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The significance of climate change in streams utilised by humans

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With 9 figures and 6 tables

Abstract: 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. Therefore, the catchment of the river Vecht (The Netherlands), representative for many human utilised, medium-sized lowland river catchments in this ecoregion, was chosen as case example. 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. As elsewhere in Europe, the agricultural, urban and other human uses increased and the morphological features of the streams showed degradation over the last 100 years. Most streams were straightened, total stream length was shortened (20 %), many connected side-arms got lost (40 %), and the number of oxbows decreased (38 %). There was a positive trend in temperature and precipitation observed over the last hundred years. But land-use and hydromorphology changes were independent from climate change. Six climate scenarios (two current and four for the years 2070–2100; SIMGRO model) showed that discharge will become somewhat more dynamic. The future low flow conditions predicted (MLR-EK-OO model) macroinvertebrate assemblages that are more often found in temporary, -mesosaprobic, natural upper courses and polysaprobic, natural and canalised upper- and middle courses. This indicates 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 will be of much greater importance than the effect of climate change.

Key words: climate change, land-use, hydromorphology, hydrological scenario, prediction, macroinvertebrate.

Introduction

Climate change effects will occur all around the globe, but it is very much unclear whether the intensity of these effects is significant in comparison to the effects of other 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).

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For Europe as a whole, an increased chance of prolonged heavy precipitation and short intense showers is calculated (KNMI 2006) resulting in floods, as well as dry periods with high air temperatures and high evapotranspiration leading to droughts. Higher precipitation will result in more surface runoff to streams and higher floods in rivers (Poff 1992, George et al. 2004). Furthermore, warmer winters will prevent ice cover and storms will disturb shallow waters.

Under the 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 (Pedersen 2009, Kail et al. 2009). Past developments resulted in the current conditions. Future conditions can only be predicted and thus include a number of assumptions.

To develop a qualitative concept 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. This catchment was selected as it is representative for many human utilised, medium-sized lowland river catchments in this ecoregion, and also because historical and present-day conditions are known. The predictions for the case river Vecht are expected to represent a general pattern and the approaches used can easily be applied to other catchments.

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 effects 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 catchment of the river Vecht (52 17 N, 07 14 E) is situated in the North-West European plain (Fig. 1). The river Vecht has a groundwater-derived baseflow and runs over 167 km from Germany, where it is called the Vechte, crosses the Dutch-German border after 106.7 km, 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. This study focused on the Dutch part of the catchment (Van Dijk et al. 1992, Janssens & Schropp 1993). The river slope is more than 100 m over the entire course, the Dutch part of the river has a slope of less than 10 m over the 60 km it flows through the Netherlands (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 glacial 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 inhabited. 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 transformed into agricultural land or changed to forest. Already around 1350 the first canal was dug and in the 17th and 19th century the river Vecht and several streams in the Regge catchment were used as shipping routes. Furthermore, several canals were dug at that time

The historical data over the last hundred years of water management developments in the catchment show 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 (1990–2000). The first two periods mark the majority of changes through a

