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Integrated Project to evaluate the Impacts of Global Change on European Freshwater Ecosystems

WP2: Climate-hydromorphology interactions

Task 2: Hydromorphological changes and aquatic and riparian biota

Subtask 2.5: Examination of existing time-series data

Deliverable No. 221

The significance of climate change in human utilised streams

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The significance of climate change in human utilised streams

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Abstract

Climate change effects will occur all around the globe but one can ask whether the intensity of these effects is significant in comparison to the effects of current and future human activities. To better understand the role of climate change in catchments that are already under pressure of human activities one needs to study past, current and future conditions. To develop a qualitative idea on the significance of the effects of climate change on streams in urbanised areas, the catchment of the river Vecht (The Netherlands) was chosen as case example. The catchment is representative for many human utilised, medium-sized lowland river catchments in this ecoregion, and also because both historical and present-day conditions are known. Canalisation of the river Vecht went along with changes in land-use and took place during three major time-intervals: ±1895-1905, 1925-1935, and 1955-1965. The area of heather and moorland peat decreased dramatically as the agricultural, urban and other human uses increased. The percentage of forest remained the same over the whole period. In general, the morphological features of the streams in the Vecht catchment show degradation over the last one hundred years. The total stream length was shortened by about 20% while the valley length remained about the same. Forty percent of the connected side-arms got lost and the number of oxbows increased in the thirties due to straightening of the major streams but decreased until today with about 38%. In general, most streams were meandering around 1900, in the thirties and sixties some were still slightly meandering, and currently most are straight. There is a positive trend in temperature and precipitation observed over the last hundred years. In general, the average discharge did not change much over the last 30 years. Macroinvertebrates were only sampled from the last decades. Land-use and hydromorphology changes were independent from climate change. Six climate scenarios (two current and four for the years 2070-2100) were applied in the hydrological model SIMGRO. Following the predictions using these climate scenarios, discharge will become somewhat more dynamic, the low and high exceedance classes 3-6 will increase while the more constant discharge classes decrease. With the MLR-EKOO model the future macroinvertebrate assemblages were predicted. The future low flow conditions will result in macroinvertebrate assemblages more often found in temporary, b-mesosaprobic, natural upper courses and polysaprobic, natural and canalised upper- and middle courses. This indicates a slight quality deterioration. But comparing the major changes in land-use in the past that dramatically affected the stream ecosystems with these predicted small climate change induced changes justifies the conclusion that future land-use change become of much greater importance than the effect of climate change.

Introduction

Climate change effects will occur all around the globe but one can ask whether the intensity of these effects is significant in comparison to the effects of current and future human activities. North-western European landscapes are, as many other densely populated areas around the world, intensely utilised almost everywhere and the historical and current agricultural and urban influence on the ecology of streams is very strong. In large parts of Europe hydromorphological alteration is the main stressor affecting streams and rivers. Alterations include, for example, channel straightening, weir and dam construction, disconnection of the river from its floodplain or its upper course, and alteration of riparian vegetation (e.g. Smits et al. 2001). Indirectly, these alterations result also in for example, a lowering of the groundwater level, increased siltation and changes in inundation regime (Kristensen & Hansen 1994).

Global warming will result in a more active hydrological cycle expressed in a substantial increase in precipitation and a greater evaporation (IPCC 2001). For Europe as a whole, an increased chance of prolonged heavy precipitation and short intense showers is calculated (KNMI 2006). This will have a large impact on streams and rivers. In the temperate zone the more extreme climate events include heavy rainfall over short periods of time resulting in floods as well as dry periods with high air temperatures and high evapotranspiration leading to droughts. Furthermore, the warmer winters prevent ice cover and storms will disturb shallow waters. Higher precipitation will result in more surface runoff to streams and higher floods in rivers (Poff 1992, George et al. 2004). Under predicted future climate conditions further stresses on streams and rivers will be introduced, including the combined effect of direct changes in precipitation and indirect climate-induced changes in land-use patterns. These in turn may cause changes in catchment hydrology that will affect runoff and discharge regimes, sediment transport and channel morphology, inundation frequency and extent, and will impact stream and river ecosystems.

To better understand the role of climate change in catchments that are already under pressure of human activities one needs to study past, current and future conditions. Developments in the past provide insight in the chain of relations going from climate pattern, to regional land-use, to stream and river hydrology and morphology, and finally to stream assemblages. Past developments resulted in the current conditions. Future conditions can only be predicted and thus include a number of assumptions.

To develop a qualitative idea on the significance of the effects of climate change on streams in urbanised areas, the catchment of the river Vecht (The Netherlands) was chosen as case example. The catchment is representative for many human utilised, medium-sized lowland river catchments in this ecoregion, and also because historical and present-day conditions are known.

As is the case for all predictions, these intend not to represent absolute truths but to direct thoughts and indicate directions in which impacts can be expected and measures can be taken. The predictions for the case river Vecht are expected to represent a general balance between climate versus human effects indicative for many other situations. The approaches used can easily be applied to other catchments as these do not need huge amounts of quantified historical data nor too complex prediction techniques.

The objective of this study is to describe the interrelations in the chain from climate to stream communities in the study catchment of the river Vecht over about the last 100 years to learn about the relation between climate and human utilisation. And next to apply this knowledge to predict the effect of climate induced changes on discharge regimes and on stream macroinvertebrate assemblages in the future (period 2070-2100) in comparison to future human utilisation?

Study area

The study catchment of the river Vecht (52 17 N, 07 14 E) is situated in the North-West European plain (Figure 1). The river Vecht has a groundwater-derived baseflow and runs over 167 km from Germany, crosses the Dutch-German border after 106.7 kilometre, to the river IJssel (The Netherlands), a branch of the river Rhine. The total catchment is 3785 km^2, of which 48% is situated in Germany and 52% in The Netherlands. Although the Vecht catchment is partially situated in Germany and partly in the Netherlands, this study focused on the Dutch part of the catchment (Van Dijk et al. 1992, Janssens & Schropp 1993). The latter choice ensured data availability and offered the possibility to study the interrelation between climate, land-use, hydrological and morphological conditions.
The river slope is more than 100 m over the entire course, the Dutch part of the river has a slope less than 10 m (Wolfert et al. 1996). The catchment is at its highest point more than 150 m above sea level. In the Dutch part both glacial hill-ridges in the south-east range up to about 80 m while the largest part of the catchment in the Netherlands is between 0 and 10 m. The whole Dutch part of the catchment slowly slopes down from east to west. The only exception is the Dinkel that runs south-north through an area east of two glaciel hill-ridges. Some of its tributaries run from west to east into the Dinkel.
The wide valley of the originally meandering river Vecht, accompanied by sand elevations, dates from about 200-130 thousand years ago (Huisink 1999). About one thousand years ago the sand elevations became occupied. Forests were cut and large areas of heather developed. Over the years the specific method of farming (sheep dung mixed with tufts of heather) raised the poor sandy soils with a layer of fertile, humic soil of about one meter thickness. The grasslands adjacent to the river were used as hay- and grazing grounds. Over the last two hundred years most areas of heather were cultivated or changed to forest.
Already around 1350 the first canal was dug and in the 17th and century 19th the river Vecht and several streams in the Regge catchment were used as shipping routes. Furthermore, a number of canals was dug at that time. With the foundation of the Provincial Water Management Department in 1882 a period of regulation, canalisation and normalisation began.
The historical data over the last hundred years of water management developments in the catchment showed that large parts of the Vecht catchment were hydromorphologically changed over four periods in the last hundred years (Van der Schrier 1983). These periods were identified by a high number of changes and took place around 1900 (years 1895-1905), 1930 (1925-1935), 1960 (1955-1965), and 2000 (1998-2000). The first two periods mark the majority of changes. A third period, between 1960 and 1980, completed

the hydromorphological deterioration by deepening and widening of a large number of smaller streams. Under the current conditions several restoration projects took place.
In general, water quality decreased in the 20th century (Waterschap Groot Salland 2002).
The current quality of the river Vecht depends on the input from the whole catchment. Based on the data over the years 2001-2006 (Waterschap Velt & Vecht 2007) and classes according the EU-WFD (European Commission 2000) the oxygen concentrations were good to high, despite drops to <2 mg l^{-1} during short periods in summer. Phosphorus levels fluctuated between moderate and good while nitrogen levels were within poor and moderate. They resulted in eutrophication, especially during low flow periods. Furthermore, chloride concentrations were too high as well as some toxicants (mostly moderate to good).

Material and methods

Past and current developments

Climate

Temperature and precipitation data, obtained from the Royal Dutch Meteorological Institute (KNMI 2004), were analysed over the last 100 years. Temperature values over the period 1900 to 2003 were available as daily average and extremes. Based on these daily averages the yearly average, and the yearly average minimum and maximum were calculated, and expressed as progressive averages over 5 years periods. Extreme temperatures were defined as absolute minimum and maximum temperatures per year as well as the number of days with a daily minimum temperature <10 °C and those with a daily maximum temperature >30°C.
Total daily precipitation data were available from 1906 to 2003. Data on daily precipitation intensity were present from 1930 to 2003. Precipitation intensity is defined as (1) number of days with a total precipitation >5 mm and an intensity ≥5 mm per hour, and (2)number of days with a total precipitation >10 mm and an intensity ≥10 mm per hour.

Land-use

For each of the historical time periods the cover percentages of the major land-use categories were extracted using either the program ArcView when digitalised maps were available or by expert estimation concerning hardcopy maps. For the first period around 1900 the digitalised map 'Historical Land-use in The Netherlands' (Runhaar et al. 2003) was available. Both the second and third period of around 1930 and 1960, respectively, only hardcopy topographical maps with a scale of 1:25000 were available. The fourth and last period concerned the recent land-use that could be extracted from the digitalised map 'Land-use in the Netherlands' (LGN 4). For the analysis of land-use, the categories distinguished were hay- and grassland; field, arable, agricultural and bare land; heather and peat-moor; forest (deciduous and coniferous); road and urban; and others like surface waters. The cover area per category was calculated for each of the six subcatchments. One stream and three rivers were selected to establish more specific the floodplain-use cover areas, namely the stream Schoonebeker Diep (500 m flood plain area of the west bank), the river Vecht (1000 m of both banks), the river Regge (500 m of both banks), and the river Dinkel (500 m of both banks).

