Ecosystem-based urban water management
A case study on the ecology of water systems in the cities of Arnhem and Nijmegen, the Netherlands

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Preface

Since the year 2000, the improvement of the water quality is approached from the ‘water quality systematics’ in the municipalities of Nijmegen and Arnhem. In the municipality of Arnhem, an extensive water quality study (2000-2003) showed that next to emission-reducing measures, water system measures can significantly contribute to improving the water quality. In the same period, the municipality of Nijmegen developed target images for the urban water systems based on vegetation monitoring (Ecoscans). From these target images, water system measures were developed. No emission-reducing measures were planned in Nijmegen.

In the search for water system measures, insight is needed on water system features, emissions and the ecological status of the water bodies. With this knowledge the water system can be assessed on resilience to emissions, public health and potentials for nature development. Furthermore the Water Framework Directive (WFD) demands an ecological/ biological assessment next to chemical assessment. For these reasons, the municipalities of Arnhem and Nijmegen, in cooperation with the waterboard Rivierenland, choose the Radboud University to execute an ecological monitoring.

The water systems of Nijmegen and southern Arnhem show an important similarity: both water systems are strongly influenced by large rivers (Waal and Rhine, respectively) and the Meuse-Waal canal (Nijmegen). Integrating monitoring in both municipalities has added value for the interpretation of results and the statistical support of the conclusions.

With this research an important contribution was made to the knowledge needed for the decision of the most optimal cost-efficient measures to improve the water quality.

It is clear that this knowledge has added value for the municipalities. In the decision making process for the next period, the rehabilitation measures toolkit has been adjusted for the ‘sewerage plans’ in Arnhem and Nijmegen (GRPs). With the new rehabilitation measures, more improvement of the water quality can be expected inducing less cost. Furthermore results show that the municipality of Nijmegen made the right choice in the past to take only water system measures.

Henk Velthorst BSc (Municipality of Arnhem)
Ton Verhoeven MSc (Municipality of Nijmegen)

Voorwoord

In zowel de gemeente Nijmegen als de gemeente Arnhem wordt de verbetering van de waterkwaliteit al vanaf het jaar 2000 benaderd vanuit de waterkwaliteitsspoor-systematiek. In de gemeente Arnhem heeft een uitgebreid waterkwaliteitsspoor onderzoek (2000-2003) aangetoond dat bovenop de emissiereducerende maatregelen in de waterketen ook watersysteemmaatregelen een significante bijdrage kunnen leveren aan de verbetering van de waterkwaliteit. In de gemeente Nijmegen zijn in dezelfde periode onderzoeken (Ecoscans) uitgevoerd op basis waarvan voor alle vijvers streefbeelden zijn opgesteld (2004), die de herinrichtings-maatregelen aansturen. In Nijmegen waren geen emissiemaatregelen gepland.

Bij de zoektocht naar watersysteemmaatregelen is van belang inzicht te hebben in de systeemkenmerken, het emissiebeeld en de ecologische toestand van het water. Hiermee kan het watersysteem worden beoordeeld op veerkracht/draagkracht van de emissielast, de volksgezondheid en potenties voor natuurontwikkeling. Ook vanuit de Kaderrichtlijn Water (KRW) is naast een chemische beoordeling de ecologische/ biologische waterkwaliteit benadrukt. Om deze reden hebben zowel Arnhem als Nijmegen, in overleg met het waterschap Rivierenland, gekozen om een uitgebreide ecologische monitoring door de Radboud Universiteit te laten uitvoeren.

Het watersysteem van Nijmegen en Arnhem-Zuid vertoont een belangrijke overeenkomst: beide systemen worden in belangrijke mate beïnvloed door de nevengelegen rivieren (respectievelijk Waal en Rijn) en het Maas-Waalkanaal (Nijmegen). Combinatie van de monitoringsonderzoeken in beide gemeenten levert daarom meerwaarde op voor de interpretatie van de onderzoeksgegevens en de statistische onderbouwing van de conclusies.

Met het onderhavig onderzoek is een belangrijke bijdrage geleverd aan het inzicht dat nodig is voor de afweging van het optimale kosteneffectieve maatregelenpakket ter verbetering van de waterkwaliteit.

Dat dit verbeterd inzicht meerwaarde heeft voor de gemeenten is evident. Bij de bepaling van de maatregelenpakketten voor de komende planperiode van de gemeentelijke rioleringsplannen in Arnhem en Nijmegen (GRP's) is gaandeweg met voortschrijdend inzicht van het onderzoek het maatregelenpakket aangepast, waardoor met beduidend minder kosten een beter effect zal worden bereikt in de verbetering van de stedelijke waterkwaliteit. In Nijmegen geven de uitkomsten van het onderzoek daarnaast aan dat in het verleden de juiste keuzes zijn gemaakt om alleen watersysteemmaatregelen te nemen.

Ing. Henk Velthorst (Gemeente Arnhem)
Drs. Ton Verhoeven (Gemeente Nijmegen)

Summary

An increasing proportion of the human population lives in urban areas. Urban waters contribute to an attractive living environment and can provide vital services such as safe discharge of storm water and upward seepage, recreation and angling. The water systems can also be a habitat for flora and fauna. Although interest in urban ecology is growing, knowledge on the biodiversity and ecological functioning of urban water systems is scarce. Insights on the effects of rehabilitation measures on biodiversity of aquatic ecosystems in rural and natural areas are not directly applicable to urban water systems, because of the large differences in hydrology, morphology and water chemistry.

The Urban Water Project (Interreg IIIb NWE) aims at sustainable water management in urban areas. The cities of Nijmegen and Arnhem are partner in this European urban water project and want to upgrade the ecological quality of urban water systems in their cities.

To support water management of the municipalities, the Radboud University Nijmegen investigated the ecological quality of urban water system, the explanatory environmental factors for aquatic biodiversity and the effects of rehabilitation measures (such as dredging, filtering of storm water and development of natural banks), in the period 2005-2008. The study focussed on aquatic macroinvertebrates (for example flatworms, oligochaetes, mussels, snails, crustaceans, larvae of caddis flies, may flies, midges, dragon- and damselflies).

The following research questions were investigated:

1. Which macroinvertebrates live in urban water systems, which types of water bodies are present and what environmental variables explain differences in species assemblages in these types?
2. Does the biodiversity in urban water systems differ from ‘reference’ systems, for example ditches or (semi)natural water courses in rural areas?
3. What is the ecological status of the urban water systems?
4. What are the short-term effects of rehabilitation measures in urban water systems?
5. What are the main bottlenecks for obtaining high biodiversity values in urban water systems and how can these bottlenecks be solved?

In the urban water systems of Nijmegen and Arnhem 179 water macroinvertebrate taxa were recorded. Two of these species are red list species.

Four water types are distinguished based on macroinvertebrate assemblages. These water types differ in values for ecological indicators (e.g. taxa richness, Shannon-index, number of red list and exotic species and rareness) and environmental conditions. The turbid urban water bodies (type 1) harbour little or no submerged vegetation and very few macroinvertebrate taxa. The absence of submerged vegetation in combination with waves and presence of benthivorous fish results in turbid water bodies with survival of very few macroinvertebrate species. The nutrient-poor water bodies (type 2) sustain the highest number of macroinvertebrate taxa and also the highest number of red list species. Next to submerged vegetation there is also nymphaeid vegetation (vegetation with floating leaves) present in some locations, creating more structure and a more diverse habitat for macroinvertebrates. The richly vegetated water bodies (type 3) have higher nutrient levels than type 2 and also harbour high macroinvertebrate taxa richness. The dominance of submerged vegetation probably plays an important role in keeping the water bodies in a ‘clear’ state. Despite the relative high nutrient levels, floating algae beds (flab) and lemnids do not dominate these systems. On the contrary, flab and/ or lemnids are often found to dominate the most nutrient-rich water bodies (type 4), harbouring very few macroinvertebrate

taxa. In this water type the number of exotic species is highest. The dominance of algae and lemnids limits the growth of submerged vegetation, diminishes the structure and creates anoxic circumstances. Exotic species are generally better adapted to survive under these harsh environmental circumstances. The most important environmental variables explaining variation in macroinvertebrate assemblages are nitrate content and transparency of the surface water, sediment composition (clayey or sandy sediment), and the presence of nymphaeid and submerged vegetation.

A general misunderstanding is that urban water systems have little value for biodiversity. This study shows that urban water systems in Nijmegen and Arnhem offer a habitat to a significant part of the Dutch aquatic macroinvertebrate species, including some rare and red list species. Taxa richness, Shannon-index, number of red list species and exotic species, and rareness in the nutrient-poor and richly vegetated urban water systems are comparable to the other drainage systems: canals, ditches in rural areas and (semi)natural lotic waters.

The European Water Framework Directive (WFD) demands a good ecological status in all surface waters by the year 2015. According to the WFD, the urban water systems of Nijmegen and Arnhem are artificial or heavily modified waterbodies. The ecological status is classified with the following scale: good, moderate, poor and bad, with colour coding green, yellow, orange and red, respectively. The ecological status of the urban water systems monitored in Nijmegen and Arnhem is generally moderate to good. Physico-chemical quality complies well with water quality standards in almost all cases, with the exception of zinc concentrations in the surface water and nitrogen concentrations in the surface waters of Nijmegen. Analysis of hydromorphological conditions indicates that banks in urban areas are generally very steep and often with hard wooden vertical bank protection. The biological quality in the nutrient-poor (type 2) and plant-rich (type 3) water bodies is good and in the turbid water bodies (type 1) the biological quality is moderate. The biological quality of water bodies dominated by duckweeds is bad, and demands improvement. The biological quality of the remaining nutrient-rich water bodies (type 4) is also relatively low (i.e. poor).

