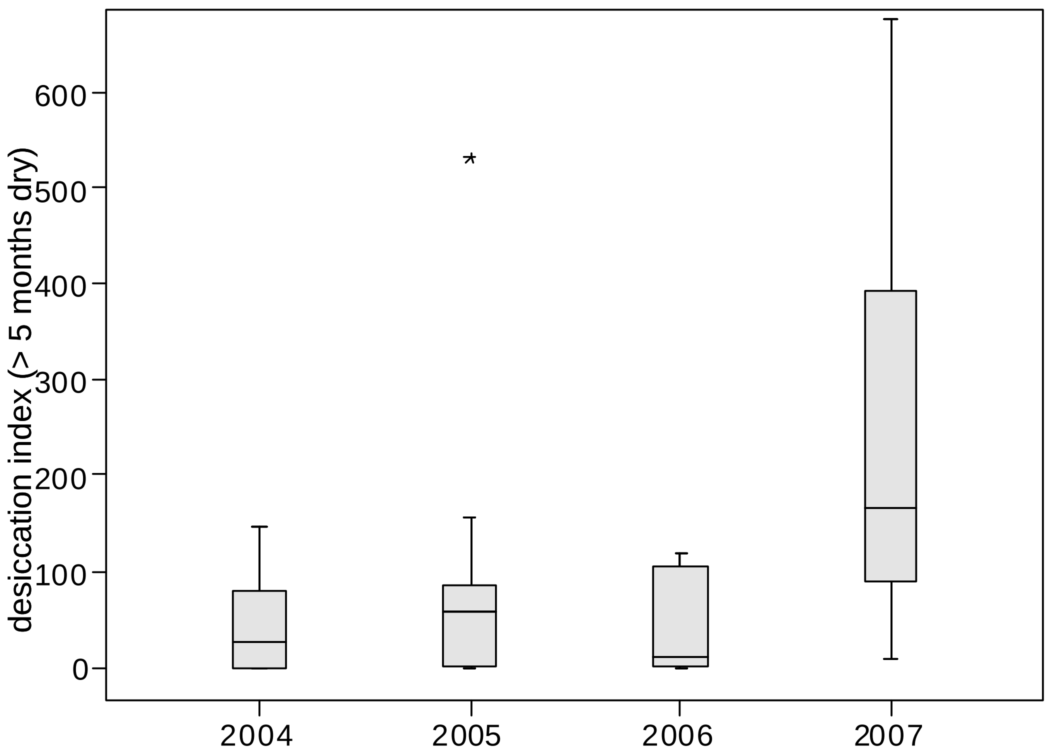

Figure 20. Desiccation index (>5 months dry) for samples in the years 2004, 2005, 2006 and 2007.

The V-index does not vary between different years (Kruskal Wallis, Chi square=2.157, P=0.054). There were thus no more and no fewer rheophilic taxa under the conditions following remeandering than there were before remeandering. As the remeandering measures were implemented up to and including 2006, a possible explanation is that colonisation is still actively taking place and the rheophilic taxa are not yet present.

The desiccation index shows very clear patterns. The indicators for drought were present in large numbers in 2007. This was the case both for indicators of long dry periods (>5 months and 3-5 months) and for those of shorter periods (6 weeks to 3 months and <6 weeks) (Table 6). This indicates that, specifically in 2007, many drought-resistant taxa were present and this is once again an indication that the colonisation process is still actively taking place.

Table 6. Chi-square test for variations in desiccation index between the years 2004, 2005, 2006 and 2007.

	>5 mth	3-5 mth	6 wk-3 mth	<6 wk	permanent
Chi-sq	10.0	9.1	8.5	8.7	19.6
P	0.018	0.028	0.036	0.033	0.000

6 Current situation

6.1 Research questions

The aim of this research is to gain insight into the processes and factors that lead to successful restoration.
Specific research questions to this end were:

- What is the abiotic situation after remeandering?
- Do changes in abiotic factors influence the focal species to be expected in the stream?
- Which species disappeared because of implementation of the restoration measures?
- Which species have returned?
- After how long and at what time did species return?