Hydrology
Discharge data were available from the province of Overijssel, the waterboard of Regge & Dinkel and Alterra. Most streams in the catchment lack continuous discharge data. Therefore, data were selected from different streams each being representative for upper, middle, and lower courses of streams, and the river Vecht, respectively (Table 1). All data sets showed missing data. Discharge was graphically expressed as moving 5-yearly averages.

Morphology
Stream morphology was expressed in the parameters sinuosity, presence of weirs and transversal profile shape. Sinuosity is defined as the ratio between the length of a stream stretch and the length of the stream valley. Sinuosity is thus a measure of degree of meandering and is classified as straight (1.00-1.15), slightly meandering (1.15-1.30), meandering (1.30-1.50), and strongly meandering (>1.50).
For most streams, sinuosity and presence of weirs was only clearly represented on map for the more downstream sections. Based on expert judgement, two to four representative larger streams were selected per subcatchment. For the periods around 1900, 1930 and 2000 digitalised topographical maps were used (1:25000). With the program ArcView 3.3 the sinuosity and presence of weirs was calculated. The topographical information from around 1960 was manually elaborated.
The shape of the transversal profile is hardly documented. Only data on the upper part of the river Dinkel (the period 1975-1995 (Doctor 1998)), and of the lower part of the river Regge (the period before 1930) were available. Recent transversal profiles were made available by the waterboard 'Regge & Dinkel'.

Macroinvertebrates
Samples were collected from 664 sites situated in the province of Overijssel (The Netherlands); 609 sites were visited in one season only and 55 sites were visited in two seasons. The sampling dates were spread over the four seasons as well as over several years (1981 up to and including 1985). Season was taken into account by defining sampling periods as nominal "environmental" variables within the analysis.
The objective was to capture the majority of the species and their relative abundances present at a given site. At each site, major habitats were selected over a 10 to 30 m long stretch of the water body and were sampled with the same sampling effort.
At shallow sites, vegetation habitats were sampled by sweeping a pond-net (200 mm * 300 mm, mesh size 0.5 mm) through each vegetation type several times over a length of 0.5-1 m. Bottom habitats were sampled by vigorously pushing the pond net through the upper few centimetres of each bottom type over a length of 0.5 to 1m. The habitat samples of the site were combined to give one sample with a standard area of 1.5 m^2 (1.2m^2 of vegetation & 0.3 m^2 of bottom). At sites lacking vegetation, the standard sampling was confined to the bottom habitats. At deeper sites, five samples were taken with an Ekman-Birge sampler from the bottom habitats. These five grabs were equivalent to one 0.5 m pond net bottom sample. Vegetation habitats were sampled with a pond net

as described above. Again the total sampling area was standardised as 1.5 m^2. Verdonschot (1990) showed that this sampling effort met the requirements to construct a regional water typology. Macroinvertebrate samples were taken to the laboratory, sorted by eye, counted and identified to species level.

A data sheet was used to note a number of abiotic and some biotic variables in the field. Some were measured directly (width, depth, surface area, temperature, transparency, percentage of vegetation cover, percentage of sampled habitat), others (such as regulation, substratum, bank shape) were classified. Field instruments were used to measure oxygen, electrical conductivity, stream velocity and pH. Surface water samples were taken to determine chemical variables. Other parameters, like land-use, bottom composition, and distance from source, were gathered from additional sources (data from water boards, maps). In total, 70 abiotic variables were measured at each site.

All macroinvertebrates and environmental data together are further indicated as the EKOO-data. These data were used to describe macroinvertebrate assemblages (Verdonschot 1990, 1995, Verdonschot & Nijboer 2000). Data processing consisted of the following six main steps:

Step 1. The study revealed 853 invertebrate taxa. The macroinvertebrate abundances were transformed into logarithmic classes. Quantitative environmental variables, except pH, were log-transformed because of skewed distributions. All other variables were nominal and dealt with by defining so-called dummy variables.

Step 2. The sites were clustered, based on the macroinvertebrates, by means of the program FLEXCLUS (Van Tongeren 1986), an agglomerative clustering technique. Clusters were accepted if they met a homogeneity > 0.4. The homogeneity of a cluster was defined as the average resemblance of its members (based on the Sorensen similarity ratio) to its centroid. The resulting clusters were further examined by comparing taxon composition and environmental variables of the sites within a given cluster. Based on biotic and abiotic similarities, in some exceptional cases clusters were divided or fused and/or sites were assigned to other clusters or set apart. The clustering finally resulted in macroinvertebrate-site clusters.

Step 3. The sites were ordinated by detrended canonical correspondence analysis (DCCA), using the program CANOCO (Ter Braak 1987). DCCA is an integration of regression and ordination and shows the response of taxa and sites to environmental variables (Jongman et al. 1987). Detrending by fourth-order polynomials was used. These techniques are fully explained by Ter Braak & Verdonschot (1995).

Step 4. Both the results of clustering (step 2) and (re-)ordination (step 3) were combined in ordination diagrams and used to establish site groups. The macroinvertebrate-site clusters were projected on to the DCCA ordination diagrams of the first two axes and sites that caused an overlap of clusters within a diagram were further examined and either assigned to the most similar cluster (> 50% identical taxa and all values within the range of the cluster) or set apart. Such a site group (so-called cenotype) is established if it was clearly recognisable along an identified environmental gradient and had of a distinct macroinvertebrate fauna.

Step 5. Two techniques were used to select the environmental variables with the highest explanatory power. In using the option “forward selection” of CANOCO (version 3.0), the program indicates how well each individual environmental variable “explains” the variation in the species data. The significance of the contribution of the variable was tested by a Monte Carlo permutation test. This selection is stopped at $P < 0.10$. Additional explanatory environmental variables were selected on the basis of the inter-set correlation (correlation > 0.3) with the axes, i.e. the correlation between a variable and an ordination axis.

Step 6. When groups of sites (cenotypes) were identified along environmental gradients the groups were deleted from the dataset and the remaining data were subsequently ordinated again (so-called re-ordination). In this way, the impact of the originally observed variable(s) was greatly reduced (Peet 1980). After five ordinations all sites were assigned to distinctive groups. The combination of steps 2, 3 and 4 indicate the iterative nature of the analysis.

Macroinvertebrate modelling

Several arguments were posed already that plea for the use of groups instead of individual taxa. Grouping is necessary for understanding, describing and explaining the enormous diversity of the mixed species populations (du Rietz 1965), is helpful in comparing waters (Pennak 1971), and is of practical value, especially with respect to water management (Hawkes 1975). Furthermore, groups in the sense of taxa assemblages or communities and their environment can be seen as integrators of the condition of a water, and as biological samples often only sample part of the community present, these groups are robust indicators in comparison to individual taxa or sites.

Multinomial logistic regression is a well-established technique and is a direct extension of ordinary logistic regression which itself is a special case of a generalised linear model (Lek et al. 2005). Multinomial logistic regression directly models the probabilities of occurrence of cenotypes (groups of sites with a comparable macroinvertebrate assemblage) as a function of the environmental variables. The EKOO-data included 70 environmental variables, which sometimes were strongly correlated. Using all variables in the model would yield unstable estimates of the regression coefficients and thus poor predictions. A first a-priori reduction took place during the (re-)ordination steps. Only those variables that appeared explanatory in the (re-)ordination were included in the modeling. Still, every environmental variable included in a multinomial logistic regression is associated with a large number of other variables. This makes assessment of the need to include an environmental variable in the model cumbersome, because a variable can be important to distinguish between some cenotypes, but not important to discriminate between other cenotypes. Such a variable is easily overlooked in a variable selection process. In group-wise hierarchical modelling separate regression models are fitted between and within hierarchical groups. Group-wise hierarchical modelling tries to both reduce the number of variables and to aid in the variable selection of those variables that specifically distinguish between a small number of cenotypes. Group-wise hierarchical modelling assumes that the effect of certain environmental variables is more or less the same for groups of cenotypes. Instead of estimating this effect for every individual cenotype, it is estimated for groups of cenotypes. In this way a reduction of the number of estimated variables is accomplished. Therefore, the 40 cenotypes were first aggregated into 12 groups, in such a way that cenotypes within a group were biologically comparable. The 12 groups were further aggregated into 4 classes, such that groups within a class were similar. Next, separate multinomial logistic models were fitted to each level of the hierarchical classification. So the first model, which is at the highest

level of the hierarchy, used all the data to build a multinomial logistic regression model to distinguish between the 4 classes. At the second level of the hierarchy, 4 regression models were constructed, one for each class to discriminate between groups within that class. Only part of the data specific to that class was used. Finally, at the lowest level of the hierarchy models were fitted to distinguish between cenotypes within each group. Note that each of these models only had a limited number of variables because of the small number of classes, the small number of groups within a class, and the small number of cenotypes within a group.
Because the number of variables is relatively small, an iterative variant of all possible regression was used to select environmental variables for each of the models. Since the number of potential environmental variables was still large, the variables were arbitrarily split into groups of 8 to 12 variables. Within each variable group the best variables were selected and these were combined in a new model selection step, which yielded a few best variables. With these few variables fixed in the model, the remaining variables were again subdivided into groups and the next iteration started. This eventually resulted in some candidate models. The predictive power of the multinomial logistic regression model was assessed, by comparing the observed indicator parameters with the predicted probabilities. Re-substitution, i.e. using the same data to fit the model and to calculate the predicted probabilities, is generally too optimistic about predictive power. Therefore, cross validation was used to assess the predictive power. In the first cross validation step the first observation was temporarily deleted from the data, called leave-one-out, and the model is fitted to the remaining data. Next, this model was used to calculate cross validation predictions for the first observation. In the same way cross validation predictions are obtained for all observations, by subsequently removing one observation from the data. The mean cross validation probability of predicting the correct cenotype was then used as a criterion for choosing among the candidate models. The cross validations of classes (73-77% correct with 66-72% deviance explained) and groups (61-73% correct with 74-83% deviance explained) were generally good while those of cenotypes fluctuated more (46-52% correct wit 71-74% deviance explained).
Finally, for the MLR-EKOO model the variables listed in Table 2 were selected. These variables are needed as input to perform predictions.