The evaluation of rehabilitation measures shows that the macroinvertebrate assemblages in urban water systems are quite stable. At the water system level ecological status changed very little over the period 2005-2007. The previously lemnid-dominated water systems improved from a bad status to a moderate or poor status. This indicates that the removal or disappearance of lemnid vegetation has positive effects on the ecological status of water bodies. The water system that received nutrient-rich water from the Linge decreased from poor to bad. On the short term, only taxa richness has increased in Nijmegen after dredging. In the other water bodies (Arnhem) no significant effects could be recorded after the rehabilitation measures dredging, filtering of storm water and development of natural banks yet. There are several explanations for the fact that statistically significant effects failed to appear, e.g., the low number of locations where rehabilitation measures took place (in this case statistical significance demands large differences), and the short monitoring time after measures were taken (colonization of species takes more time). The rehabilitation measures did not have unexpected adverse effects on the macroinvertebrate assemblages.

The main bottleneck for rehabilitating urban water systems in Nijmegen is the upward seepage from the Meuse-Waal canal, which introduces a lot of nutrients into the urban water systems. The upward seepage from the Meuse-Waal canal has a much bigger impact on the water quality in the urban water systems, than the impervious areas. Improvement of the ecological quality of these water bodies demands reduction of the nutrient loading of the rivers Meuse and Waal.

In Arhem the main bottlenecks for rehabilitating the urban water systems are the discharge of the effluent of the water purification plant, effluent of sewage overflows, illicit connections, the inlet of water from the Linge and the relatively high nutrient input by faeces (and excessive feeding) of waterbirds.

To gain knowledge on the (middle) long-term effects and the sustainability of the rehabilitation measures, it is recommended to continue monitoring for a few more years and subsequently to repeat monitoring at least every 5 years.

It is recommended that management should aim at:

1. lowering nutrient levels
    a. regular dredging,
    b. avoid inlet of nutrient-rich water,
    c. avoid pollution from sewage overflows/ illicit connections
    d. decrease (excessive) feeding of waterbirds and fish,
2. stimulating vegetation and transparency
    a. optimize mowing regime,
    b. development of natural banks,
    c. decrease nutrient loading by waterbirds and benthivorous fish.

Samenvatting

Een groeiend aandeel van de wereldbevolking woont in stedelijke gebieden. Stedelijke waterstelsels dragen bij aan een aantrekkelijke leefomgeving en vervullen belangrijke functies, zoals veilige afvoer van regen en kwelwater, recreatie en sportvisserij. De watergangen bieden ook een habitat voor flora en fauna. Ondanks toenemende belangstelling voor de urbane ecologie is kennis over de biodiversiteit en het ecologisch functioneren van stedelijke waterstelsels schaars. Inzichten over de invloed van inrichting en beheer op de biodiversiteit van aquatische ecosystemen in landelijke gebieden en natuurterreinen zijn niet zonder meer toepasbaar op urbane watersystemen vanwege grote verschillen in hydrologie, morfologie en waterkwaliteit.

Het ‘Urban Water Project’ (Interreg IIIb NWE) heeft als doel het duurzaam beheren van water in stedelijke gebieden. De steden Nijmegen en Arnhem zijn partner in dit Europese project en willen de ecologische kwaliteit van de watergangen in de stad verbeteren.

Voor de onderbouwing van het gemeentelijke waterbeleid heeft de Radboud Universiteit Nijmegen in de periode 2005-2008 onderzoek verricht naar de ecologische kwaliteit van stedelijke waterstelsels, de verklarende milieufactoren voor aquatische biodiversiteit en de effecten van inrichting en beheersmaatregelen (zoals baggeren, filteren van regenwater en de ontwikkeling van natuurvriendelijke oevers). Dit onderzoek is toegespitst op de aquatische macrofauna (bijvoorbeeld platwormen, borstelwormen, mosselen, slakken, kreeftachtigen en larven van kokerjuffers, haften, muggen en libellen).

De volgende onderzoeksvragen zijn aan bod gekomen:

1. Welke macrofauna leeft in stedelijke waterstelsels, welke watertypen zijn aanwezig en welke omgevingsfactoren verklaren de verschillen in soortensamenstelling van deze typen?
2. Verschilt de biodiversiteit in stedelijke waterstelsels ten opzichte van ‘referentie’ systemen, zoals sloten of (semi)natuurlijke watergangen in landelijke gebieden?
3. Wat is de ecologische status van de stedelijke waterstelsels?
4. Wat zijn de korte termijn effecten van beheersmaatregelen in stedelijke waterstelsels?
5. Wat zijn de belangrijkste knelpunten voor het verkrijgen van hoge biodiversiteitswaarden in stedelijke waterstelsels en hoe kunnen die knelpunten worden opgelost?

In de stedelijke waterstelsels van Nijmegen en Arnhem zijn in totaal 179 aquatische macrofauna taxa waargenomen, waaronder twee rode lijst soorten.

Op basis van de macrofaunasamenstelling zijn vier watertypen onderscheiden. Deze watertypen verschillen in waarden voor diverse ecologische indicatoren (taxarijkdom, Shannon-index, aantal rode lijst soorten, aantal exoten en zeldzaamheid) en omgevingsfactoren. In de troebele wateren (type 1) groeien weinig ondergedoken planten en zijn weinig macrofauna taxa waargenomen. De afwezigheid van vegetatie in combinatie met golfslag en aanwezigheid van bodemwoelende vissen resulteert in troebel water, waarin slechts enkele soorten overleven. In de nutriëntenarme watergangen (type 2) komen de meeste macrofauna taxa voor, en ook het hoogste aantal rode lijst soorten. Naast ondergedoken vegetatie komen waterplanten met drijfbladeren voor in sommige locaties, waardoor een meer divers en structuurrijk habitat voor macrofauna aanwezig is. De plantenrijke watergangen (type 3) hebben hogere nutriëntengehalten dan type 2 en herbergen ook veel macrofauna taxa. De dominantie van ondergedoken vegetatie speelt waarschijnlijk een belangrijke rol bij het helder houden van deze wateren. Ondanks de relatief hoge nutriëntenbeschikbaarheid is in deze wateren geen woekering van drijvende draadalgen (flab) of kroos waargenomen. Daarentegen is in de meest nutriëntenrijke waterstelsels (type 4) vaak een dominantie van draadalgen en of kroos opgetreden en komen weinig taxa macrofauna voor. In dit watertype is het hoogste aantal exoten (uitheemse soorten) aanwezig. De dominantie van algen en kroos belemmert de groei van ondergedoken vegetatie, vermindert de structuur en creëert zuurstofloze omstandigheden. Exoten zijn over het algemeen beter aangepast om onder deze milieuomstandigheden te overleven. De belangrijkste omgevingsfactoren voor de variatie in watermacrofauna samenstelling zijn het nitraatgehalte en doorzicht van het oppervlaktewater, de bodemsamenstelling (kleiïge of zandige bodem) en de aanwezigheid van waterplanten met drijfbladeren en ondergedoken planten.

Een algemene misvatting is dat stedelijke waterstelsels relatief weinig waarde hebben voor biodiversiteit. Het voorliggend onderzoek toont dat de stedelijke waterstelsels in Nijmegen en Arnhem een habitat bieden voor een aanzienlijk deel van de Nederlandse watermacrofauna-soorten, waaronder ook enkele zeldzame en rode lijst soorten. De taxa rijkdom, Shannon-index, aantal rode lijst soorten, aantal exoten en zeldzaamheid in de nutriëntarme en plantrijke stedelijke waterstelsels (typen 2 en 3) was vergelijkbaar met andere drainage systemen zoals kanalen en sloten in landelijke gebieden en (semi)-natuurlijke waterlopen.

De Europese Kaderrichtlijn Water (KRW) vereist dat alle oppervlaktewateren in 2015 een goede ecologische status hebben. De urbane wateren in Arnhem en Nijmegen vallen in de KRW-categorie ‘kunstmatige en sterk veranderde watersystemen’. Bij de beoordeling van de ecologische status is de volgende intervalschaal voorgeschreven: goed, matig, onvoldoende en slecht met respectievelijke kleurcodes groen, geel, oranje en rood. De huidige ecologische status van de onderzochte stedelijke waterstelsels in Arnhem en Nijmegen is over het algemeen matig tot goed. De fysisch-chemische kwaliteit voldoet vrijwel altijd aan de waterkwaliteitsnormen, met uitzondering van het zinkgehalte van het oppervlaktewater en het nitraatgehalte van het oppervlakte water in Nijmegen. De analyse van de hydromorfologische toestand toont dat veel oevers van stedelijke waterstelsels een onnatuurlijk steil profiel en vaak harde beschoeiing hebben. De biologische kwaliteit in nutriëntenarme (type 2) en plantrijke waterstelsels (type 3) is goed en in de troebele wateren (type 1) matig. De biologische kwaliteit van waterstelsels met een dominant dek van kroos is slecht en vereist verbetering. Ook de score van overige nutriëntenrijke waterstelsels (type 4) is relatief laag (onvoldoende).