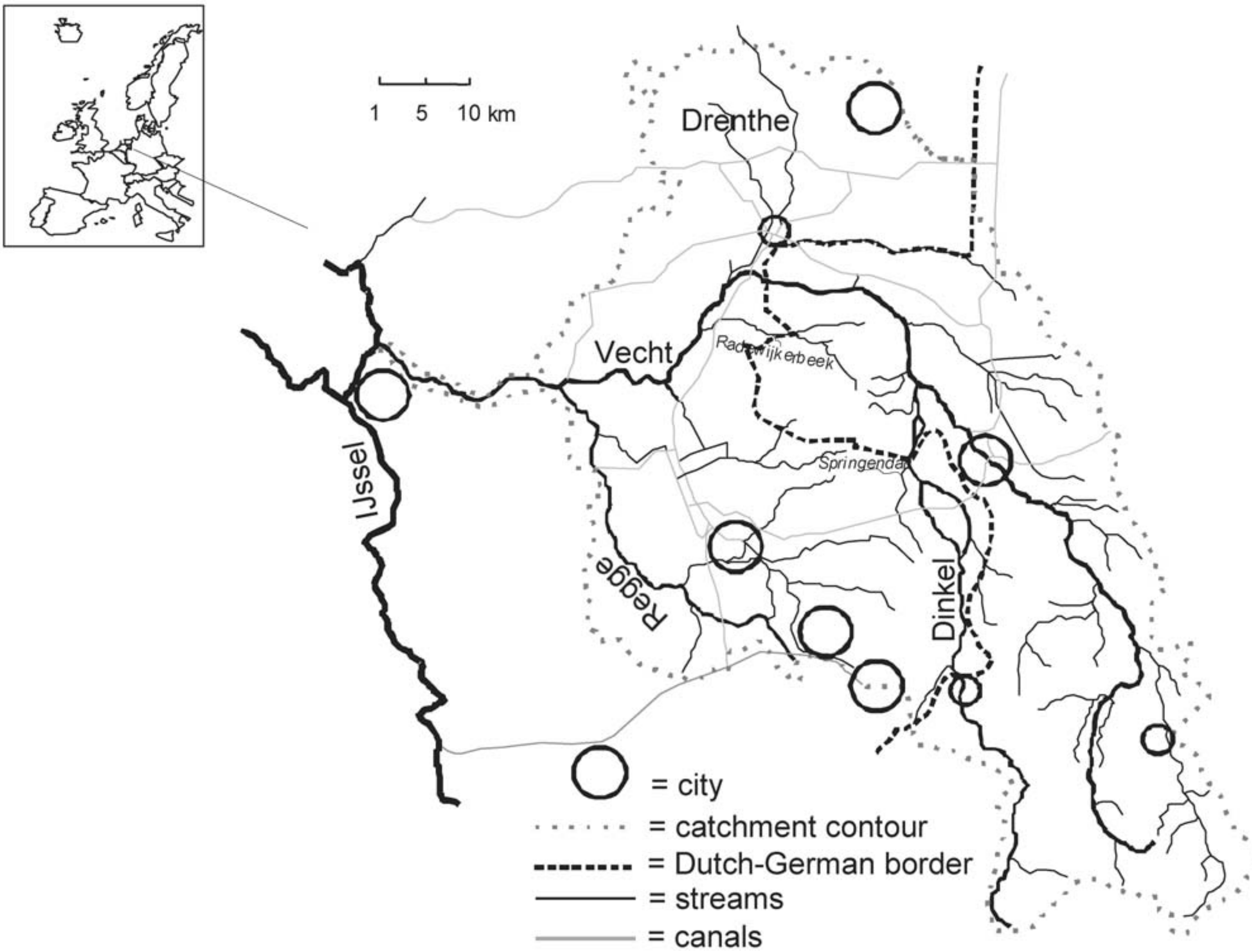

Fig. 1. Map of the Vecht catchment.

period of regulation, canalisation and normalisation. During the third period the hydromorphological deterioration was completed by deepening and widening of a large number of smaller streams. In the last period several restoration projects took place.

In general, physicochemical conditions deteriorated in the 20th century (Waterschap Groot Salland 2002). Based on the data over the years 1990–2006 (Waterschap Velt & Vecht 2007) the average oxygen concentration was 9.0 mg l^{-1} (± 2.6), despite drops to < 2 mg l^{-1} during short periods in summer. The average total phosphorus concentration was 0.36 mg l^{-1} (± 0.25) and average total nitrogen was 7.1 mg l^{-1} (± 2.8). The nutrients indicate eutrophication, that especially occurs during low flow periods. Furthermore, the average chloride concentration was 60.5 mg l^{-1} (± 25.7).

Material and methods

Past and current developments

Climate

Air temperature and precipitation data, obtained from the Royal Dutch Meteorological Institute (KNMI 2004), were analysed over the last 100 years. Daily average temperature values over the period 1900 to 2003 were available. Based on these daily averages the yearly average, and the yearly average minimum and maximum were calculated, and expressed as running average with a window of 5 years. 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 time periods 1895–1905, 1925–1935, 1955–1965, and 1990–2000, 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 1:25,000 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 average cover area per category was calculated.

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. The oldest available measurements date from 1957 on for the small river Regge. The data selected are representative for the stream types present in the catchment (Table 1). All data sets showed missing data. Discharge was graphically expressed as running average with a window of 5 years.

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 the map for the more downstream sections. Two to four representative larger streams were selected per subcatchment. For the periods around 1900, 1930 and 2000 digitalised topographical maps were used (1:25,000). 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'.

Table 1. Availability of discharge data.