Predictions

Climate

The Dutch National Research Programme commissioned the Hadley Centre for Climate Prediction and Research to provide them with a climate scenario for the European weather in the period 1980-2100 (Viner & Hulme 1998, Verweij & Viner 2001). This scenario was generated by Hadley's General Circulation Model (GCM). We used the predicted data for 2070-2100 as these data provide the most extreme case.
As climate is not a fixed parameter, climate variation was included in the analysis by using 6 different scenarios. With this approach justice is done to the uncertainties with respect to future conditions, and as I did not strive for real predictions but performed analyses in a 'what-if' manner.
Six climate scenarios were used (Table 3). The first two scenarios represent the current climate conditions (CurRa, CurVe). The four future scenarios comprised the variations derived from the Hadley Centre scenario (Had, HadPr, HadEv, HadPrEv). The grid cell

of the Hadley GCM chosen (Eastern Longitude between 5.625° to 9.375°, Northern Latitude between 51.25° to 53.75°) has its centre in the Vecht catchment and the most western boundary crosses the mouth of the river Vecht. The Hadley weather variables used were daily values of precipitation (mm d^{-1}), temperature (°C), relative humidity (%), and total downward surface short-wave flux (W m^{-2} d^{-1}). As the Hadley data for the current weather conditions deviate from the measured ones, the Hadley weather series were adjusted as indicated in Table 3 (Van Walsum et al. 2001).

Hydrology
To predicting the effects involving climate interactions in streams, a regional hydrologic model of the comprehensive type was selected. Comprehensive models have the advantage that they describe all aspects of the regional system in great detail. However, the disadvantage is that they are computationally very intensive and allow only the simulation of short time periods. As we defined 'climate' for a period of 30 years (2070-2100) it was of importance that long periods would be simulated. A period of 30 years is used to reflect the long term average of a more or less dynamic process weather dependent discharge events. Furthermore, such a data series would allow statistics of events with a recurrence interval of 5 years. Therefore, the model SIMGRO (Veldhuizen et al. 1998) was used as this model covers all relevant aspects of the regional hydrologic system in a manner that allows the simulation of long time periods, even for our mid-sized drainage basin. This has been achieved by setting integration above detail in the model conception. SIMGRO also has specific options suitable for describing the special aspects of lowland hydrology. SIMGRO virtually sections streams in discrete units as a kind of gutter compartments. For a comprehensive description of the model the reader is referred to Veldhuizen et al. (1998).
The application covered for our approach a 'model region' of about 8800 ha with 423 nodes representing the individual streams and stream sections. After calibration SIMGRO was fed with the climate scenarios and computed discharge statistics on average daily basis for the period 2070-2100 per scenario
For scenario evaluation these discharge statistics were further elaborated to quantify the variability in discharge, with special attention for extremes at the low and high end of the discharge spectrum. In a natural lowland stream the retention capacity of the catchment is capable of 'absorbing' the rain water deposition and afterwards releasing this water slowly to the stream. Thus a natural stream will show a stable discharge pattern without high peaks or low drops in discharge. With this rationale on natural discharge regime, discharge dynamics were summarised in the so-called discharge dynamics index (DDI):

$$DDI = [\text{sum} (Ri * si)] [\text{sum} (Ri)]^{-1}$$

si : indicative weight per discharge dynamic class (i=1…6)
Ri : total number of scores in the repective discharge dynamics class R

The index runs from class 1 for a very constantly discharging stream towards class 6 for a very dynamic stream (Table 4) at both low and high exceedance frequencies. The lower and upper bounds of both ranges of classes are defined in terms of a factor times the median discharge (Q_{50}). For example, the high exceedance class O3 is graphically illustrated in Figure 2. O3 is the percentage of discharges in the interval:

$4 * Q50 < Q < 8 * Q50$ (interval O3)

The index represents the rate in discharge dynamics indicated by continuously measured discharge data over one (hydrological) year period in a stream.

The DDI's were next calculated for each of the climate scenarios at each of the 423 points in the respective streams in the catchment. Next the index scores were compared to the current situation and summarised.

Macroinvertebrates

The group-wise hierarchical model was used to predict the probability of occurrence of classes, of groups within classes, and of cenotypes within groups. These probabilities were multiplied to obtain the probability of occurrence of cenotypes. Therefore, the environmental data of 189 samples (26 site) taken by the waterboard 'Regge & Dinkel' over the period 1980-1991 in the Dinkel subcatchment were used. The samples were taken using the same methods as described for the EKOO-data. This dataset is representative for the Vecht catchment and covers small upper courses up to the river Dinkel. For validation purposes, identical to the EKOO-data clustering and ordination techniques were applied to these Dinkel-data.

The environmental data, made available by the waterboard 'Regge & Dinkel', were used as model input with only the discharge scenario results as changing parameter. To calculate the future effect of changed discharge on the stream macroinvertebrate assemblages both current velocity and depth were adapted to the predicted discharge according to the velocity-area method, in formula $Q = w * [d * v]$ (Gordon et al. 2004). As changes, especially lowered discharges, mainly change current velocity and depth, only these parameters were changed with the same factor as was done in the macroinvertebrate assemblage predictions.

Results

Past and current developments

Climate

Minimum, average and maximum temperature all showed a positive, significant (ANOVA, F = 0.000) trend over the period from 1901 to 2003 (Figure 3). The slope of the trend line in the maximum temperature is much lower than those for the average and minimum temperature. Still all three slopes showed a positive tendency. The number of days with a daily minimum temperature <10^{o}C and those with a daily maximum temperature >30^{o}C did not show a significant trend (not shown), though both were going up. Precipitation also showed a positive, significant (ANOVA, P = 0.000) trend over the last hundred years. Based on these data the precipitation will increase over the next 100 years with about 8.6 (s.e. 5.0) mm per year (Figure 4). Also the duration of precipitation is significantly (ANOVA, P = 0.000) increasing, with on average 0.7 (s.e. 0.001) hours per year (not shown).

Land-use

Three major land-use changes took place over the last 100 years in the Vecht catchment. In all subcatchments, the area of heather and moorland peat decreased dramatically as the agricultural, urban and other uses increased (Figure 5). The percentage of forest remained about the same over the whole period. Especially, the Dinkel subcatchment (about 22%) had a high percentage of forest. The urban area was somewhat lower in the Drenthe subcatchment in comparison to the others. Urban areas are limited in the whole Vecht catchment but increased considerable during the last period. The land-use in the floodplains was and is mainly grassland, except the floodplain of the river Dinkel that is partly covered by forest. For the other three subcatchments, the percentage of maize fields increased strongly in the floodplains during the last forty years.

Hydrology

Based on the data available discharge patterns did not change much, except for both the river Regge and Beneden Dinkel that showed a lowered discharge in the seventies due to a sequence of warmer and drier years (Figure 6). For the river Regge the discharge off the fifties and sixties is quite comparable with that of the nineties.

Morphology

In general, the morphological features of the streams in the Vecht catchment showed a degradation over the last century (Figure 7). Note that the streams in the Regge East catchment were already straightened at the beginning of the twentieth century (not included in the table). The total stream length was shortened by about 20% (only the river Dinkel is still slightly meandering), while the valley length remained about the same. Forty percent of the connected side-arms got lost and the number of oxbows increased in the thirties due to straightening of the major streams but decreased until today with about 38%.

Sinuosity decreased over the last 100 years, except for the streams in the subcatchment Dinkel (Figure 8). In general, most streams were meandering around 1900, except the river Vecht and the stream Radewijkerbeek, both were already regulated before 1900. In the thirties and sixties some streams were still slightly meandering and currently most are straight.

In the subcatchments of Drenthe, Regge West, Regge East, and Dinkel only a few weirs were present around 1900 (Figure 9). Today most streams are regulated by weirs, except again some of the streams in the subcatchment Dinkel.

Little is documented on transversal profile in the past. The river Dinkel (upper part) was widened in 1975 and its profile was documented over 20 years (Doctor 1998). After widening (from 14 to 17 m^2), the profile through erosion and sedimentation slowly decreased again to 16 m^2. The downstream part of the river Regge was documented before straightening in between 1920 and 1930. In 1920 the wet profile (cross-sectional area) was 28.8 m^2, and in 1930 66 m^2, the latter is about the same as today.