De evaluatie van inrichtings- en beheersmaatregelen laten zien dat de samenstelling van de aquatische macrofauna in stedelijke waterstelsels vrij stabiel is. Op water systeem niveau zijn er weinig veranderingen in ecologische status over de periode 2005-2007. De aanvankelijk door kroos gedomineerde watersystemen verbeterden van een slechte naar een onvoldoende of matige status. Dit indiceert dat het verwijderen en verdwijnen van kroos een positief effect heeft op de ecologische status. Het watersysteem dat nutriëntenrijk water uit de Linge ontvangt, is verslechterd van een onvoldoende naar slechte ecologische status. Op de korte termijn is alleen in Nijmegen de taxa rijkdom significant toegenomen na baggeren. In de overige wateren (Arnhem) zijn nog geen statistisch significante effecten waargenomen van baggeren, filteren van regenwater en de aanleg van natuurvriendelijke oevers. Hiervoor zijn verschillende verklaringen: bijvoorbeeld het kleine aantal locaties waarin maatregelen zijn getroffen (statistische significantie vereist dan grote verschillen) en de korte tijd tussen monitoring en de beheersmaatregelen (vestiging van soorten vergt meer tijd). De beheersmaatregelen hebben geen ongewenste effecten op de macrofauna veroorzaakt.

Het grootste knelpunt voor het herstel van de stedelijke waterstelsels in Nijmegen is de kwel vanuit het Maas-Waalkanaal, die nutriëntenrijk water introduceert in de oppervlaktewateren. De kwel vanuit het Maas-Waalkanaal heeft een grotere invloed op de waterkwaliteit van de waterstelsels dan het aangekoppelde verhard oppervlak. Verbetering van de ecologische

kwaliteit van deze waterstelsels vereist daarom ook een verdergaande sanering van de nutriëntenbelasting van de rivieren Maas en Waal.
In Arnhem zijn de belangrijkste knelpunten voor het herstel van de stedelijke waterstelsels: lozing van het effluent van de rioolwaterzuiveringsinstallatie, rioolwateroverstorten, foutaansluitingen, de inlaat van water uit de Linge en de relatief hoge nutriëntenbelasting door uitwerpselen (en overtollig voer) van watervogels.

Om inzicht te krijgen in de effecten op (middel)lange termijn en de duurzaamheid van getroffen inrichting- en beheersmaatregelen wordt aanbevolen om de monitoring nog enkele jaren te continueren en vervolgens ten minste 5 jaarlijks te herhalen. Aanbevolen wordt dat het beheer zich richt op de volgende aandachtspunten:

1. het verminderen van de hoeveelheid nutriënten:
    a. regelmatig baggeren,
    b. vermijden van de inlaat van nutriëntenrijk water,
    c. verminderen van de vervuiling van oppervlaktewater door overstorten/ foutaansluitingen,
    d. verminderen van het voeren van watervogels en vissen,
2. het stimuleren van vegetatie en doorzicht:
    a. optimaliseren van het maaibeheer,
    b. aanleg van natuurvriendelijke, glooiende oevers, en
    c. verlagen van de nutriëntenbelasting door watervogels en bodemwoelende vissen.

Chapter 1 Introduction

1.1 Background

1.1.1 Scientific background

Nowadays, approximately 50% of the human population lives in urban areas (United Nations, 2008). Therefore interest in urban ecology is growing (Grimm et al., 2008). In the Netherlands, more than 80% of the population lives in urban areas (United Nations, 2008). Urbanization leads to ecosystem destruction and species extinction (Malmqvist and Rundle, 2002, McKinney, 2006). Therefore, restoration, preservation and enhancement of biodiversity in urban areas are becoming more and more important (Savard et al., 2000). Urban waters are considered as attractive for citizens and are therefore given a more prominent place in new suburbs. It can be considered a novel opportunity to design them as ecological solutions to provide vital services such as biodiversity (Palmer et al., 2004; Wang et al., 2006). At present, data are missing to assess the potential of these systems for biodiversity.

Aquatic ecosystems in urban areas differ in many ways from natural ones, for example in hydrology, morphology, water chemistry, and the composition of flora and fauna (Ehrenfeld, 2000, Paul and Meyer, 2001, Walsh et al., 2005). Hydrology can be altered, with higher and more frequent peak discharges due to fast run-off from impervious areas, while water levels are kept constant by artificial measures (e.g. dam up and pumping). Water systems are often canalized, which changes their morphology into wider, deeper and less complex systems. Nutrient and contaminant loadings are usually higher. Flora and fauna diversity generally declines; tolerant species increase while sensitive species decrease or disappear (Paul and Meyer, 2001, Walsh et al., 2005).

Although many studies have investigated the influence of urbanization on water systems (Lenat and Crawford, 1994, Wear et al., 1998, Paul and Meyer, 2001, Roy et al., 2003, Booth et al., 2004, Miller and Boulton, 2005), very few have focused specifically on urban water systems as a habitat for flora and fauna (Girgin et al., 2003, Heckman, 1982). Paul and Meyer (2001) stressed the importance of gaining knowledge on the ecology of urban streams and the challenge to integrate physical, chemical and biological processes in impaired systems. The European Union Water Framework Directive (WFD) demands an enhanced protection and improvement of the aquatic environment (EU, 2000). Water systems in urban areas have to be included in the assessment and improvement of the aquatic environment. More knowledge on the ecology of urban water systems is required to improve the ecological quality of these systems and to solve management problems.

1.1.2 Interreg IIIB NWE Urban water

The Interreg IIIB programme “Sustainable development of flood plains (SDF)” is developed for the river-basin of the Rhine. The Urban Water Project is the counterpart of this programme, because the measures taken in the cities can lead to less discharge of storm water into the rivers and an improvement of the water quality in rivers. The Urban Water Project aims at sustainable water management in urban areas. Eight partners from Scotland, France, the Netherlands and Germany work together on solutions to integrate spatial planning and water management regarding healthy, sustainable and attractive urban water systems (http://www.urban-water.org/cms/). One of the main objectives is cooperation and trans-national exchange of experiences, and knowledge transfer to regional and national organizations. Each partner within the Urban Water project offers best practice solutions to the other partners. On the regional level in the Netherlands, the municipalities, water boards, province of Gelderland and the Directorate-General for Public Works and Water Management decided to upgrade the ecological quality of urban water systems in the cities of Nijmegen and Arnhem, and agreed to raise a broad awareness about sustainable water management in these cities.

1.1.3 Municipalities of Nijmegen and Arnhem

Recently the municipalities of Nijmegen and Arnhem developed water management plans to guarantee a sustainable water chain with a healthy and attractive aquatic environment, for example by improving soil and water quality and making water bodies more attractive for citizens (Tauw, 2001, Arnhemse Waterpartners, 2003). However, urban water systems in Nijmegen and Arnhem face several environmental and management problems. The water and soil quality is moderate to poor due to upward seepage of nutrient rich water from the river Nederrijn and/or the Meuse-Waal canal and polluted storm-water run-off from roofs and roads. Moreover, most urban water systems are man-made and have unnatural, steep banks, because they were predominately designed to regulate the groundwater level and to manage the discharge of water into rivers. The Radboud University Nijmegen monitored the ecological quality of the urban water systems and evaluated the effects of rehabilitation measures, such as dredging, filtering of storm water and development of natural banks, in Nijmegen and Arnhem over the period 2005-2007.

1.2 Main aim and research questions

This project focuses on gaining knowledge on the ecology of urban water systems in Nijmegen and Arnhem. The following research questions are investigated:

1. Which macroinvertebrates live in urban water systems, which types of water bodies are present and what environmental variables explain differences in species assemblages in these types?
2. Does the biodiversity in urban water systems differ from ‘reference’ systems, for example ditches or (semi)natural water courses in rural areas?
3. What is the ecological status of the urban water systems?
4. What are the short-term effects of rehabilitation measures in urban water systems?
5. What are the main bottlenecks for obtaining high biodiversity values in urban water systems and how can these bottlenecks be solved?

The study focussed on aquatic macroinvertebrates.

1.3 Reading guide

This report describes the results of the research on the ecology of urban water systems in Nijmegen and Arnhem that took place form 2005 till 2008. First of all the study area, sampling sites, materials and methods are described (chapter 2). The functions of urban water systems, and especially the ecological function, are discussed and biodiversity in urban water systems is described and compared with drainage systems in rural areas and (semi)natural water courses (chapter 3). The influence of storm water run-off and upward seepage from rivers and canals on the water quality in urban water systems is analysed and discussed (chapter 4). The ecological status of various urban water systems is assessed (chapter 5). The short-term effects of rehabilitation measures are described (chapter 6). Finally, the results are discussed (chapter 7), conclusions are drawn and recommendations are made (chapter 8).

Chapter 2 Material and methods

2.1 Research area

2.1.1 Nijmegen and Arnhem

The cities of Nijmegen and Arnhem are located in the eastern part of the Netherlands (Fig. 1). Nijmegen lies along the river Waal and is intersected by the Meuse-Waal canal, connecting the rivers Meuse and Waal. The city of Arnhem is intersected by the river Nederrijn.

Fig. 1 Geographical location of Nijmegen and Arnhem.