		Discharge from year	**data 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

Macroinvertebrates

Samples were collected from 664 sites; 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 1 m. The habitat samples of the site were combined to give one sample with a standard area of 1.5 m^2 (1.2 m^2 of vegetation and 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, and counted and identified to species level.

Some variables 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 collected 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.

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. 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 indicates 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 (DuRietz 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 waterbody, and as normally only a part of the community is sampled, these groups are more 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 modelling. 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).

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}
calcium	mg l^{-1}
chloride	mg l^{-1}
pH	–
conductivity	µS m^{-1}
width	m
depth	m
current velocity	m s^{-1}
slope	m km^{-1}
cover % floating vegetation	%
cover % submersed vegetation	%
cover % total vegetation	%
intermittency	nominal
peat bottom	nominal
not line shaped, profile shape regular	nominal
not line shaped, profile shape irregular	nominal
irregular line shape	nominal
regular line shape	nominal
profile shape regular	nominal
profile shape irregular	nominal

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. Climate variation was included in the analysis by using six different scenarios (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 predict 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. 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 allows statistics of events with a recurrence interval of 5 years. 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 for our mid-sized drainage

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)

basin 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):

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

where si = indicative weight per discharge dynamic class (i = 1…6), Ri = total number of scores in the respective discharge dynamics class R.

The index runs from class 1 for a very constantly discharging stream (discharges all are near the median discharge Q_{50}) towards class 6 for a very dynamic stream (Table 4) at both low (indicated by L) and high exceedance frequencies (indicated by H). 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 H4 is the percentage of discharges in the interval:

$$4 * Q50 < Q < 8 * Q50 \qquad \text{(interval H4)}$$

Table 4. Discharge extremity classes for evaluating the variability of the discharge. The 6 lower (L categories) and 6 upper bounds (H categories) 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
H6	16	∞
H5	8	16
H4	4	8
H3	2	4
H2	1.5	2
H1	1	1.5
L1	0.75	1
L2	0.5	0.75
L3	0.25	0.5
L4	0.125	0.25
L5	0.0625	0.125
L6	0	0.0625

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, $P < 0.001$ trend over the period from 1901 to 2003 (Fig. 2). 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 °C and those with a daily maximum temperature > 30 °C did not show a significant trend (not shown), though both were going up. Precipitation also showed a positive, significant (ANOVA, $P < 0.001$) trend over the last hundred years. If this trend continues, precipitation will increase over the next 100 years with about 8.6 (s.e. 5.0) mm per year (Fig. 2). Also the duration of precipitation is significantly (ANOVA, P < 0.001) increasing, with on average 0.7 (S. E. 0.001) hours per year (not shown).

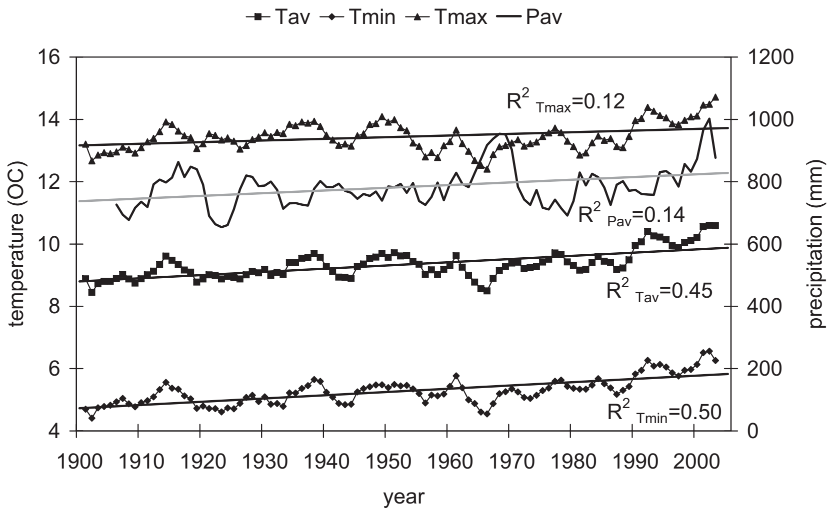

Fig. 2. The minimum (Tmin), average (Tav) and maximum (Tmax) running mean temperature and the daily average precipitation (Pav) measured over the period 1901 to 2003, expressed a running average with a window of 5 years.