Macroinvertebrate assemblages (cenotypes)

In total, five (re-)ordinations were necessary to analyse the entire dataset. Partial results of these analyses were published by Verdonschot & Schot (1987) and Verdonschot (1992a, b, c, 1995). All five ordinations were tested. The first four appeared significant at the 1% level. The fifth run was only significant at the 9 % level. By using direct gradient analysis the environmental factors were related to the site groups in two-dimensional space. Four major key factors, “stream character”, acidity, duration of drought, and

dimensions, represent the environmental gradients that run through the whole EKOO-dataset. Additional significant environmental relations between the cenotypes were extracted from the environmental characterisation of the cenotypes. In total, 42 cenotypes were described. The graphical result of the first DCCA run, axes 1 and 2, is used as a basis to illustrate the mutual relationships between the cenotypes (Figure 10). The diagram provides a web, i.e. an integrated description of the cenotypes (based on taxon composition and abundances) versus environmental factors representing major ecological processes. The contour line indicates the variation in faunal composition and environmental conditions present between the sites. All sites together form a continuum, but the macroinvertebrate site groups are represented as the centroids of the cenotypes (circles with codes) arranged along environmental gradients. Four major key factors, "stream character", acidity, duration of drought, and dimensions, represent the environmental gradients that run through the whole diagram (see inset, Figure 10). Additional significant environmental relations between the cenotypes have also been extracted from the environmental characterisation of the cenotypes (for further information see Verdonschot 1990). The spatial configuration of cenotypes in Figure 10 more or less corresponds to their ecological similarity. The two most aberrant cenotypes consist of only one, extremely organically polluted site, which is reflected in the absence of almost all taxa. The next most dissimilar cenotypes were helocrene springs and small streams (spring streams and small upper courses; types coded h3, s1 and s4 in Table 5). They represent an environment inhabited by a characteristic macroinvertebrate fauna, clearly distinct from that of the other water types. All these sites were situated on the steepest slopes of ice-pushed hill ridges. The cenotypes coded s5 to s13, and r9 and r3 in Table 5, represent larger running waters (middle reaches of streams to rivers). The remaining cenotypes can be separated into temporary versus permanent, and running versus stagnant types. The polysaprobic upper and middle reaches of streams, such as s5, appear to be similar to temporary upper reaches (i.e. d8). Both desiccation and extreme organic enrichment have, to a certain extent, a corresponding effect upon the fauna. The similarity between middle and lower reaches of regulated streams, small rivers, ditches and medium sized, more or less stagnant waters (like r1), is due to the impoverishment of the macroinvertebrate fauna due to human-induced environmental disturbance.
Macroinvertebrate samples taken by the waterboard 'Regge & Dinkel' describe the past subcatchment Dinkel situation. Clustering and ordination revealed 10 groups of samples which are plotted in the ordination diagram (Figure 11). These groups were separated due to differences in naturalness in length and transversal profile as well as due to differences in nitrogen (saprobic condition) and phosphorus (trophic condition) contents. Also stream type and intermittency played a role in the grouping (Table 6).

Predictions

Climate

The future climate will become somewhat warmer. The average temperature rise ranges from 9.1-9.9°C currently to 11.9-12.6°C in the period 2070-2100 (Van Walsum et al. 2001), the relative humidity will lower only slightly from 82-88% to 80-86%, and the shortwave flux will increase from 113-114 to 118-120 W m^{-2} d^{-1}.

Comparison of the precipitation means showed that the Hadley series for 2070-2100 was only slightly different from that for the current conditions: winter precipitation was the same, and the summer precipitation reduced by 7%. Also the frequency distributions did not show significant changes (not shown). The adjustment of the precipitation data took seasonal differences between summer and winter into account, because of hydrological and ecological importance. The average, summer and winter precipitation (mm yr^{-1}) changed from 746-794, 377-403 and 343-417, respectively in 1984-1998, to 771-877, 349-389 and 422-488 respectively in 2070-2100, taking both evapotranspiration and changed precipitation into account. The predicted four future climate scenarios were taken as the input for the future hydrology.

Hydrology

With the climate predictions of the period 2070-2100 applied in the hydrological catchment model SIMGRO a change in hydrological extremes can be seen (Figure 12). Each of the Hadley scenarios was compared to the 'current situation for the Vecht catchment' (CurVe) scenario. It appears that the peak discharges of streams are sensitive to precipitation. All Hadley scenarios showed that the investigated streams reach almost 3-5% times more often the high exceedance discharge classes of 3 or higher. Thus all scenarios show a regime shift. But overall the increase of precipitation is smoothened by about a factor three in the peak discharges. The underlying cause of this reaction to increased winter precipitation is the buffer capacity of the areas along the stream-valley bottoms.

In the relative difference of the current situation versus the scenarios HadEv and HadPrEv the possible effects of reduced evapotranspiration was investigated. This reduction of crop evapotranspiration will take place as a consequence of increased CO2-content in the atmosphere. The reduction of evapotranspiration investigated in scenarios HadEv and HadPrEv showed a reduction of high exceedance discharges caused by the lowering of ground water tables at the end of summer, meaning that the build-up of high ground water tables and thus higher discharge events during the winter period is somewhat reduced. Still, overall the high exceedance discharge classes of 3 or higher occur more often. On the other extreme, drought events increase with about 6.5% and the low exceedance classes of 0.5 times base flow and lower also will occur more often. Again this is due to the changes in precipitation intensity (more concentrated in the future) and the longer droughts periods, especially in the Hadley scenario and the Hadley of solely reduced evapotranspiration scenario (HadEv) (Figure 12).

Macroinvertebrate assemblages

Four scenarios were applied with the MLR-EKOO prediction model (Figure 13). The models chosen focussed to the effects of low exceedances of base flow. Low flow conditions were selected because we expected that these conditions would most strongly affect the macroinvertebrates assemblages. The most important classes were the low exceedance class R3 (0.5 times median flow) and the more extreme low exceedance class R6 (0.0625 times median flow). These two conditions will more often occur as was shown by the discharge predictions for the period 2070 to 2100. In the first and the third scenario only the current velocity was lowered by 0.5 (scenario 1) and 0.0625 (scenario 3), respectively. In the second and fourth scenario also depth was lowered. To reach the

same discharge lowering both current velocity and depth were equally reduced by a factor 0.707 (scenario 2) and 0.25 (scenario 4), respectively.
In total, thirteen macroinvertebrates assemblages in terms of cenotypes were predicted for the current situation (Table 5, column 3).
These groups were compared to the results of the assignment to the cenotypes. In the different scenarios six cenotypes did not change in number of samples assigned to. In all four scenarios, both cenotypes s4 and s5 showed an increase in number of samples assigned to while the cenotypes s6 and s7 decreased in numbers. This distribution of samples is more pronounced going from scenario 1 to scenario 4. The changes in other cenotypes are only related to one or two sampled differently assigned and do not add much to future changes to be expected. In conclusion, low exceedance events resulted in macroinvertebrate assemblages that formerly could be characterised as occurring in a-mesosaprobic, half-natural and canalised middle courses to assemblages more often found in temporary, β-mesosaprobic, natural upper courses and polysaprobic, natural and canalised upper- and middle courses. As intermittency always results in assemblages more characteristic for organically richer environments (Verdonschot 1990) and low flow conditions more resemble smaller stream stretches (Vannote et al. 1980), the predictions show that climate change really will affect stream communities.

Discussion and conclusions

Large parts of the Vecht catchment were hydromorphologically changed over three periods in the last hundred years. The first two periods 1895-1905 and 1925-1935 mark the majority of changes. A third period, between 1960 and 1980, completed the hydromorphological deterioration by deepening and widening of a large number of smaller streams. Along with these changes also land-use changed. The area of heather and moorland peat decreased dramatically as the agricultural, urban and other uses increased. The percentage of forest remained the same over the whole period.
There was a positive trend shown in temperature and precipitation over the last hundred years. Comparing climate change to land-use/hydromorphology changes no relation whatsoever occurred. Societal and agricultural developments had a large impact on our environment as was seen all over Europe (Kristensen & Hansen 1994) strongly over-dominating other slight changes, like the climate one. And moreover most changes took place in the first decennia of the 20th century.
In general, discharge did not change much over the last 30 years and followed the meteorological (climatological) developments. Macroinvertebrates were also only known from the last decades. Their composition reflected the macroinvertebrate composition of many agricultural lowland areas (e.g. Verdonschot 1990 for the same area).
The evaporation and precipitation assumptions in the climate scenarios both showed effects on the results. The reduction of crop evapotranspiration will possibly take place as a consequence of increased CO_2-content in the atmosphere. This reduction added to the computed peak discharges. In the scenario with a 17% increased precipitation the streams reacted with additional peak discharges. It appears that the peak discharges of lowland streams are highly sensitive to precipitation. The cause of this reaction to increased

precipitation is the increase of wet areas (rise in groundwater tables) along the stream-valley bottoms.

Six climate scenarios (two for the current conditions and four for the years 2070-2100) were applied in the hydrological model SIMGRO. Following the predictions using the climate scenarios, discharge will become somewhat more dynamic, especially the low and high exceedance classes 3-6, while the more constant discharge classes decrease. This will affect both stream morphology and stream ecology.

In general, one should clearly define what parameters were taken into consideration in formulating a scenario. Other factors could also change the results, like wind speed but also chemical parameters. An increase in temperature of about 4^{o}C with a higher precipitation and more extreme climate events will result, especially in streams, in an increase in temperature that can cause cold-stenothermic species to disappear (Verdonschot 2006), a lower concentration of dissolved oxygen, a higher de-nitrification rate and thus a lower N-load, and to an increase the internal P loading (Liikanen et al. 2002). Furthermore, it can lead to a reduced snow cover and thus snow melt which will result in a reduction in nutrient leakage towards small streams and thus to a decrease in productivity (Moss et al. 2003). The increase in precipitation, both during summer storms and more intensive winter rainfall, can result in an increase in run-off and transportation of water from the catchment land to the stream. This will increase, especially in the Netherlands with nutrient-rich large rivers and a high nutrient level in the agricultural soils in the catchment, through nutrient leakage in sediment and nutrient loading (Mooij et al. 2005). An increase in precipitation will also result in faster run-off and higher floods in the streams which can lead to more inundations, more in-stream sediment transport, stream erosion, and nutrient loading (Lewis & Grant 1979), but on the other hand will also lead to a reduction in primary production and respiration, particularly in winter (Uehlinger & Naegeli 1998), in reductions in algae, bryophytes, debris dams and associated detritus patches caused by scouring (D'Angelo et al. 1991), an increase in nutrient spiral length and reduction of nutrient uptake (Newbold 1996), and to a decrease in summer precipitation will result in periods of drought which have even a greater effect than floods (Boulton 2003).