Both cities have approximately 150,000 inhabitants and the surface areas of Nijmegen and Arnhem are 72 km^2 and 102 km^2, respectively (Statistics Netherlands, 2006). In the nineteen seventies urban water systems have been designed to regulate the groundwater level and to manage the discharge of water into rivers. Approximately 4% of the surface area in these cities consists of watercourses connected via culverts. The slow-flowing, permanent watercourses can vary from small linear ditches to large ponds generally with a width between 5 and 40 metres and a depth up to 3 metres. Land use in the study area is predominantly residential, with an impervious area of approximately 30% (roads, roofs and parking lots), and 66% is covered by gardens, parks and other green areas. This study focuses mainly on the western quarters of Nijmegen and the southern quarters of Arnhem.

2.1.2 Geology

Nijmegen

During the Würm glacial (12,000-110,000 years ago) a river braided through the area, creating a complex geological pattern (Theunissen, 1960). At the end of the Würm glacial, in a slightly warmer period, the river left the area and the riverbeds were partly filled with peat.

The result of these geological processes is a complex top-soil system with layers of clay, sand, gravel and peat intersecting each other (Fig. 2).

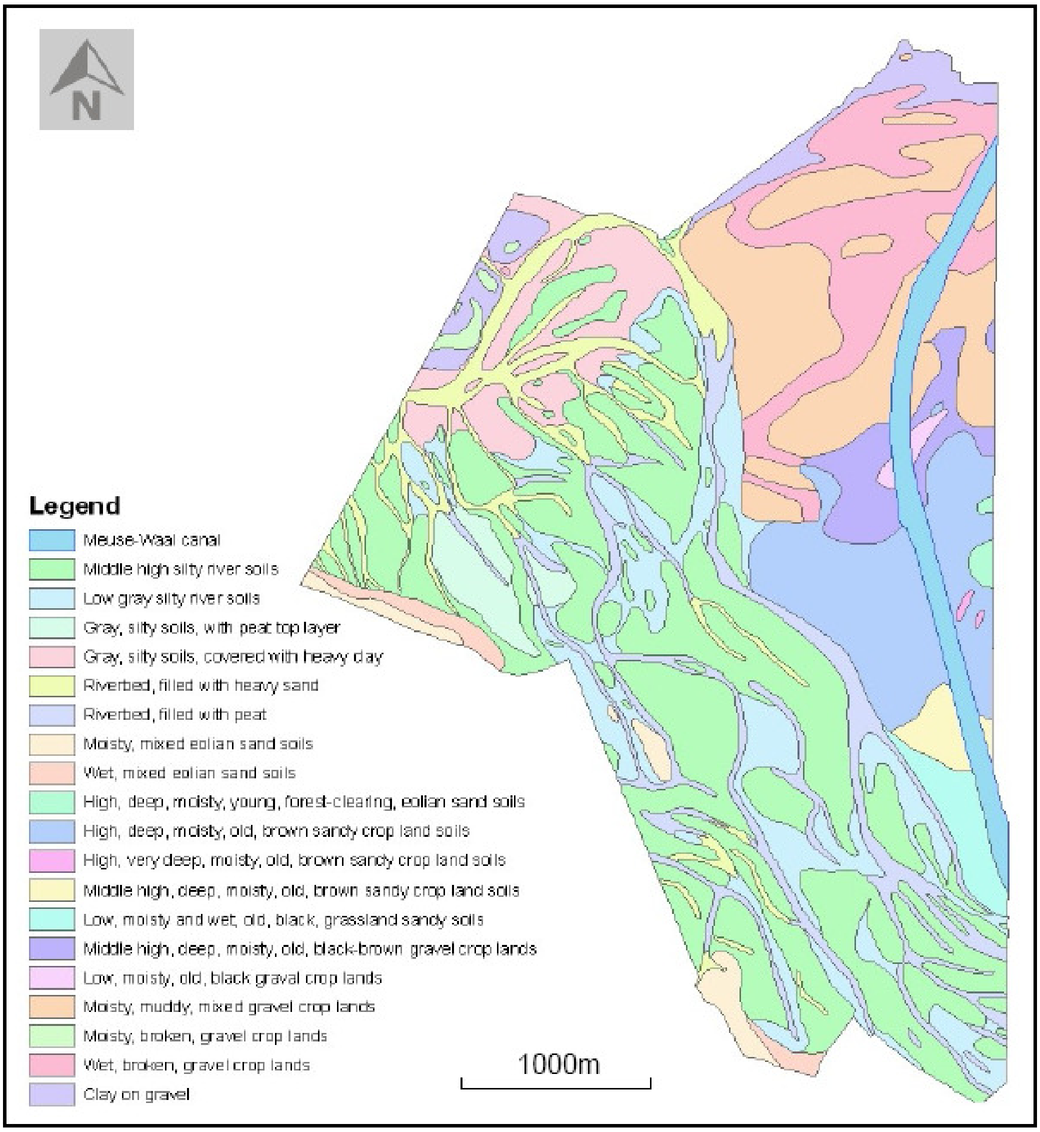

Fig. 2 Geological map of top-soil (0-1m) in the western quarters of Nijmegen (digitized and edited after Pons, 1957).

Arnhem

Soils in the southern quarters of Arnhem consist of mainly, clay, silt, sand and gravel (Berendsen & Stouthamer, 2001, Gouw, 2007). The western parts of the quarters are mainly bowl-grounds (‘komgronden’ in Dutch). The eastern part lies on old stream deposits and is therefore more strongly influenced by seepage from or to the Nederrijn.

2.2 Hydrology

Nijmegen

The water bodies in the western quarters of Nijmegen (Dukenburg and Lindenholt) are mainly fed by storm water and upward seepage from the Meuse-Waal canal. Dukenburg and Lindenholt have a separate sewage system, what means that storm water is led directly into the water systems, and sewage is pumped to a water treatment plant and is not discharged into these systems. The storm water run-off, from roofs, roads and other hard surfaces, is polluted with fine materials, metals and organic contaminants. The amount of upward seepage depends on the water level in the canal and the permeability of the soil. The water in the Meuse-Waal canal has a moderate water quality (Ministry of Transport, Public Works and Water Management, 2005). The water level in the urban area varies from 6.2m in the western part till 6.5m above Amsterdam Ordnance Datum (AOD) near the Meuse-Waal canal (Tauw, 2001).

Arnhem
The water system in the southern quarters of Arnhem is divided in two areas with different water levels (Van Slobbe et al., 2004, Fig. 3).

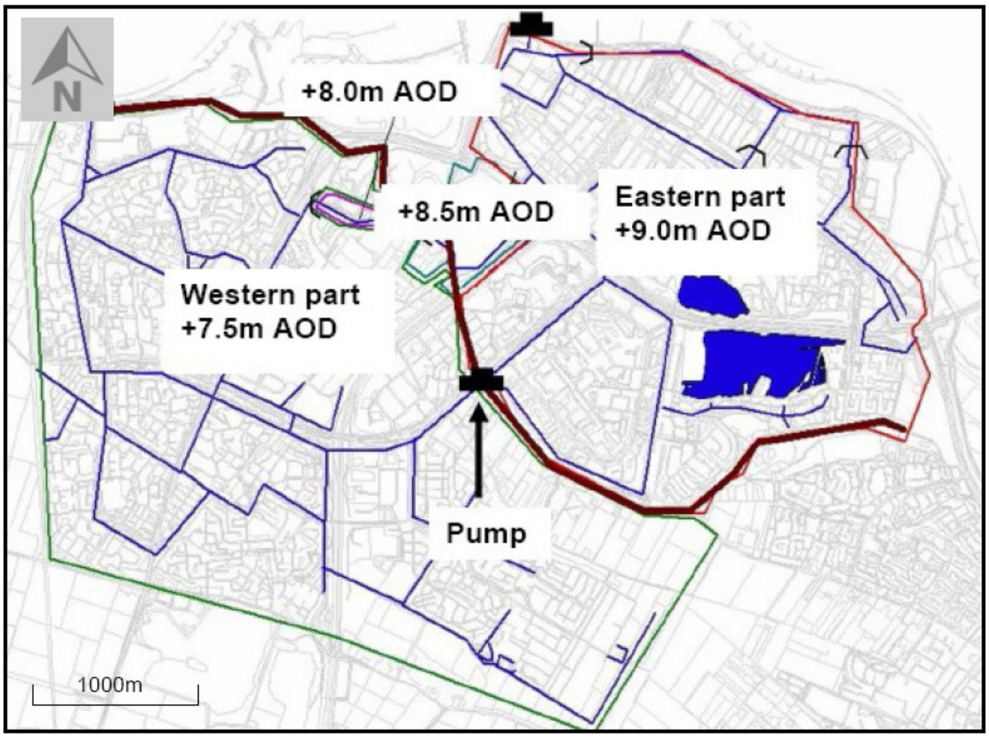

Fig. 3 Water system in the southern quarters of Arnhem (Van Slobbe et al., 2004); AOD: Amsterdam Ordnance Datum.

The water level in the western part is kept at 7.5 m above AOD and the eastern part at 9.0 m above AOD. The two parts are connected with a pump, introducing water from the western part into the eastern part. The water system is mainly fed by storm water and upward seepage from the Veluwe. At high water levels of the river Nederrijn, there is also upward seepage from the Nederrijn into the urban water systems. In the summer of 2003 a connection was made with the Linge, to guarantee water flow in dry periods. The Linge comes from a rural area and introduces water of bad/ moderate water quality.