6.2 What is the abiotic situation after remeandering?

6.2.1 Hydrology

Before remeandering the stream was deeply incised, the bank was high and the water deep. As a result of the incision there was also little difference in height between the different parts of the stream and the stream was characterised by its short length and limited fall. Using profile measurements from before and after remeandering it can be concluded that in its altered condition the stream is longer, with a greater fall, less pronounced incision and a shallower water body. A notable structure that features strongly in all measurements is the fish ladder, which is installed just before the canal. This fish ladder is characterised by its significant height and fall, with very deep water and high banks directly after the ladder. In all patterns measured the fish ladder produces outliers that influence the average pattern.
The water level fluctuated from a few centimetres in April 2007 to nearly one metre during heavy rainfall in January 2007. It can clearly be seen that the water level follows the precipitation pattern. The flow rate was 0.10 m/s on average in 2006, compared with 0.02 m/s in 2005 and 0.06 m/s in 2004. It appears that the new watercourse flows in some locations, but there are not enough data.

6.2.2 Nutrients

The reference values (GEC) of the WFD reference type R5 for the nutrients total nitrogen and total phosphorus are 4 mg N/l and 0.14 mg P/l. These values, in particular for total phosphorus, were frequently exceeded in the remeandered Geeserstroom. It was also noticeable that rainfall in winter and in some months of the summer appeared to be linked to increases in nitrogen and phosphorus concentrations. Conversely, during dry periods nutrient concentrations were lower, which points to the influence of ground water seeping in. Oxygen concentrations were very variable but never fell below the limit of 2 mg/l, which is lethal for most fish and macrofauna. Concentrations of other ions also varied greatly, without there being any clearly visible differences between the periods before and after remeandering.

6.3 Do the changes in abiotic factors influence the focal species to be expected in the stream?

The new profile leads to altered flow conditions. It is expected that typical lowland stream species will be able to benefit from the increased fall and the changed hydromorphology, with the associated increase in flow rate and decrease in depth. However, the remeandering process and the changing weather conditions in 2006 and 2007 led to major fluctuations in abiotic conditions. As a result, species that are resistant to disturbances have so far predominated in the stream after remeandering. Furthermore, the concentrations of nutrients in the stream have hardly changed and the diatom community has thus also not showed a clear reaction to the remeandering. Nutrient-rich water from the agricultural land has not yet been diverted, so that the water in the stream is too high in nutrients. As it is an upper-course system, the target values are a total phosphorus norm of 0.14/0.12 mg P/l and a total nitrogen norm of 4 mg N/l (those of the natural references R5/R4) for which it can be expected that typical lowland stream flora and fauna will develop.

6.4 Which species disappeared due to implementation of the restoration measure?

Fifty-one taxa (25%) disappeared following remeandering, mainly mites, bivalves, leeches, freshwater shrimps, alder flies, dragonflies and worms. It was noticeable that there were a large number of taxa that could not fly, such as snails, worms, mites and leeches. In addition, the habitat of many taxa was linked to nutrient-rich, vegetation-rich, still or regulated waters, as for example in the case of the beetles *Anacaena limbata, Graptodytes pictus* and *Helochares punctatus,* the true bugs *Hebrus ruficeps, Ranatra linearis* and the alder fly *Sialis lutaria.* These taxa were typical inhabitants of the Geeserstroom before remeandering.

6.5 Which species have returned?

The majority of the taxa (60 %) returned in 2007. In addition, 36 new taxa appeared. The new taxa that arrived after remeandering mainly use flight for locomotion (true bugs, chironomid midges and mosquitoes), but some non-flying worms and snails also appeared. Some of these were typical colonists that are resistant to disturbances or that can survive in semi-permanent waters, for example the beetles *Hygrotus impressopunctatus* and *Hydroglyphus geminus*, and the true bugs of the genus *Sigara.* Some flow indicator species also appeared, such as blackfly *Simulium,* and the fairly rare beetle *Berosus signaticollis.* This last-mentioned species could indicate that the new, remeandered, stream offers habitat for stream organisms that were previously not present.
There was no increase in the number of rheophilic species following remeandering but there was a strong increase in 2007 in the number of indicators for drought, both for shorter as well as for longer periods of drought. The presence of many drought

indicators points to the colonisation process still being very much in progress. This conclusion is also based on the diatom community of the Geeserstroom, which up to 2008 was still in an unstable condition.