A stream community reflects the adjustment of the biota to the natural pattern of hydrologic variation (the local hydrological regime the species are selected against) over long (evolutionary) periods (Meyer et al. 1999). Thus, the ecological response to a change in flow regime depends on how the regime is altered relative to the historical or natural one (Meyer et al. 1999). More dynamic systems, like lowland streams in the temperate zone, balance between favourable and unfavourable environmental conditions through space and time. These shifting conditions offer species with different environmental needs niches to survive and as such sustain higher biodiversity (Resh et al. 1988, Poff et al. 1997).

With the MLR-EKOO model the future macroinvertebrate assemblages were predicted. The low flow conditions result in macroinvertebrate assemblages more often found in temporary, b-mesosaprobic, natural upper courses and polysaprobic, natural and canalised upper- and middle courses. This prediction was used to indicate trends in ecosystem development. Together with the above indicated changes in dissolved oxygen, nutrient runoff and changed temperature conditions the macroinvertebrate assemblages will change even more whereby a decrease in ecological quality seems supported.

Still, this shift between cenotypes is expected to be relatively small compared to the shifts that must have occurred during the major periods of land-use and stream morphology change. Within these periods the more or less natural stream ecosystems present until around the beginning of the nineteen hundreds shifted towards those described in the web of cenotypes. Large numbers of sites were canalised, regulated and polluted causing complete alterations in community compositions. A process that took place all around lowlands in North Western Europe, and most probably took and takes all over the world in urbanised areas. Climate change will induce only a relatively slight quality deterioration. Comparing the major changes in land-use in the past that dramatically affected the stream ecosystems with these predicted small climate change induced changes justifies the conclusion that future land-use change become of much greater importance than the effect of climate change.

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Figure legends

Figure 1. Map of the Vecht catchment.

Figure 2. Graphical illustration of the discharge extremity class O_3. O_3 is the percentage of discharges between 4 and 8 times the median discharge Q_{50}.

Figure 3. The minimum, average and maximum temperature from 1901 to 2003, expressed as 5-years averages.

Figure 4. The daily average precipitation (mm) measured over the period 1901 to 2003, expressed as 5 years averages.

Figure 5. Percentage of land-use in the Dutch part of the river Vecht catchment in four time periods over the last 100 years.

Figure 6. Discharge (moving 5-years average of daily discharge) pattern of different stream types in the Vecht catchment.

Figure 7. General morphological features of the Vecht catchment and its subcatchments.

Figure 8. Trend in the average sinuosity of some selected streams per subcatchment taken at four periods over the last 100 years.

Figure 9. The number of weirs in selected streams from the subcatchments.

Figure 10. The web of cenotypes. The contour line describes the total variation present in all site scores. The centroid of each cenotype is indicated by a code (for the for this study relevant codes see Table 5). The arrows between cenotypes indicate the most important environmental relations. The inset represents the four most important environmental gradients (key factors) in the total dataset.

Figure 11. DCCA ordination diagram of the axes 1 and 2. Ten groups of samples are indicated by contour lines. Explanatory environmental variables are shown as arrows.

Figure 12. Relative differences in discharge exceedance events for the period 2070 to 2100 compared to the current climate (CurVc). The differences in average (%) of daily discharge exceedance classes was calculated for 423 stream sections in the subcatchment of the Vecht: Hollander Graven. (scenario codes are explained in the text).

Figure 13. Relative changes (%) in macroinvertebrate assemblages under four low flow scenarios based on the hydrological predictions for the period 2070 to 2100. For interpretation of the cenotype codes (horizontal axis see Table 10).

Table 1. Availability of discharge data.

		Discharge data	
		from year	**until year**
Vecht	river	1970	1998
Regge (downstream)	smaller river	1957	2003
Regge (upstream)	lower course	1974/1990	1983/2003
Dinkel (downstream)	small river	1976	2003
Dinkel (upstream)	lower course	1980	2003
Radewijkerbeek	middle course	1980	1993
Springendalse beek	upper course	1993	2003

Table 2. MLR-EKOO input parameters.

Parameter	**Unit**
total phosphate	mgP l^{-1}
nitrate	mgN l^{-1}
ammonium	mgN l^{-1}
oxygen content	mg l^{-1}
width	m
depth	m
current velocity	m s^{-1}
slope	m km^{-1}
pH	-
conductivity	µS m^{-1}
intermittency	nominal
peat bottom	nominal
cover % floating vegetation	%
cover % submersed vegetation	%
cover % total vegetation	%
not line shaped, profile shape regular	nominal
not line shaped, profile shape irregular	nominal
irregular line shape	nominal
regular line shape	nominal
calcium	mg l^{-1}
chloride	mg l^{-1}
profile shape regular	nominal
profile shape irregular	nominal

Table 3. The six climate scenarios.

Scenario	**Climate conditions**	**Based on**
CurRa	current	averaged regional data of six stations distributed over The Netherlands for the years 1984-1998
CurVe	current	data from the one station in the Vecht catchment (weather station 'Losser') over the years 1970 to 2000
Had	future	downscaled and calibrated Hadley scenario for 2070-2100
HadEv	future	change of crop evapotranspiration factor as a reduction of 10% for grassland and of 36% for arable land crops due to the rising CO_2-concentration (Schlesinger & Mitchell 1987, Haasnoot et al. 1999)
HadPr	future	a long-term average increase of 1% of the mean summer and of 6% of the mean winter precipitation per degree Celsius temperature rise (Können et

		al. 1997)
HadEvPr	future	both reduced evapotranspiration (HadEv) and adjusted precipitation (HadPr)

Table 4. Discharge extremity classes for evaluating the variability of the discharge. The lower and upper bounds are defined in terms of a factor times the median discharge Q50 (m^3 s) (median flow). Per class the percentage of discharges is determined that falls within the interval defined by the lower and upper bounds

Discharge extremity class	**Lower discharge boundary**	**Upper discharge boundary**
O6	16	∞
O5	8	16
O4	4	8
O3	2	4
O2	1.5	2
O1	1	1.5
R1	0.75	1
R2	0.5	0.75
R3	0.25	0.5
R4	0.125	0.25
R5	0.0625	0.125
R6	0	0.0625

Table 5. List of predicted macroinvertebrate assemblages by the four low flow scenarios based on the hydrological predictions for the period 2070 to 2100.

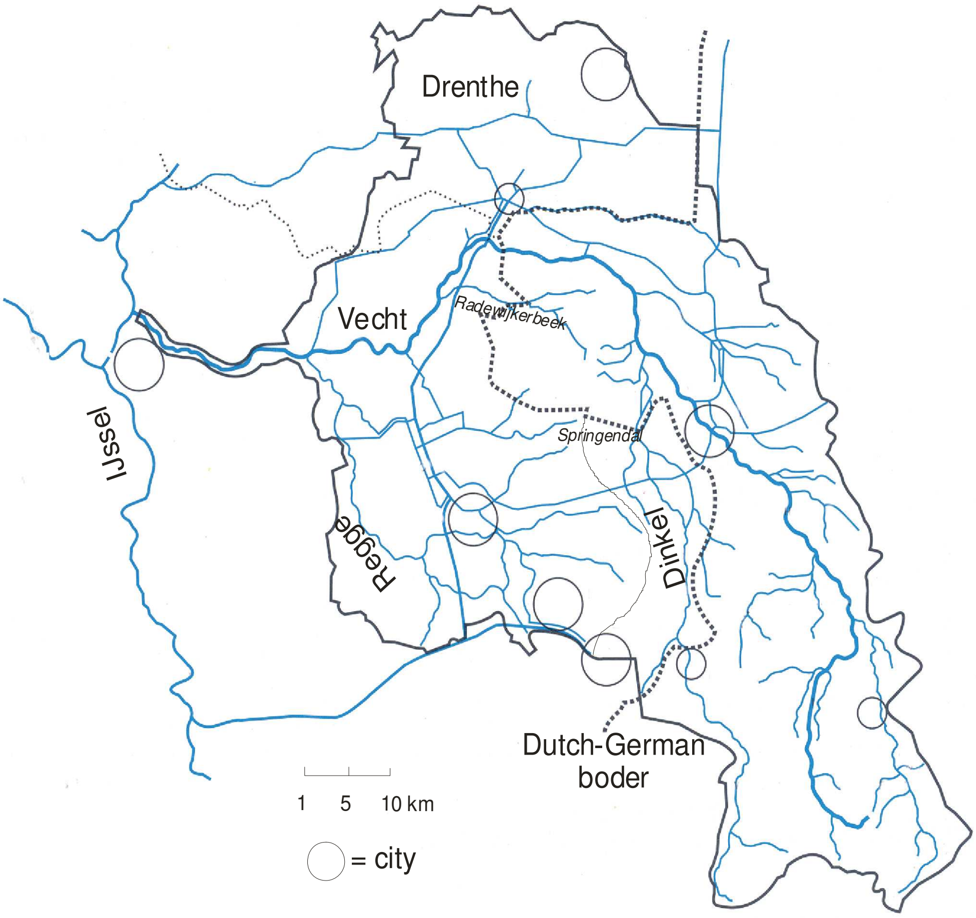
Cenotype code	**Cenotype description**	**Number of samples predicted**
d3	permanent, a-mesosaprobic, shallow ditches and canalised streams	3
d8	temporary, slowly running, a-meso-ionic, a-mesosaprobic, small ditches	4
h3	weakly acid to neutral, oligo- to b-mesosaprobic helocrene springs	1
s1	oligo- to b-mesosaprobic springfed small upper courses	5
s3	temporary, a-mesosaprobic, natural, small upper courses	1
s4	temporary, b-mesosaprobic, natural upper courses	34
s5	polysaprobic, natural and canalised upper- and middle courses	11
s6	half-natural, a-mesosaprobic middle courses	9
s7	a-mesosaprobic, canalised middle courses	15
r1	b- to a-mesosaprobic, very slowly running, canalised lower courses and small rivers	1
r3	a-mesosaprobic, weakly meandering, slowly running, small rivers	1
r4	a-meso-ionic, b- to a-mesosaprobic, slowly running, canalised lower courses and small rivers	4
r9	a-meso-ionic, a-mesosaprobic, slowly running, lower courses and small rivers	100

Table 6. Grouping of the macroinvertebrate samples taken by the waterboard ‘Regge & Dinkel’ in the period 1980-1991 in different streams in the Dinkel subcatchment.