2.3 Monitoring

2.3.1 Locations

For determining the biodiversity values and the different water types, 25 water bodies in Nijmegen and 11 water bodies in Arnhem were selected (Fig. 4-5, Appendix 1). The urban water bodies in Nijmegen were monitored in the period April-May 2005 and a second time in the period August-September 2005. In Arnhem sampling was carried out in September 2005 and May 2006. Locations were chosen to include variety in morphology, water quality, and vegetation. For the evaluation of rehabilitation measures 11 locations in Nijmegen and 11 locations in Arnhem were selected and monitored in 2006 and 2007 (Appendix 1).
In addition, 82 locations in Nijmegen were sampled twice in April (17, 18 April) and May (7, 8 May) 2007 to compare water quality with impervious area and upward seepage (Hermus & Van Weperen, 2007).

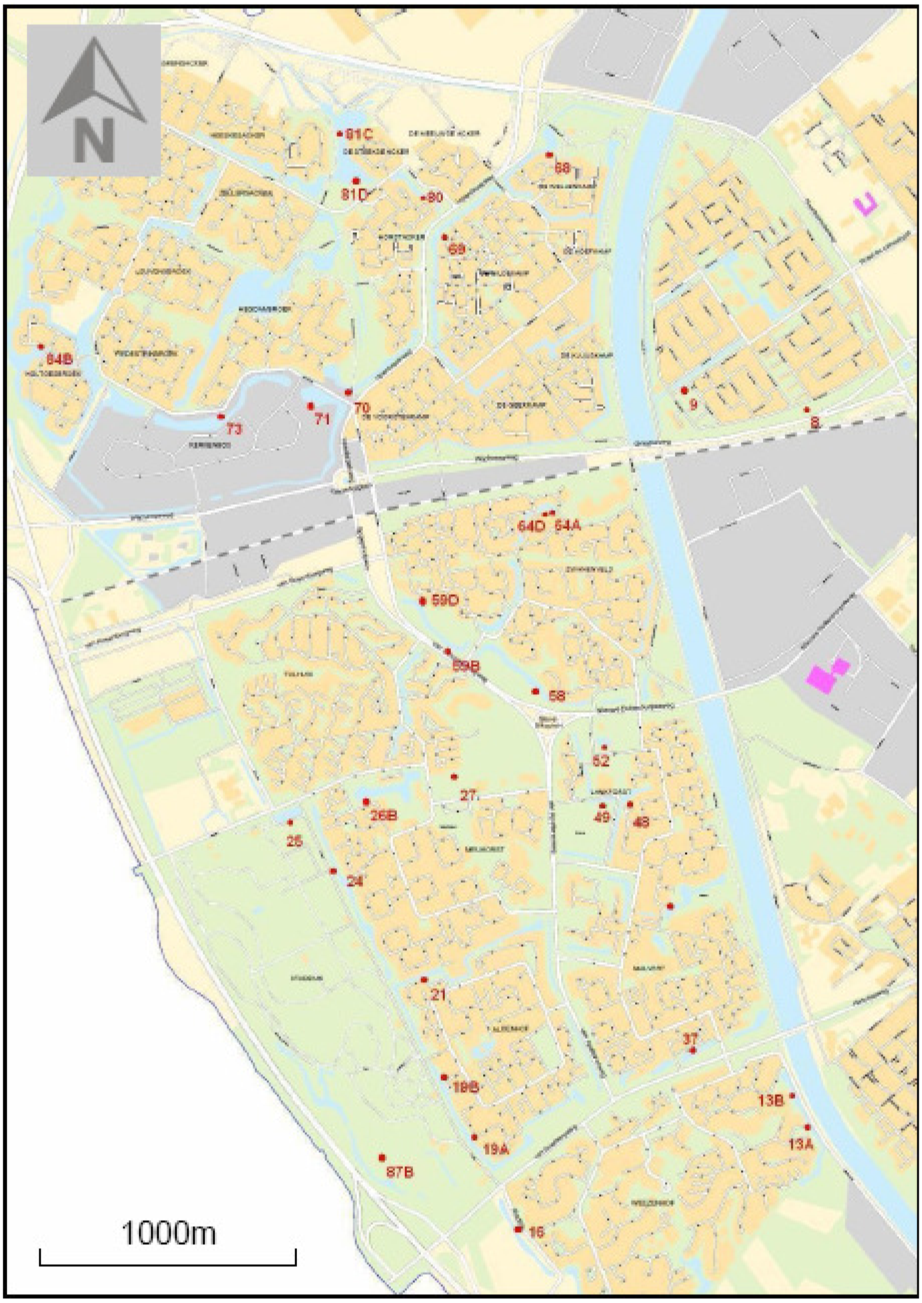

Fig. 4 Locations monitored in Nijmegen.

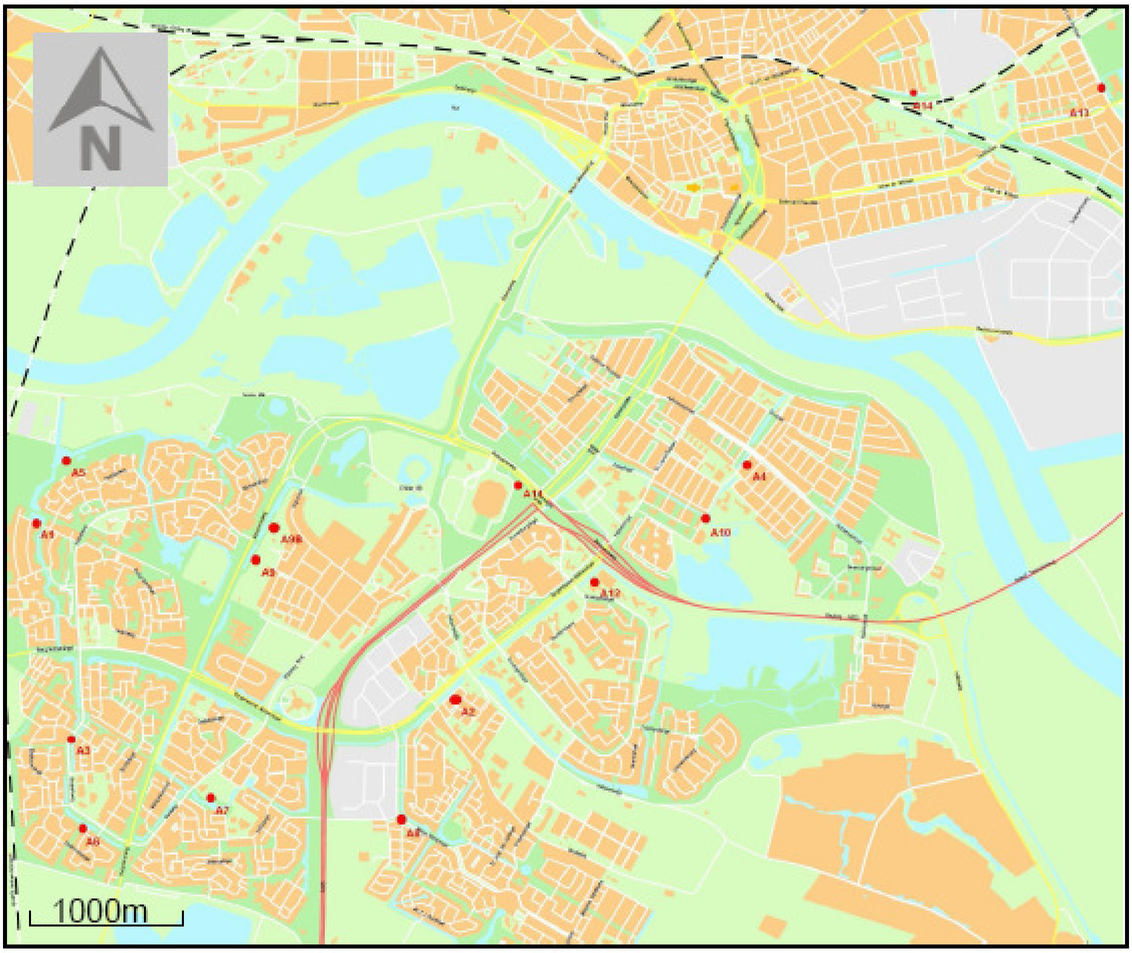

Fig. 5 Locations monitored in Arnhem.

2.3.2 Flora and fauna

Aquatic macroinvertebrates are commonly used for gaining knowledge on the ecology of water systems, because they are sensitive to changing environmental conditions. They are abundant, relatively easy to catch, and integrate environmental conditions over longer periods of time than microorganisms and plankton (Metcalfe, 1989). Aquatic macroinvertebrates were sampled using a 20*30 cm pond net with ½ mm mesh size. A sample consisted of two sweeps of approximately 2 metres in open water just above the sediment, one sweep from the central part in direction of the bank, and one sweep along the bank. Benthic macroinvertebrates in the top layer of the sediment were sampled using a core sampler (diameter 7 cm* height 9 cm) pushed into the sediment at approximately 75 cm, 150 cm and 225 cm from the bank at each sampling station. All samples were washed over three sieves with 2, 1 and ½ mm mesh size and sorted in the laboratory. The following groups were identified to species level: Tricladida, Gastropoda, Bivalvia (except: *Pisidium* sp.), Hirudinae (except: *Erpobdella* sp.), Crustacea, Odonata (except: *Aeshna* sp., Libellulidae, *Coenagrion puella/ pulchellum/ Ischnura elegans*), Ephemeroptera, Heteroptera (except: *Gerris* sp. and *Notonecta* sp.), Coleoptera (exception: Hydrophilidae), and Trichoptera. Acari was identified to genus level, Diptera to family level, and Oligochaeta was left at sub-class. An overview of all macroinvertebrates recorded in this study was given in appendix 18.
The abundance of waterbirds was recorded for approximately 30 minutes; only the area visible from the sample point was taken into account.
The percentage cover by submerged (e.g. *Elodea nuttallii*, *Ceratophyllum demersum),* nymphaeid (e.g. *Nuphar lutea, Nymphaea alba*), lemnid (*Lemna* sp.) vegetation and floating algae beds (FLAB) was estimated. Furthermore, in August/September 2007 vegetation species composition was recorded, using the Tansley scale (d = dominant, cd = co-

dominant, a = abundant, f = frequent, o = occasional, r = rare, l = local (in combination with the other classes)). Submerged, nymphaeid, floating vegetation and helophytes were monitored for approximately 20 metres along each sampling location.