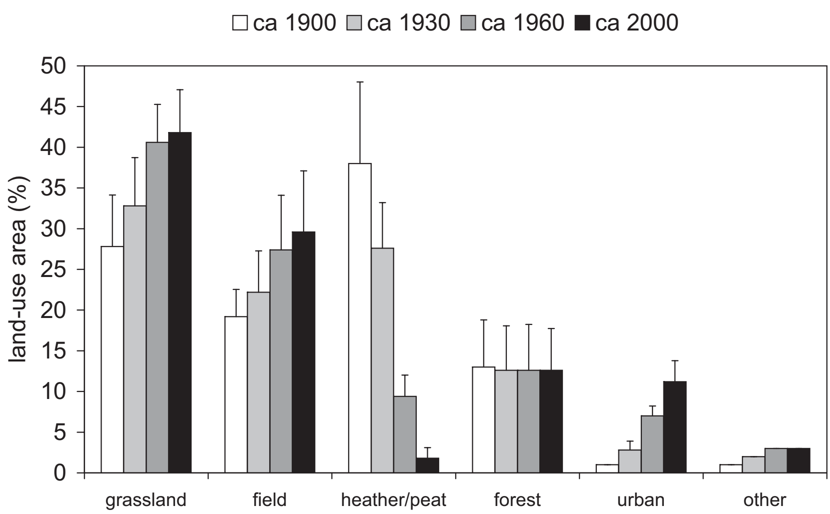

Fig. 3. Percentage of land-use in the Dutch part of the river Vecht catchment in four time periods over the last 100 years.

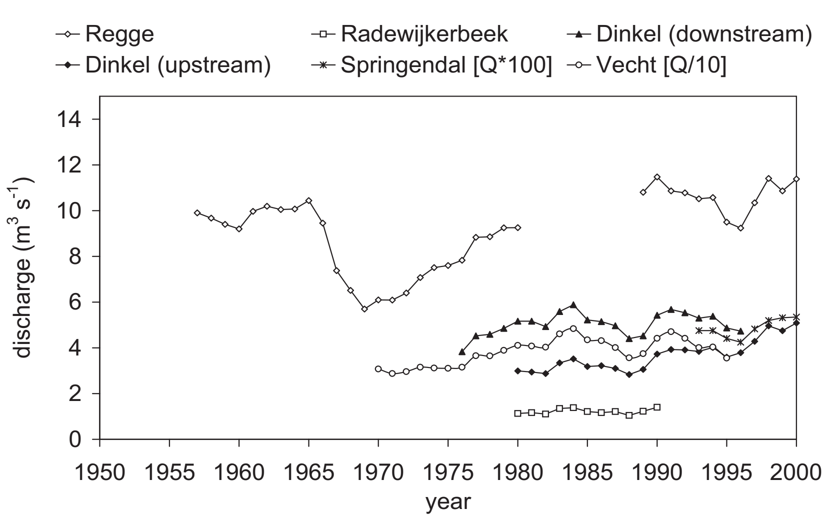

Fig. 4. Discharge (moving 5-years average of daily discharge) pattern of different stream types in the Vecht catchment.

Land-use

Four major land-use changes took place over the last 100 years in the Vecht catchment. The area of heather and moorland peat decreased dramatically as the agricultural, urban and other uses increased (Fig. 3). The percentage of forest remained about the same over the whole period.

Hydrology

Based on the data available discharge patterns did not change much, except for both the river Regge and Dinkel (downstream) that showed a lowered discharge in the seventies due to a sequence of warmer and drier years (Fig. 4). For the river Regge the discharge in the nineteen-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 (Fig. 5). 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 (Fig. 5). 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 of the last century some streams were still slightly meandering and currently most are straight. Only the streams in the subcatchments Dinkel mostly still meander. There were only a few weirs present around 1900, but today most streams are regulated by weirs, except again some of the streams in the subcatchment Dinkel (Fig. 5). Little is documented on transversal profile in the past. The river Dinkel (upstream) 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 ”width and depth”, 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 illus-