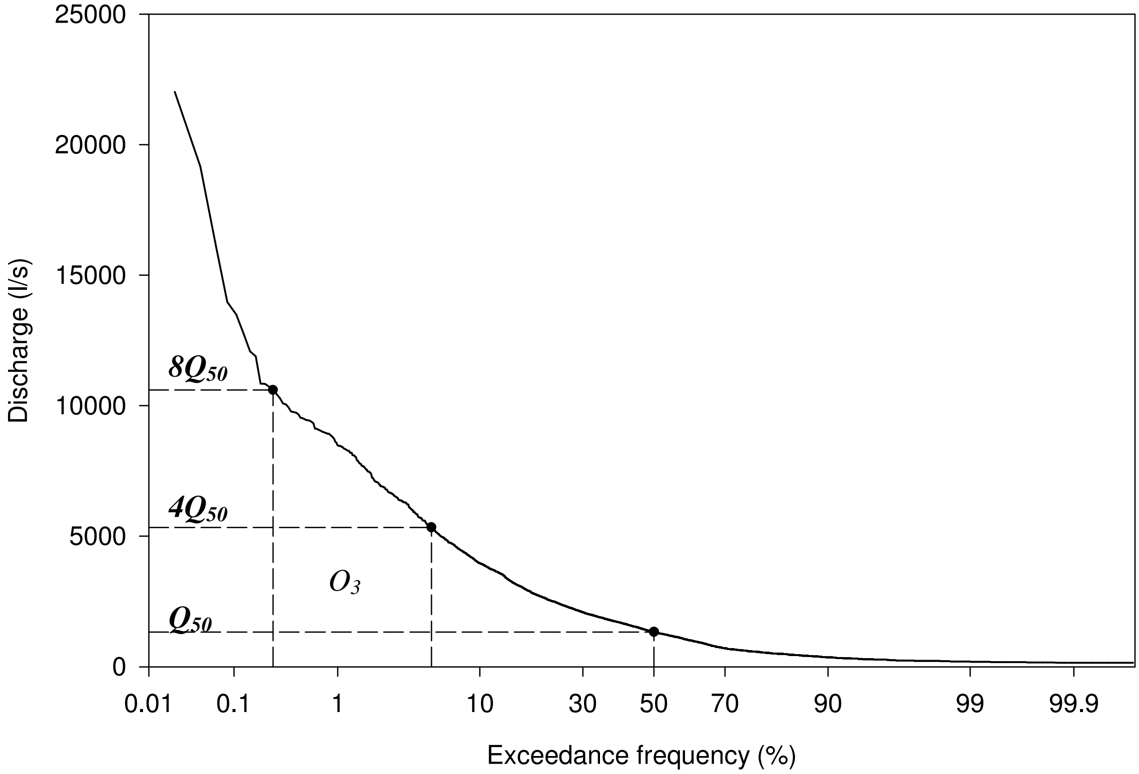
Group number	**Group description**	**Number of samples**

1	b-mesosaprobic, hypertrophic, canalised lower courses (moderate depth)	11
2	b-mesosaprobic, hypertrophic, canalised lower courses/small rivers (deep)	60
3	polysaprobic, hypertrophic, canalised middle/lower courses	13
4	b-mesosaprobic, eutrophic, half-natural middle courses	6
5	a-mesosaprobic, hypertrophic, canalised middle/lower courses (moderate depth)	46
6	b-mesosaprobic, hypertrophic, near-natural upper/middle courses	7
7	b-mesosaprobic, hypertrophic, half-natural upper/middle courses	19
8	a-mesosaprobic, hypertrophic, half-natural upper/middle courses	12
9	a-mesosaprobic, hypertrophic, stagnant, canalised lower courses (deep)	3
10	intermittent, a-mesosaprobic, hypertrophic, half-natural upper/middle courses	8