2.3.3 Physico-chemical parameters

The following parameters were measured in the field: electrical conductivity (Hanna Combo meter), stream velocity (SENSA-RC2 water velocity meter), dimensions of the water body, percentage of shadow, the slope of the bank, depth near the bank, and transparency (Secchi depth). Water bodies that were clear to the bottom were assigned a Secchi depth of 1 metre, because otherwise deeper clear waters would have a larger relative influence on the analysis than shallow clear waters. Two water samples, four pore water samples and three sediment samples were taken for further analysis. The water and pore water samples were stored overnight at 4°C; pH and alkalinity were measured the following day. CO_2 was measured with ABB Advance Optima Infrared Gas Analyzer (ABB Automation Products, Germany), CO_3^{2-} and HCO_3^- could be calculated from CO_2 and pH. Water samples were stored at -20°C until further analysis after adding citric acid (125 mg l^{-1}). The following substances were measured colorometrically (Auto Analyzer 3, Digital colorimeter, Bran + Luebbe, Germany): NO_3^- according to Kamphake et al. (1967), NH_4^+ according to Grasshoff & Johannsen (1972), PO_4^{3-} according to Henriksen (1965), Cl^- according to O'Brien (1962). Na^+ and K^+ were measured photometrically with a flame photometer (Radiometer, Copenhagen). Metals were measured by inductively coupled plasma mass spectrometry (Thermo Electron Corporation, United Kingdom). Sediment samples were dried for 24 hours at 100°C and grain size was determined with a Coulter LS 230 laser diffraction device (Beckman Coulter, Inc, Fullerton CA, USA). Carbon and nitrogen content in the sediment was measured with a Carbo Erba NA 1500 Nitrogen Carbon Sulphur Analyzer. All physico-chemical factors were measured at least twice; average values were used for the data analysis. An overview of physico-chemical data over the period 2005-2007 was given in appendix 19.

2.4 Data acquisition

2.4.1 Macroinvertebrates in other water systems

To compare biodiversity in urban water systems with other water systems in the Netherlands two methods were used. First of all the urban water systems were compared with total freshwater macroinvertebrate species richness in the Netherlands, within the taxa that were generally identified to species level. Secondly, for a broader comparison with other drainage systems, 30 locations were chosen from the National database of water boards (STOWA, 2006), including 10 canals, 10 ditches, and 10 lotic waters. Canals and ditches were chosen to represent drainage systems in rural areas, while lotic waters were selected to include more natural drainage systems. Data of two seasons in the period 2000-2005 was pooled and converted to the same taxonomic resolution as was used for the urban water systems.

2.4.2 Upward seepage

Upward seepage was modelled by Witteveen+Bos, adjusting an existing model 'MODFLOW' in MicroFEM (Witteveen+Bos, 2005). The model has been calibrated with 24 piezometers. A model was made for summer and winter conditions. Upward seepage was divided in seven classes (0-2.5, 2.5-5, 5-10, 10-15, 15-20, 20-30, >30 mm day^{-1}); these classes were used for correlations with water quality. Average upward seepage of summer and winter was used for this analysis, because data was compared with April and May.

2.4.3 Effective impervious area

The municipality of Nijmegen provided a map with impervious areas connected to inlets. Effective impervious area was calculated from this map, by adding up all connected impervious areas on one inlet (Hermus & Van Weperen, 2007).

2.4.4 Soil permeability

Geology maps were used to determine the different types of soils in Nijmegen (Fig. 2; Pons, 1957). The soil types were arranged from least to most permeable and classified from 1 to 8 (from heavy clay to sand/ gravel).

2.5 Data analysis

2.5.1 Multivariate analysis

Types of urban water bodies were distinguished using Two Way Indicator Species Analysis (TWINSPAN; Hill, 1979). Significant differences between types were calculated by comparing dissimilarity between and within types (Verberk et al., 2006). Canoco for Windows Version 4.0 (Ter Braak and Šmilauer, 1998) was used to perform Detrended Correspondence Analysis (DCA) in order to relate urban water types to environmental variables. An indirect method was chosen, because the prime interest is the variation in macroinvertebrate species assemblages (Jongman et al., 1995). A unimodal response model was selected, because there was a broad gradient in environmental variables. Before analysis macroinvertebrate abundances were transformed according to Preston (1962): Preston class = ^{2}log (abundance+1).

Environmental variables with broad ranges (total-Fe, Li^+, PO_4^{3-}) were log-transformed; Cu^{2+} and stream velocity were transformed to an ordinal scale. An ordinal scale was also used for abundance of water birds, cover by submerged, nymphaeid vegetation and floating water plants (*Lemna* sp.). The percentage of clayey and silty fraction (<64 µm) was used as a measure for sediment composition. Several environmental variables were not included in multivariate analyses (i.e. Na^+, P, NH_4^+, HCO_3^-, Ca^{2+}, Mg^{2+}, electrical conductivity and CO_2), because of high correlations with other variables (i.e. Na^+ – NO_3^-, P – PO_4^{3-} – NH_4^+, alkalinity – HCO_3^- – Ca^{2+} – Mg^{2+} – electrical conductivity and pH – CO_2). Nutrients and metals in the sediment and pore water were also highly correlated with nutrients and metals in surface water; therefore only nutrients and metals in surface water were used for data analysis. Nutrients and metals in surface water were also more relevant since most species included in data analysis occurred in the surface water. Significance of environmental variables was tested with Canonical Correspondence Analysis (CCA), using 500 Monte Carlo permutations under full model conditions.

2.5.2 Ecological indicators macroinvertebrates

The following ecological indicators were used for ecological analyses: taxa richness, Shannon-index, rareness, red list species, exotic species and species accumulation curves. Taxa richness was expressed as the number of taxa in each location. Shannon-index was calculated according to Shannon (1948) using natural logarithms: $H' = -\sum_{i=1}^{S} p_i \ln p_i$

H' is the Shannon-index, S the number of species and p_i the relative abundance of each species. Based on Foster et al. (1990), a score for rareness was calculated for each location. Each species was assigned a score according to rareness in the Netherlands over the period 2000-2005 (STOWA, 2006). The species were scored 1 to 6, which corresponded with > 2,000, 1,000-2,000, 500-1,000, 200-500, 100-200, <100 times encountered in the national database, respectively. The score for rareness of a location was calculated as the sum of all species rareness scores of a location divided by the number of species present.

Numbers of red list were determined according to Veerman (2004). Red list species have disappeared or are threatened in the Netherlands (Bal et al., 2001). Exotic species were determined according to Van der Velde et al. (2002). Exotic species have recently established in the Netherlands after intentional or unintentional introduction by human activities far from their original biogeographic area.

Species accumulation curves were calculated to show the trend in which additional species were encountered when sample sizes increased, according to the following formula (Kindt et al., 2006):

$$S_N = \sum_{i=1}^{S_{tot}} \left(1 - \prod_{a=1}^{N} \frac{F_{tot} - f_i - a + 1}{F_{tot} - a + 1} \right)$$

S_{tot} is the total number of species encountered in a group of water bodies, N is the number of sites, f_i is the number of sites where species i occurs and F_{tot} is the total number of sites.

2.5.3 Statistics

Significant differences between water types were tested with ANOVA, post-hoc Gabriel ($p<0.05$) and comparisons with other water types were done with pairwise student t-tests ($p<0.05$). Correlations with environmental variables were tested with Spearman's Rho correlation ($p<0.05$).

2.6 Assessment system

The WFD distinguishes natural and artificial or heavily modified water bodies (EU, 2000). An artificial water body is a body of surface water created by human activity. Urban water systems in Arnhem and Nijmegen are all created by human activity and therefore artificial water bodies. The ecological status of artificial and heavily modified water bodies is divided in four classes: good, moderate, poor and bad, with colour coding green, yellow, orange and red, respectively (fig. 6). The division is based on physico-chemical quality and biological quality. In natural water bodies an extra class (high) is distinguished based on hydro-morphological quality. Although hydro-morphological quality was not used for determining the ecological status here, it was included in the total analysis.

2.6.1 Physico-chemical quality

Physico-chemical quality was determined based on nutrients: total-nitrogen, total-phosphate and chloride, metals: cadmium, lead, nickel and zinc, and the other physico-chemical parameters: transparency, temperature and pH (table 1). For nutrients and metals a maximum allowable concentration (MAC) was available from the Fourth National Document on Water Management Government Decision (Ministry of Transport, Public Works and Water Management, 1998). Standards for transparency, temperature and pH were also available from this document. For physico-chemical variables the standards were used to distinguish between the good/ moderate class and the poor/ bad class (table 1). If a target value was also available, then this value was used to distinguish the good and moderate quality class.