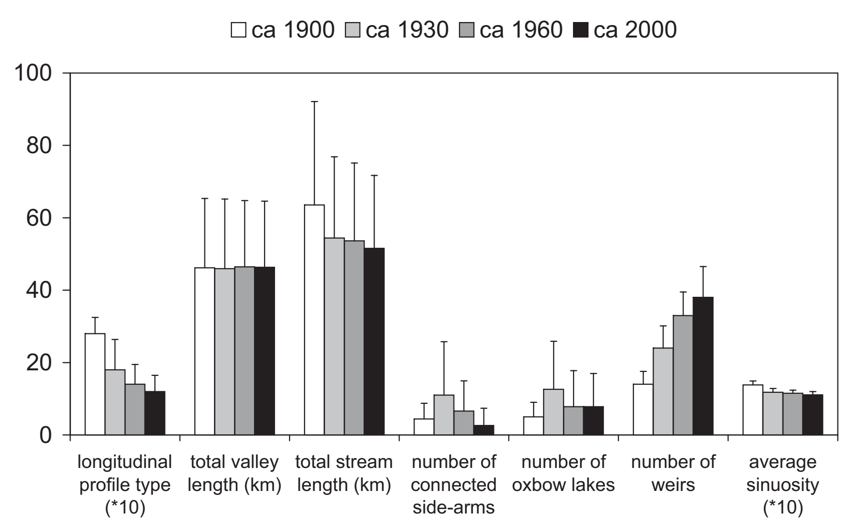

Fig. 5. General morphological features of the Vecht catchment and its subcatchments.