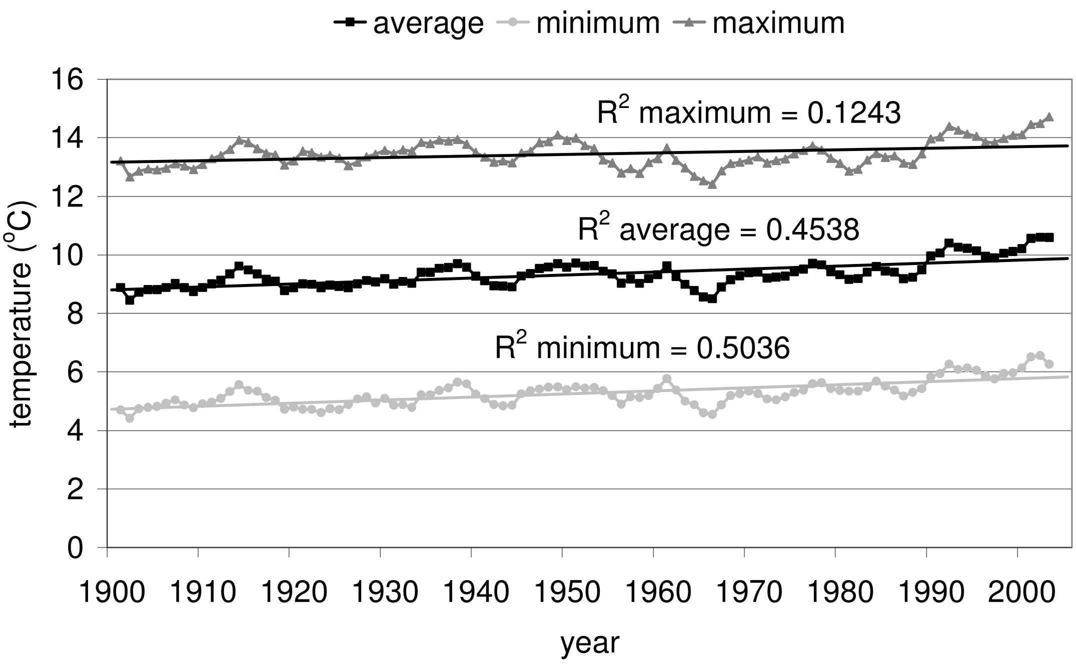
Verdonschot, Figure 1



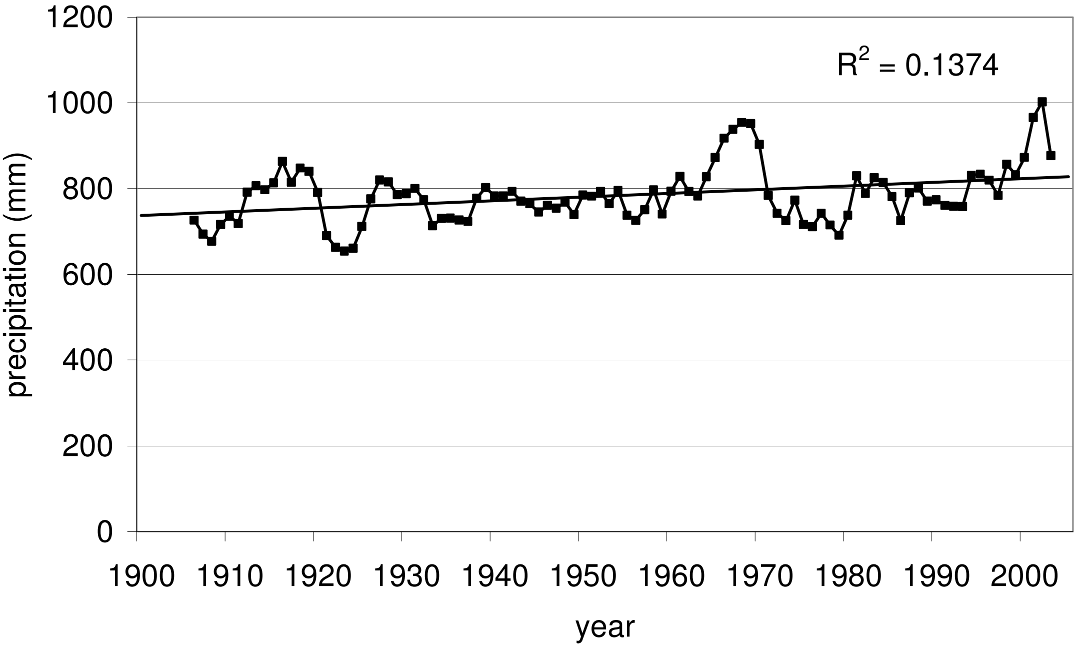
Verdonschot, Figure 2



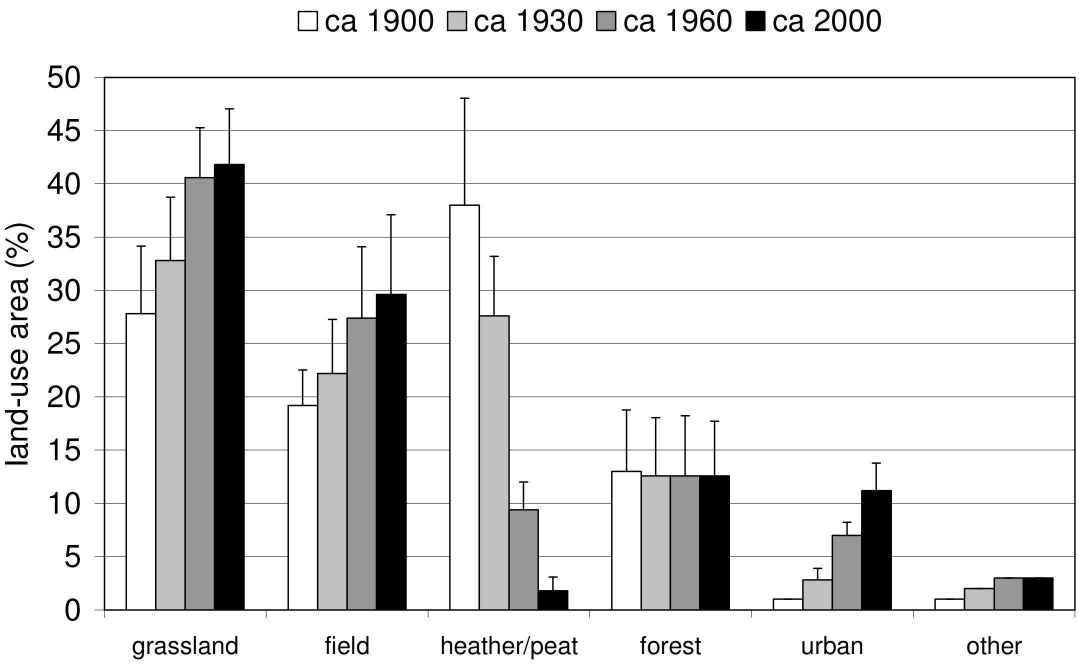
Verdonschot, Figure 3



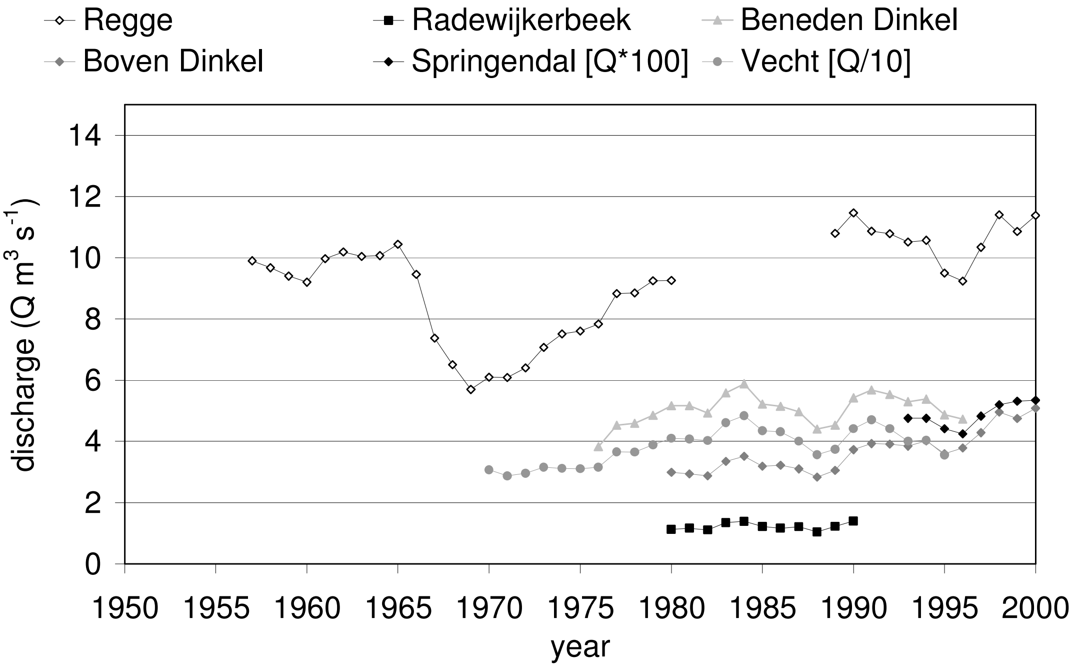
Verdonschot, Figure 4



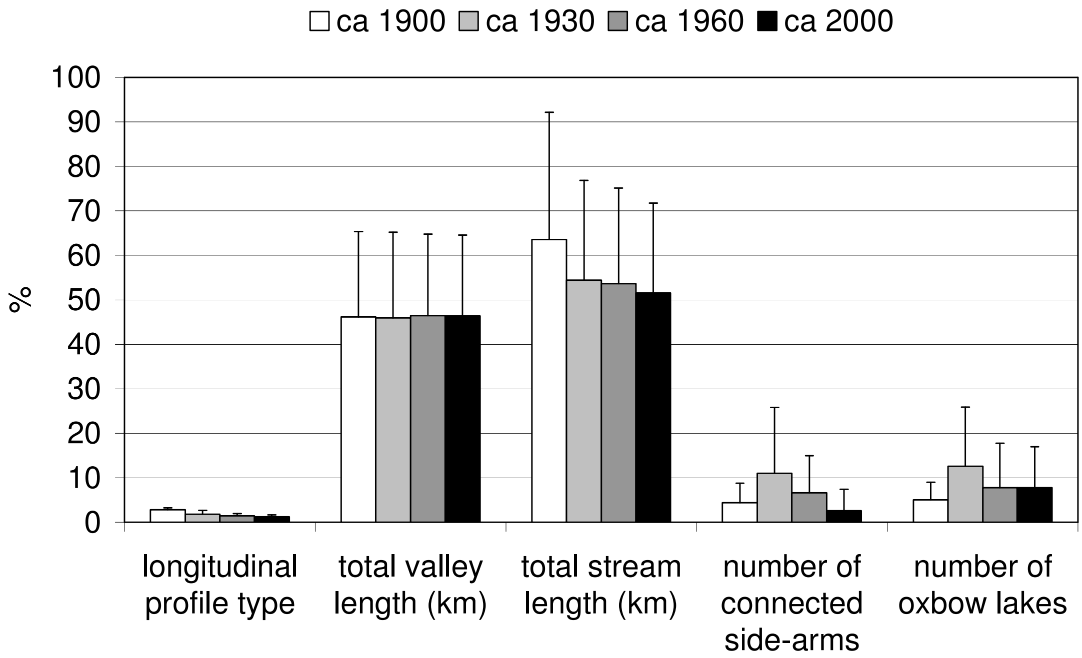
Verdonschot, Figure 5



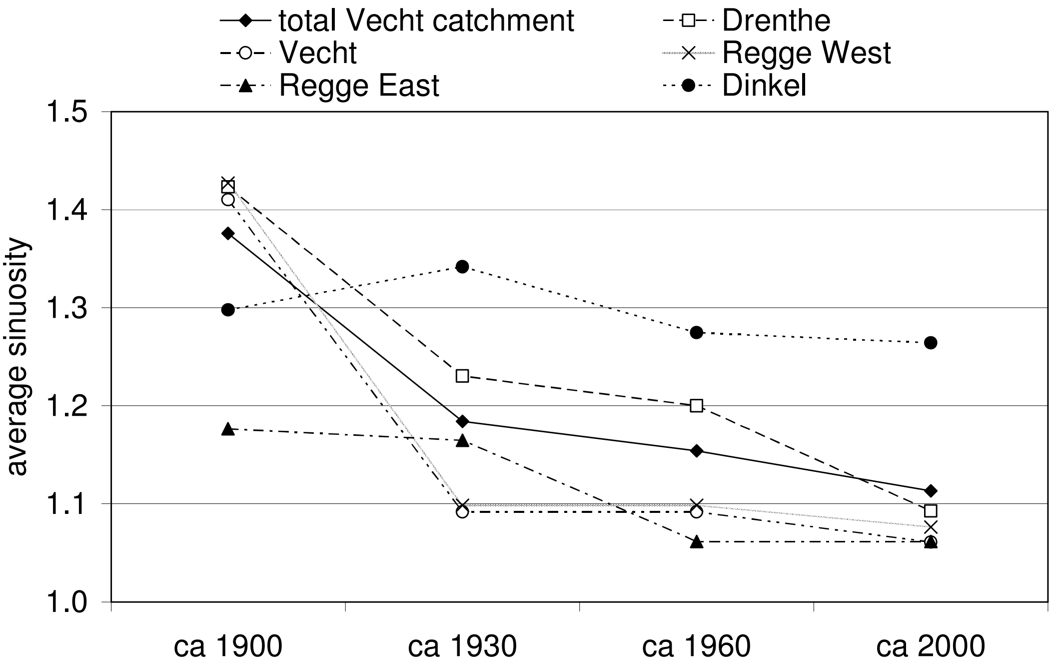