Table 1 Physico-chemical parameters, the target value and standard for each parameter, and the boundaries for the quality classes.

Physico-chemical	Target value[a]	MAC/ standard[a]	Good	Moderate	Poor	Bad
Total nitrogen (mg N l^{-1})	<1.0	<2.2	0.03-1.0	1.0-2.2	2.2-4.4	4.4-8.8
Total phosphate (mg P l^{-1})	<0.05	<0.15	0.01-0.05	0.05-0.15	0.15-0.30	0.30-0.35
Chloride (mg Cl l^{-1})		<200	28.96-150	150-200	200-300	300-350
Cadmium (µg l^{-1})	<0.08	<0.4	0.0-0.08	0.08-0.4	0.4-2.0	2.0-4.0
Lead (µg l^{-1})	<0.3	<11	0.07-0.3	0.3-11.0	11.0-15.0	15.0-30.0
Nickel (µg l^{-1})	<3.3	<5.1	1.39-3.3	3.3-5.1	5.1-10.0	10.0-25.0
Zinc (µg l^{-1})	<2.9	<9.4	0.0-2.9	2.9-9.4	9.4-40.0	40.0-80.0
Transparency (m)		>0.4	1.0-0.6	0.6-0.4	0.4-0.3	0.3-0
Temperature (°C)		<25	15-25	25-27.5	27.5-30	30-35
pH		6.5-9.0	6.5-9.0	9.0-9.5/ <6.5	9.5-10.0	>10.0

[a] Ministery of Transport, Public Works and Water Management, 1998)

A quality ratio could then be calculated by linear interpolation of the value measured and the difference between quality ratios in the separate classes (fig. 6, Evers et al., 2007). If for example a total nitrogen concentration 1.5 mg N l^{-1} was found, than the quality ratio would be 0.48 (linear interpolation of 1.5 in the class 1.0-2.2: (1.5-1.0)/(2.2-1.0)=0.42, scale to quality ratio moderate 0.4-0.6: 0.42*(0.6-0.4)=0.08, 0.4+0.08=0.48). An exception to this rule was pH, since pH increasing from 6.5 and 9.0 is not automatically better or worse. The value of 0.8 was assigned to pH between 6.5 and 9.0.

Fig. 6 Quality ratios and colour codes for the quality classes

In the next step the quality parameters were averaged for each physico-chemical element (nutrients/ macro ion, metals and other physico-chemical parameters) and in the last step these physico-chemical elements were assigned a class (and colour) according to the one-out, all-out principle (fig. 7).

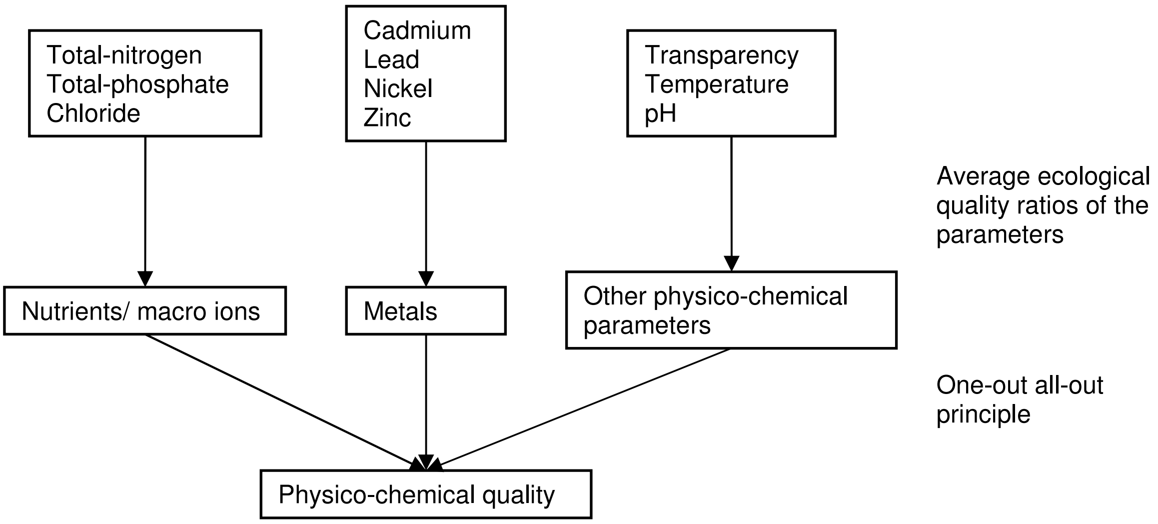

Fig. 7 Overview of the steps in the calculation of the physico-chemical quality.

2.6.2 Hydromorphological quality

Hydromorphological quality was determined as the naturalness of the banks and was calculated by averaging quality ratios for depth near the bank and slope of the bank (table 2).

Table 2 Hydromorphological parameters and the boundaries for the quality classes.

Hyrdomorphological	Good	Moderate	Poor	Bad
Depth near bank (m)	0.1-0.5	0.5-0.7	0.7-0.9	0.9-1.1
Slope bank (°)	5-15	15-30	30-45	45-65

In the WFD hydromorphological quality is used only to distinguish high ecological status and good ecological status. In artificial water bodies this distinction is not made. Therefore hydromorphological quality was only used to indicate the hydromorphological quality, but it was not included to evaluate the final ecological status.

2.6.3 Biological quality

Vegetation

Vegetation was assessed based on submerged vegetation, floating algae beds (FLAB) and floating vegetation (*Lemna* sp., table 3).

Table 3 Vegetation parameters and the boundaries for the quality classes.

Vegetation	Good	Moderate	Poor	Bad
Submerged vegetation (%)	30-90	10-30/ 90-95	5-10/ 95-100	0-5
FLAB (%)	0-15	15-30	30-60	60-100
Floating vegetation (*Lemna* sp. (%))	0-15	15-30	30-60	60-100

If the cover of submerged vegetation was between 30 and 90%, then the score 0.8 was assigned, because an increase from 30 to 90% does not mean the vegetation is increasingly better. Probably intermediate levels of submerged vegetation would be best, but to calculate an exact optimum is impossible. Submerged vegetation is very important as habitat for macroinvertrebrates. Therefore vegetation quality is determined by a weighted average of submerged vegetation (weight 0.5), FLAB (weight 0.25) and floating vegetation (weight 0.25, fig 8).

Macroinvertebrates

Macroinvertebrates were assessed based on diversity (taxa richness and Shannon-index), exotic species (relative number and relative abundance of exotic species), rareness and Average Score Per Taxon (ASPT, table 4). The boundaries of the quality classes were calculated with the whole data set. The good quality class ranged from the maximum to the median, the moderate quality class ranged from the median to the 25th percentile, the poor quality class ranged from the 25th percentile to the 5th percentile and the bad quality class ranged from the 5th percentile to the minimum

Table 4 Macroinvertebrate parameters and the boundaries for the quality classes.

Macroinvertebrates	Good	Moderate	Poor	Bad
Taxa richness	60-34	34-31.69	31.69-30.07	30.07-10
Shannon-index	2.80-1.91	1.91-1.81	1.81-1.74	1.74-0.5
Relative number of exotic species	0.0-7.69	7.69-8.98	8.98-9.89	9.89-30
Relative abundance exotic species	0.0-2.03	2.03-3.83	3.83-5.10	5.1-50
Rareness	3.5-2.28	2.28-2.21	2.21-2.16	2.16-1.5
ASPT	5.0-4.2	4.2-4.14	4.14-4.09	4.09-3.00

The calculation of taxa richness, Shannon-index, number of exotic species and rareness was explained in paragraph 2.5.2. The relative number of exotic species was the number of exotic species divided by the total number species and multiplied by 100%. The relative abundance of exotic species is the abundance of all exotic species, divided by the total abundance of all species and multiplied by 100%. ASPT is a biotic index of organic pollution (Walley & Hawkes, 1996, 1997). A higher score indicates less disturbance by organic pollution. Each family was assigned a BMWP (British Monitoring Working Party) score in range 1 to 10, according to tolerance to organic pollution. Highest scores were given to families intolerant to organic pollution. The ASPT was then calculated by adding all BMWP scores and dividing by the number of BMWP families. The final calculation of all elements within the biological quality was summarized in fig. 8. Species richness and Shannon-index were first averaged to a diversity index. Relative number of exotic species and relative abundance were also averaged to one index for exotic species. These elements were likely to respond in a similar way to pressures and should therefore be combined (ECOSTAT, 2003).