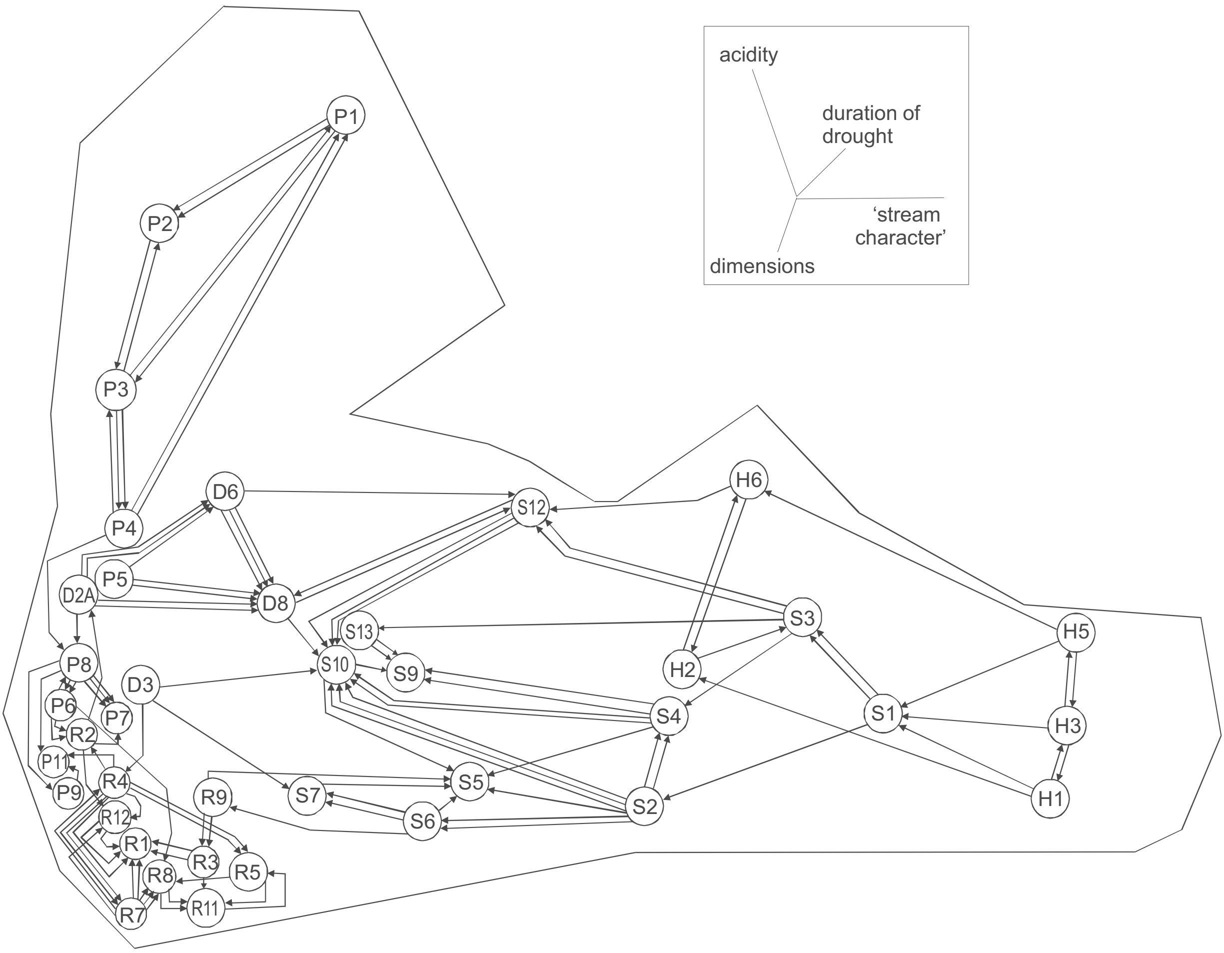

Fig. 6. The web of cenotypes. The contour line describes the total variation present in all site scores. The centroid of each cenotype is indicated by a code (for the for this study relevant codes see Table 5). The arrows between cenotypes indicate the most important environmental relations. The inset represents the four most important environmental gradients (key factors) in the total dataset.

trate the mutual relationships between the cenotypes (Fig. 6). 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. (Fig. 6). 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 Fig. 6 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 be-

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, α-mesosaprobic, shallow ditches and canalised streams	3
D8	temporary, slowly running, α-meso-ionic, α-mesosaprobic, small ditches	4
H3	weakly acid to neutral, oligo- to β-mesosaprobic helocrene springs	1
S1	oligo- to β-mesosaprobic springfed small upper courses	5
S3	temporary, α-mesosaprobic, natural, small upper courses	1
S4	temporary, β-mesosaprobic, natural upper courses	34
S5	polysaprobic, natural and canalised upper- and middle courses	11
S6	half-natural, α-mesosaprobic middle courses	9
S7	α-mesosaprobic, canalised middle courses	15
R1	β- to α-mesosaprobic, very slowly running, canalised lower courses and small rivers	1
R3	α-mesosaprobic, weakly meandering, slowly running, small rivers	1
R4	α-meso-ionic, β- to α-mesosaprobic, slowly running, canalised lower courses and small rivers	4
R9	α-meso-ionic, α-mesosaprobic, slowly running, lower courses and small rivers	100

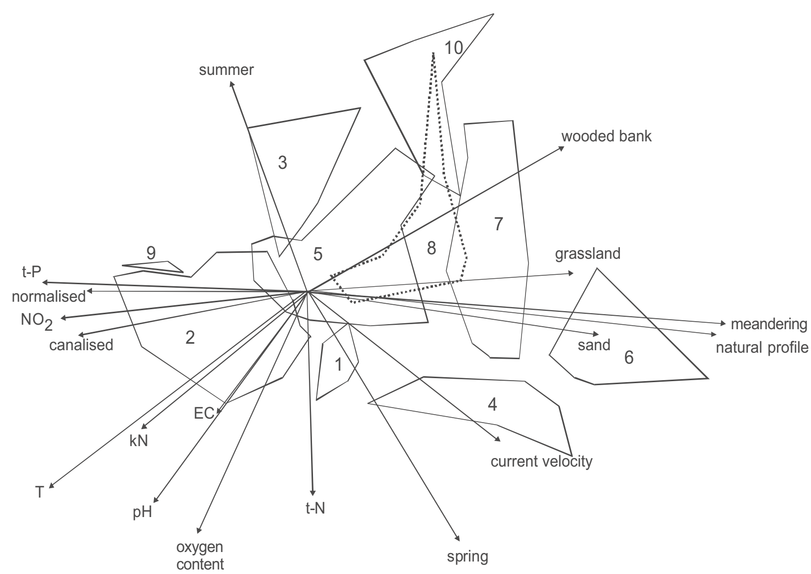

Fig. 7. DCCA ordination diagram of the axes 1 and 2. Ten groups of samples are indicated by contour lines. Explanatory environmental variables are shown as arrows.

tween 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 (Fig. 7). 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 short-wave 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 distribu-