6.6 After how long and at what time did species return?

In 2006 the number of macrofauna taxa and their abundances were very low. The majority of taxa only returned in 2007. The expected arrival of typical lowland stream species and focal species has not occurred so far. This can be explained by changing weather conditions and unchanged concentrations of nutrients. Some parts of the remeandering plan were also carried out differently in the end, so that the stream that finally resulted did not flow or dried out in many places. Finally, one cannot rule out dispersal problems for the lowland stream species that were expected and it is possible that barriers for the species still play a major role in the colonisation of the remeandered stream. However, these species will only have a chance of becoming established if the abiotic conditions meet the Good Ecological Condition norms.

6.7 The future

There are various indications from the diatom and macrofauna communities that the colonisation process in the remeandered Geeserstroom is still very much in progress. Monitoring of the remeandering over a long period will probably give a different and more complete picture of the effects of a large-scale remeandering project than the results after just two years described in this report.
It is possible that in future years there will be more changes that will influence the restoration of the Geeserstroom. In this context one can think of the diversion of the nutrient-rich water from agricultural land or the removal or restructuring of the fish ladder which would make it possible to increase the fall of the mid-course and lower course. It will also be interesting to see whether the extremes of weather of the last few years, which appear to have had a considerable influence on the stream's hydrological conditions, will increase or decrease in frequency.

6.8 Other recommendations

Some effects of the remeandering measures have not been investigated by means of the current monitoring of the abiotic aspects and ecological community effects of the Geeserstroom remeandering project. However, frequent visits to the remeandering project have produced findings relating to the hydrology and ecology of the stream, which are described here as 'other recommendations'.

6.8.1 "Inoculating" the macrofauna community

It appears so far that flying insects in particular reach the remeandered area quickly, while, on the contrary, bivalves, mites and leeches do not. The question is whether this alteration in taxa is related to the presence or absence of the appropriate habitat or to the dispersal ability of particular taxa. Deep, still-water, and often plant-rich regulated stream sections have made way for shallow, flowing sections without plants, or temporarily dry places. The species shift observed might be linked to this habitat shift. In contrast, the dispersal ability, i.e. the ability of organisms to reach the newly structured habitat, is a factor that might also explain the changes in species composition. Flying species can reach the newly remeandered locations from nearby water bodies or other parts of the stream. Furthermore, it is possible that during the intensive excavation activities some taxa were in a terrestrial phase as adults and thus suffer no direct negative effects from the remeandering process. Bivalves, mites, leeches, freshwater shrimps, snails and worms do not experience such a flying phase (exceptions to this are taxa that are carried by other insects or birds). These groups can thus easily be moved or buried during excavating work. Moreover, these groups can only reach a newly dug watercourse if there is a direct connection by water to the new location. If members of these groups occur in the old stream and are wanted in the newly remeandered conditions, it may be advisable to 'inoculate' taxa of these groups into the new location. This can be done by temporarily evacuating the taxa during excavation work or by introducing small numbers of taxa from locations where no excavations have taken place. Such an exercise has never taken place, so the effectiveness of this type of measure cannot be described using the present research.

6.8.2 Channel

The aim for the part of the area north of the Koemaatsendijk was to create a dug-out channel into which water could seep. However, the sill installed at the Koemaatsendijk holds back so much water that a pool approximately 70 cm deep has been created. Discharge from this pool into the stream is either zero or negligible. An upstream pool would drain into the stream if the barrier were lowered, but this would also mean warmer water reaching the upper course, which would be an undesirable situation. The recommendation would be to remove the barrier completely and allow the original channel to fulfil its role for the benefit of the stream and the natural character of the landscape.