Verdonschot, Figure 6



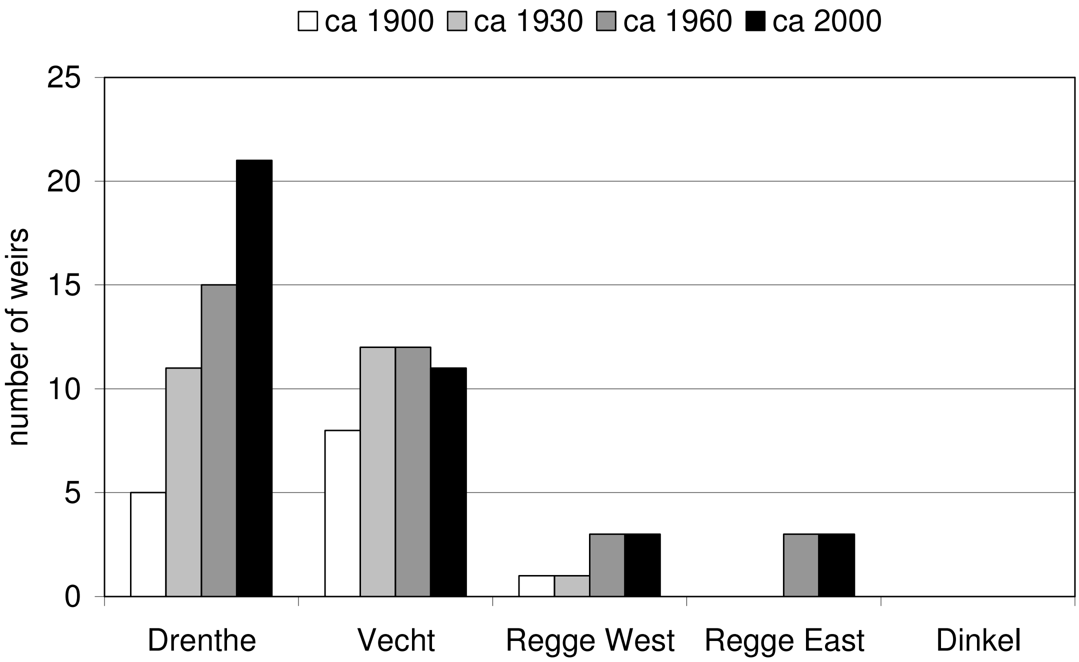
Verdonschot, Figure 7



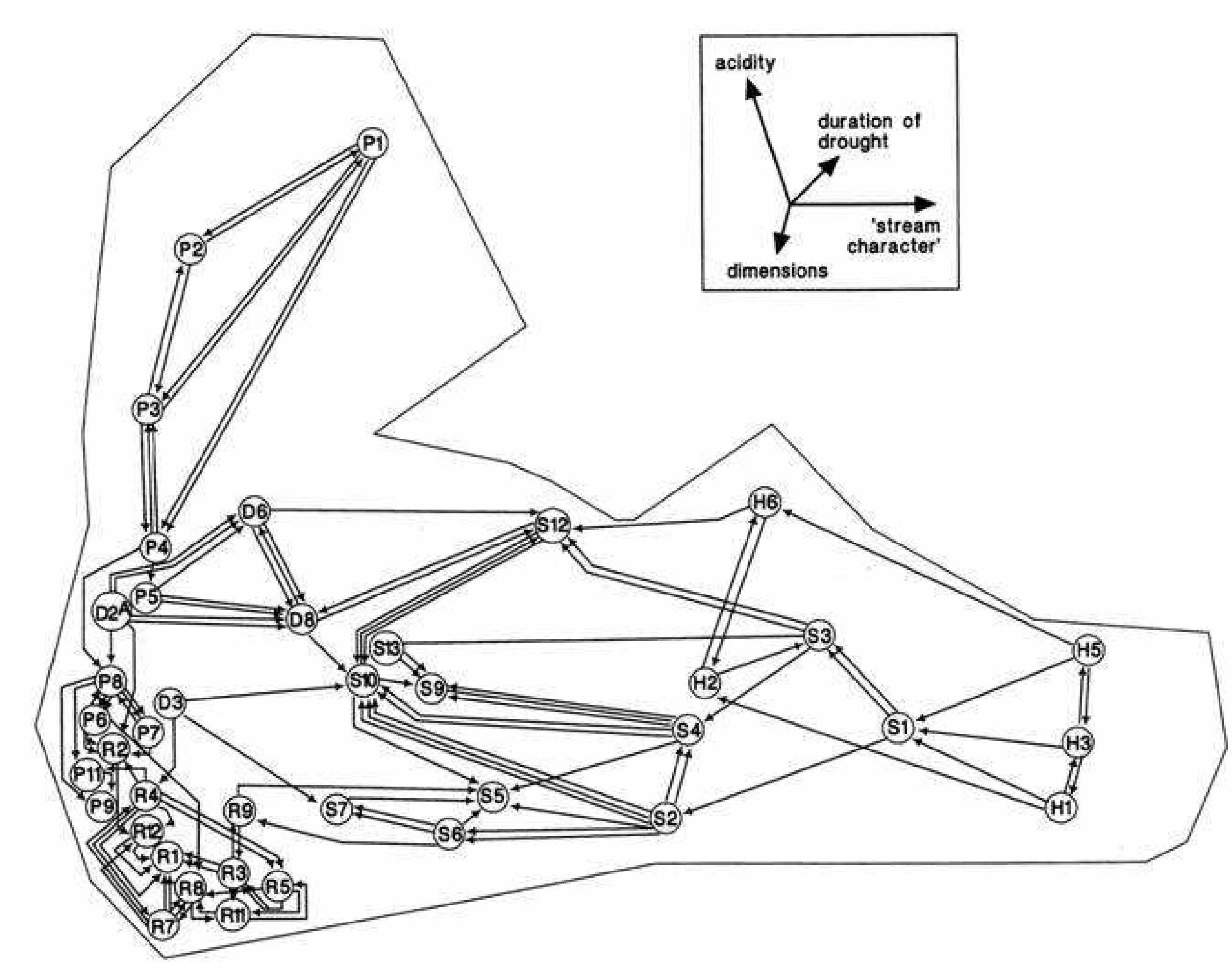
Verdonschot, Figure 8



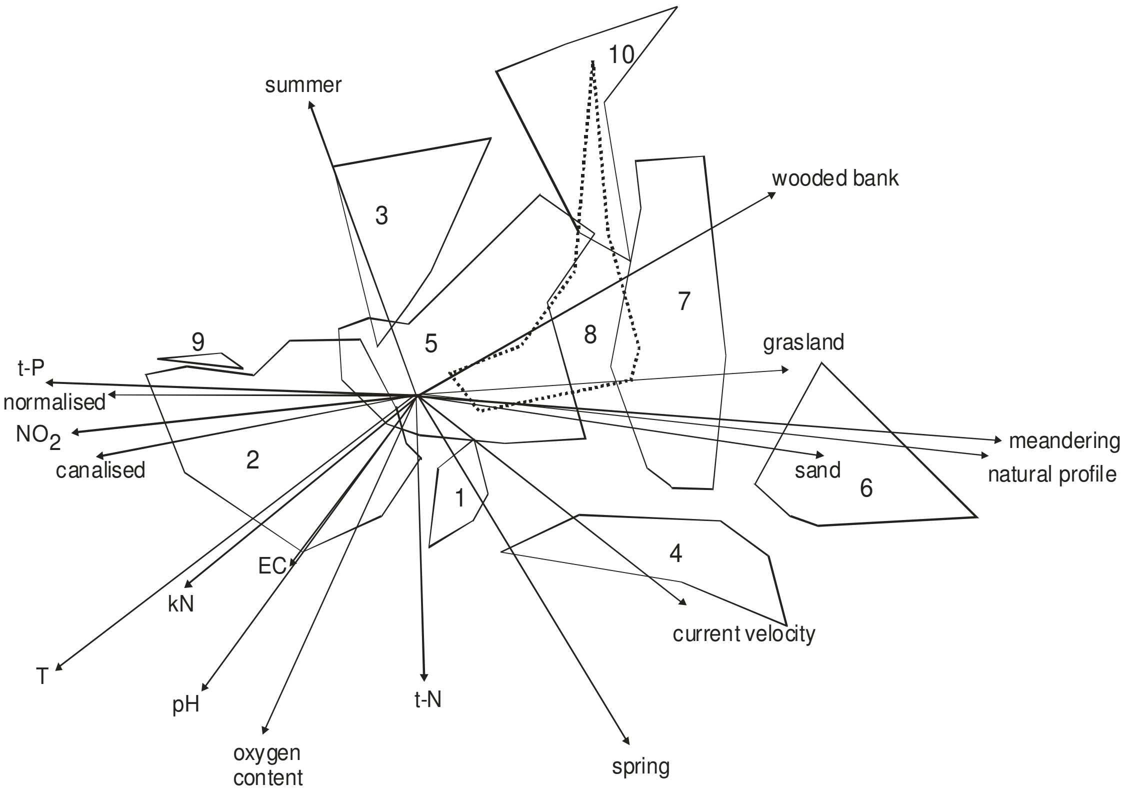
Verdonschot, Figure 9



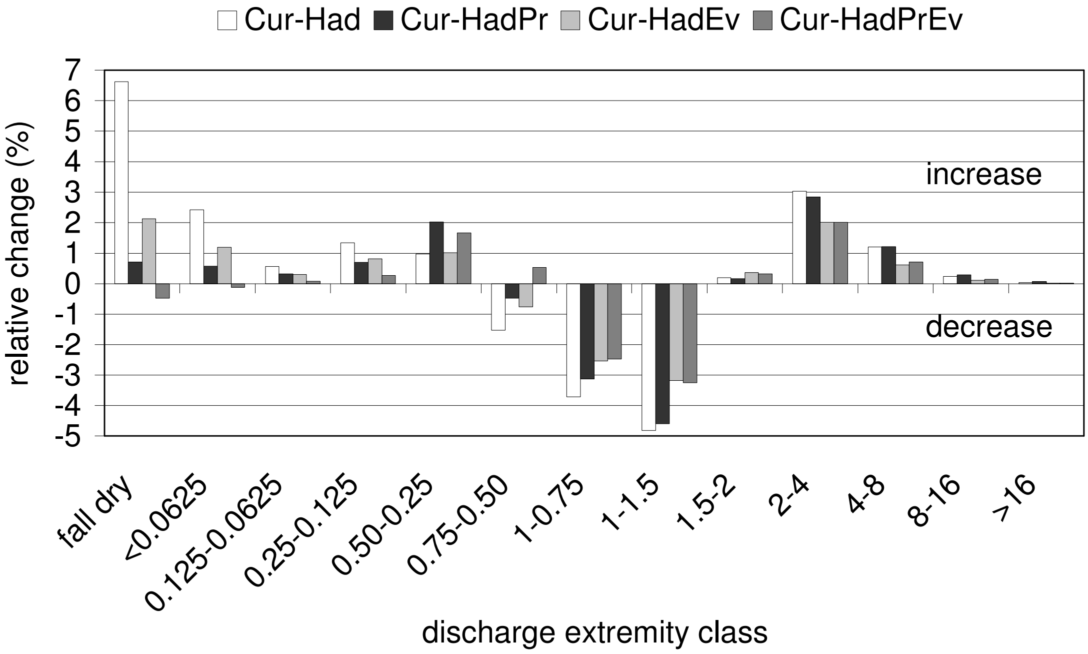
Verdonschot, Figure 10



Verdonschot, Figure 11



Verdonschot, Figure 12



Verdonschot, Figure 13