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

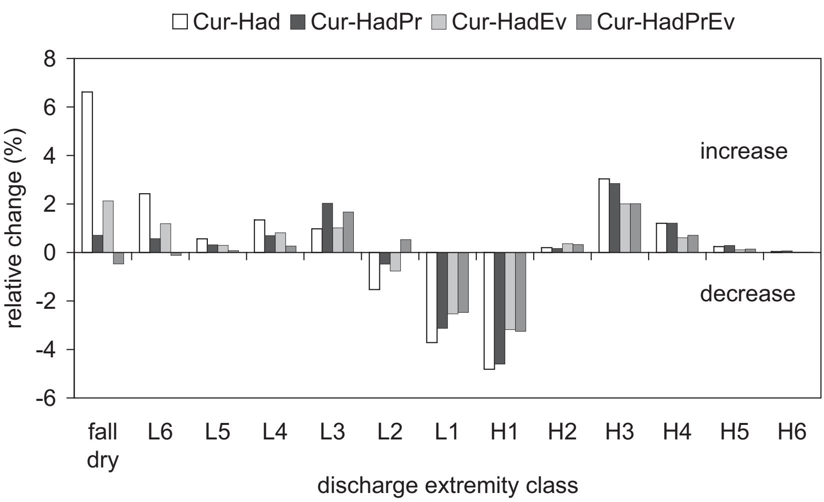

Fig. 8. Relative differences in discharge exceedance events for the period 2070 to 2100 compared to the current climate (CurVc). The differences in average percentage of daily discharge exceedance classes was calculated for 423 stream sections in the catchment of the Vecht (scenario codes are explained in the text).

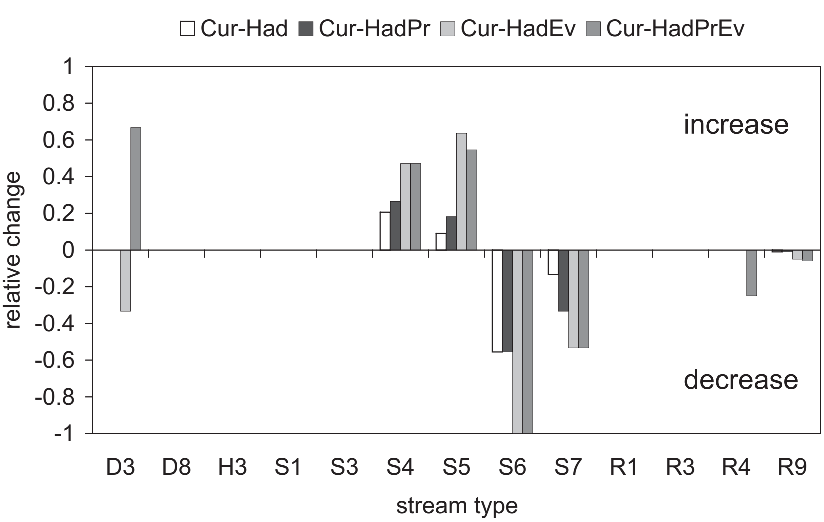

Fig. 9. Relative changes in macroinvertebrate assemblages under four low flow scenarios based on the hydrological predictions for the period 2070 to 2100. For interpretation of the cenotype codes (horizontal axis see Table 5).

tions 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}) are predicted to change 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 (Fig. 8). 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. 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 CO_2-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) (Fig. 8).

Macroinvertebrate assemblages

The four scenarios were applied with the MLR-EKOO prediction model (Fig. 9). 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 0.5 times median flow and the more extreme low exceedance class 0.0625 times median flow. These two conditions will occur more often 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 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. In conclusion, low exceedance events resulted in macroinvertebrate assemblages that formerly could be characterised as occurring in α-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

There was a positive trend shown in temperature and precipitation over the last hundred years. This climate related trend clearly differs from the stepwise changes in land-use, as indicated by the four period of major change. Societal and agricultural developments had a large impact on our environment as was seen all over Europe (Kristensen & Hansen 1994). Moreover, most of these changes took place in the first decennia of the 20th century. I expect that these major changes in land-use strongly dominate over the climate related changes.

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 of the scenario calculations. 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, and 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. Following the SIMGRO predictions using the climate scenarios, discharge will become somewhat more dynamic, especially the low and high exceedance classes three to six, while the more constant discharge classes decrease. This will affect both stream morphology and stream ecology, as was also shown by Buffagni et al. (2009).

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 4ºC 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). 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 lead, especially in the Netherlands with nutrient-rich large rivers and a high nutrient level in the agricultural soils in the catchment, through nutrient leakage to sediment and nutrient loading (Mooij et al. 2005). The faster runoff 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). Also periods of drought will increase and these will even have a greater effect than floods on stream communities (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). Lowland streams are moderate dynamic systems over space and time. Therefore, these streams 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, β-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 biodiversity 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 place all over the world in urbanised areas. In comparison, 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 if land-use will change in the near future, which depends on societal and economic circumstances and is hard to predict, this change will be of much greater importance than the effect of climate change.

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