6.8.3 River marshes

Because, partly due to the fish ladder, there is only a limited fall in parts of the new watercourse, there is frequent flooding. These inundation zones have developed relatively rapidly into semi-permanent river marshes. This has altered the character of the intended marshy grasslands. These river marshes are a natural feature in Dutch lowland streams and in the Geeserstroom they are also situated in the flattest parts of the stream valley. We would recommend that these marshes be further developed. However, to this end water should also be present in the summer, or high groundwater levels should be maintained. To achieve this the stream can be closed in the flat areas so that the whole marsh develops as a water retention system. In the current semi-permanent bogs large numbers of mosquitoes develop, which plague the people who visit the area for recreation. Improving the water management of these river marshes could also reduce the mosquito problem.

6.8.4 Drought

In 2006 large sections of the stream ran dry. This drying out is less desirable and should only occur as an exception (once every 25 years). More seepage of groundwater into the stream is needed to prevent drought in the future. To achieve this the parallel ditches and drainage areas that are still present in the stream valley should be closed. One could also consider increasing water retention by the river marshes, which would in turn stabilise the drainage of water into the stream, by further reducing the width and depth of the stream profile.

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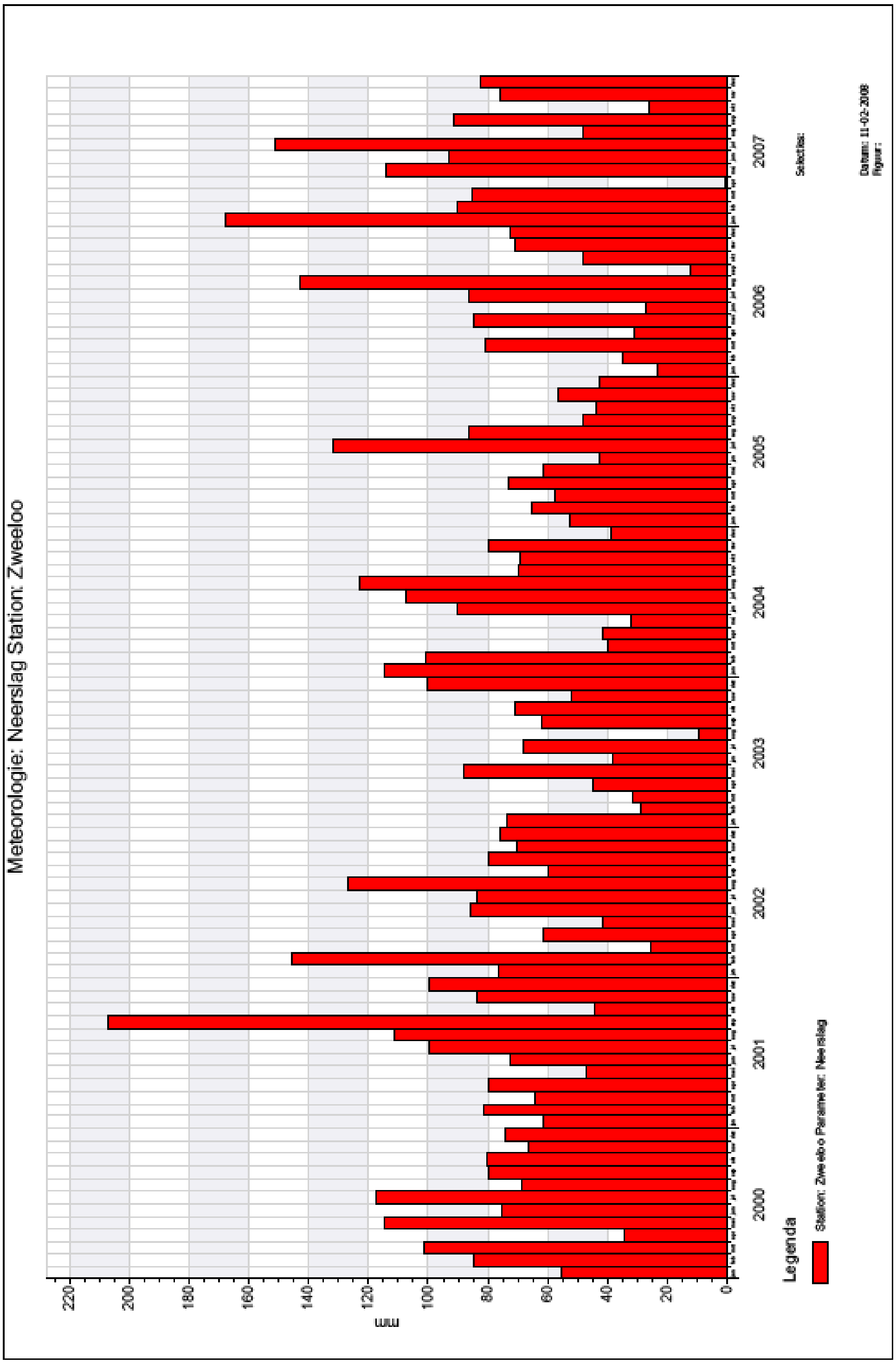
Appendix 1 Sampling points

Appendix 2 Precipitation at the Zweeloo weather station



Appendix 2. Van Dam Index

Tabel 7. Characteristics of diatom sapmles. Location, month and year of sampling; VD Van Dam Index: O_2 oxygen; NH nitrogen metabolism; SA salinity; SAP sapbrobity; TRO trophic state; AE humidity; PH acidity; taxa total number of taxa.

location	month	year	VDO2	VDNH	VDSA	VDSAP	VDTRO	VDAE	VDPH	taxa
01	April	2005	1.8	1.9	1.8	2.5	2.8	3.0	1.8	15
02	April	2005	2.1	2.3	2.0	2.6	4.9	3.0	3.1	20
04	April	2005	2.8	2.3	2.0	3.1	4.7	2.9	3.3	24
01	October	2005	1.9	1.8	1.8	2.2	1.4	3.0	1.5	15
03	October	2005	3.1	2.6	2.0	3.4	5.1	2.7	3.2	34
04	October	2005	2.3	2.3	2.0	2.8	5.2	2.9	3.1	20
06	October	2005	1.8	2.1	2.0	2.3	4.9	2.7	3.2	20
07	October	2005	2.9	2.0	1.9	2.1	4.9	2.1	3.7	11
08	October	2005	2.0	1.7	1.9	2.0	4.1	2.2	3.2	19
06	April	2006	2.0	2.3	2.0	2.4	4.3	2.5	3.3	25
08	April	2006	2.6	2.6	2.1	2.6	4.8	2.5	3.6	30
09	April	2006	2.6	2.2	2.0	2.8	4.8	2.0	3.1	14
06	October	2006	2.1	2.4	2.0	2.5	5.0	2.8	3.3	21
09	October	2006	2.9	2.0	2.0	2.9	5.0	1.0	3.0	5
13	October	2006	1.5	2.1	2.0	2.1	5.0	2.8	3.2	9
14	October	2006	3.5	3.0	2.0	3.7	5.6	2.5	3.4	18
10	December	2006	2.8	2.2	1.9	3.1	4.5	2.7	3.3	19
16	December	2006	2.3	2.1	2.0	2.7	4.8	2.5	3.1	26
09	April	2007	3.1	2.7	2.0	2.9	5.0	2.1	3.4	18
10	April	2007	2.9	2.4	2.2	2.9	4.9	2.4	3.4	18
11	April	2007	1.9	2.1	2.0	2.3	4.7	2.7	3.2	21
13	April	2007	1.3	2.0	2.0	2.1	4.4	2.8	3.1	14
14	April	2007	2.4	2.5	2.1	2.6	4.8	2.4	3.5	31
16	April	2007	1.5	2.1	2.0	2.2	4.9	2.9	3.1	22
09	October	2007	2.0	2.3	2.0	2.6	4.9	2.9	3.3	11
10	October	2007	3.0	2.0	2.0	2.0	5.0	2.0	4.0	2
11	October	2007	3.0	2.0	2.0	2.0	5.0	2.0	4.0	3
13	October	2007	2.3	2.3	2.0	2.6	4.9	2.8	3.2	17
14	October	2007	3.0	2.1	1.9	2.7	5.1	2.3	3.7	17
16	October	2007	3.0	2.0	2.0	2.1	5.0	2.1	3.9	10