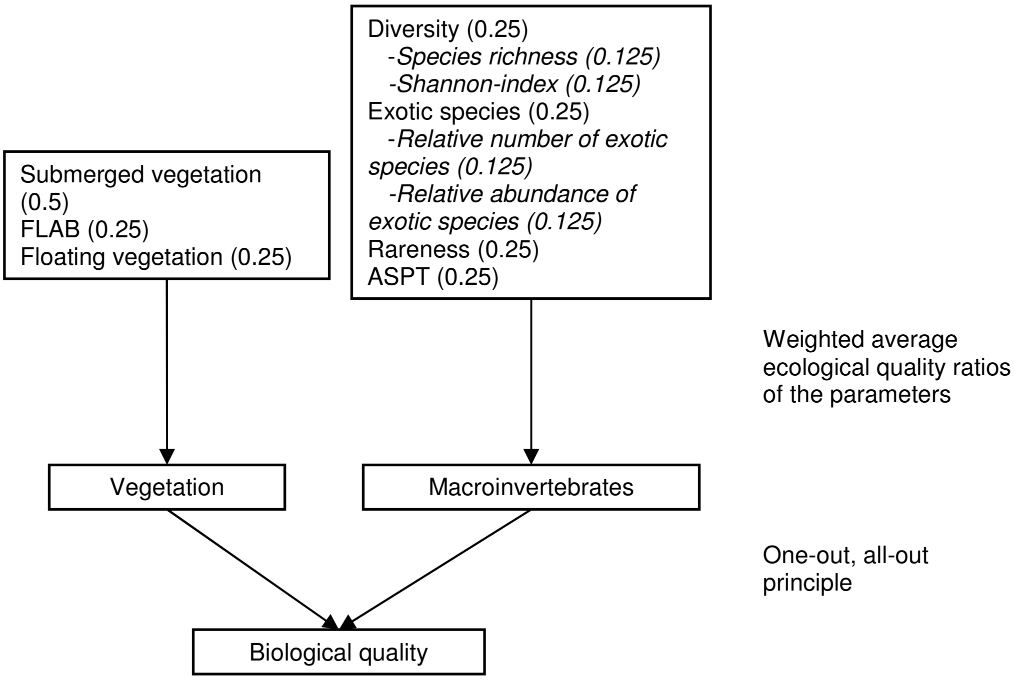

Fig. 8 Overview of the steps in the calculation of the biological quality. In brackets the weights for averaging the elements was given.

Waterbirds

Waterbirds were the last group included in the analysis (table 5). The boundaries for the quality classes were calculated in the same way as the boundaries for the quality classes for the macroinvertebrates. Since waterbirds are normally not considered within the WFD, they were not taken into account for calculating the biological quality (fig. 8).

Table 5 The boundaries for the quality classes for the waterbirds.

	Good	Moderate	Poor	Bad
Waterbirds (#/ha)	0-37.2	37.2-49.25	49.25-57.72	72.72-300

2.6.4 Ecological status

The ecological status was determined from the physico-chemical and the biological status following the one-out-all-out principle. This meant that the worst status class found in either physico-chemical or biological quality was used to assign the ecological status to the classes good, moderate, poor or bad.

2.7 Evaluation rehabilitation measures

Several rehabilitation measures took place from autumn 2005 till summer 2007. In Nijmegen some locations were dredged, natural banks were developed, culverts were cleaned and mowing regime was optimized. In Arnhem all locations were dredged, some locations before the monitoring period and most locations during the monitoring period. Furthermore in three locations a pilot project was started with filtering storm water A lamella filter, sand filter and soil bank passage were tested. In one location a natural bank was developed. Adaptive management of the water level was applied to the south-eastern part of the city.
The changes in ecological status over the years were determined. Some rehabilitation measures might have effects on the water system, but not on a specific location, e.g. cleaning of culverts, adaptive management of the water level. It is difficult to demonstrate specific effects of these rehabilitation measures, therefore we focused on dredging,

development of natural banks and filter systems. Locations where rehabilitation measures took place were compared with locations where these rehabilitation measures did not take place, if these locations were available. An overview of these comparisons is given in table 6. Since locations in Arnhem were not monitored in spring 2005, analysis in Arnhem were performed on the autumn seasons.
Number of taxa gained was the number of taxa that occurred in the next year(s), but not in the first year, while the number of taxa lost was the number of taxa that occurred in the first year, but not in the following years. Number of taxa gained minus number of taxa lost was the netto taxa turnover. Functional feeding groups were determined according to Verdonschot (1990).

Table 6 Locations where effects of rehabilitation measures were tested

Rehabilitation measure(s)	Locations
No dredging (Nijmegen)	13A, 71, 73, 19A, 24, 59B, 59D
One year after dredging (Nijmegen)	64A+D, 81A+B, 59B+D (2006-2007)
Two years after dredging (Nijmegen)	64A+D, 81A+B
No dredging (Arnhem)	A2, A8 (aut ’05-‘06), A4, A12 (aut ’05-’06 and aut ’05-’07)
One year after dredging (Arnhem)	A1, A3, A5, A6, A7, A9, A11 (aut ’05-’06)
	A2 and A8 (aut ’06-’07)
Two years after dredging (Arnhem)	A1, A3, A5, A6, A7, A9 and A11
No natural bank (Arnhem)	A1, A5 (aut ’05-’06 and aut ’05-’07)
One year after natural bank (Arnhem)	A7
Two years after natural bank	A7
No filter system	A5, A6, A8 (aut ‘05-’06 and aut ’05-’07)
One year after filtering storm water	A1, A2, A3
Two years after filtering storm water	A1, A2, A3

Furthermore changes in the water systems Dukenburg, Lindenholt, southwest and southeast Arnhem were investigated.

Chapter 3 Functions of urban water system

3.1 Social, historical and geological functions

A pleasant living environment and recreation opportunities in cities improve people's mental and physical health (Tyrväinen, 1997). The availability of green areas and water bodies in cities can even be reflected in property prices. Encounters with flora and fauna in cities are often highly appreciated (Gilbert, 1989). Butterflies, dragonflies, amphibians, water birds and fish find there habitat in urban water systems and are easily visible for citizens either in spring, summer or all year round. Furthermore citizens find it important that the water bodies do not cause plagues of for example midges or rats.

In the quarter of Dukenburg (Nijmegen) some water systems also have historical values. For example the 'Geologenstrook' (Geologists zone) has a complex pattern of sedimentation in a former, braided river bed of the Meuse (Theunissen, 1960). Furthermore the 'Grand Canal' (Big canal), was a major transport route to downstream areas (Verhoeven, 2003).

One of the main aims in the water plans (Tauw, 2001, Arnhemse Waterpartners, 2003) is to create a more attractive water system for the people who live in Nijmegen and Arnhem. Experiencing the water as an integrated part of their living environment is becoming more important. Not all water bodies are suitable for an active experience, therefore some water bodies are assigned specifically for experiencing the water. In these water systems attention is paid to ecology, water quality and possibilities for recreation.

3.2 Ecological function

3.2.1 Typology

Multivariate analysis and TWINSPAN revealed four types of water bodies within the urban water systems based on macroinvertebrate assemblages (Fig. 9). Multivariate analysis showed the variation in macroinvertebrate assemblages between locations on two axes. Each symbol in figure 9a represented a location; similar locations were plotted close to each other and the different symbols represented the four different water types. Furthermore the variation in macroinvertebrate assemblages was linked to the environmental variables and displayed as arrows in figure 9b. Pictures of the water types are shown in figure 10.

Water bodies of type 1 were characterized by low nutrient levels, sandy soils, turbid water, and little vegetation (appendix 2). In type 2 nutrient levels were also low, but there was a clayey soil with vegetation always present. In almost half of the locations nymphaeids (e.g. *Nuphar lutea, Nymphaea alba*) were present. Type 3 was characterized by high nutrient levels, high transparency, and submerged vegetation was richly present. In type 4 nutrient levels were highest, submerged vegetation was developed poorly; in four locations lemnids (*Lemna* sp.) were dominant.

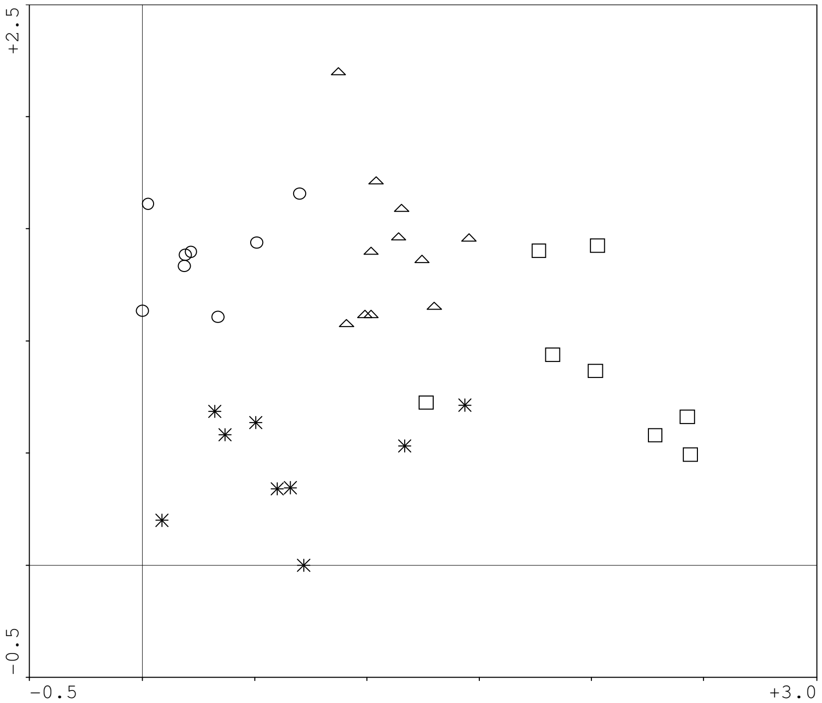

Fig. 9a Invertebrate detrended correspondence analysis. Symbols represent different water types, distinguished with TWINSPAN (squares = type 1, triangle = type 2, circle = type 3, star = type 4).

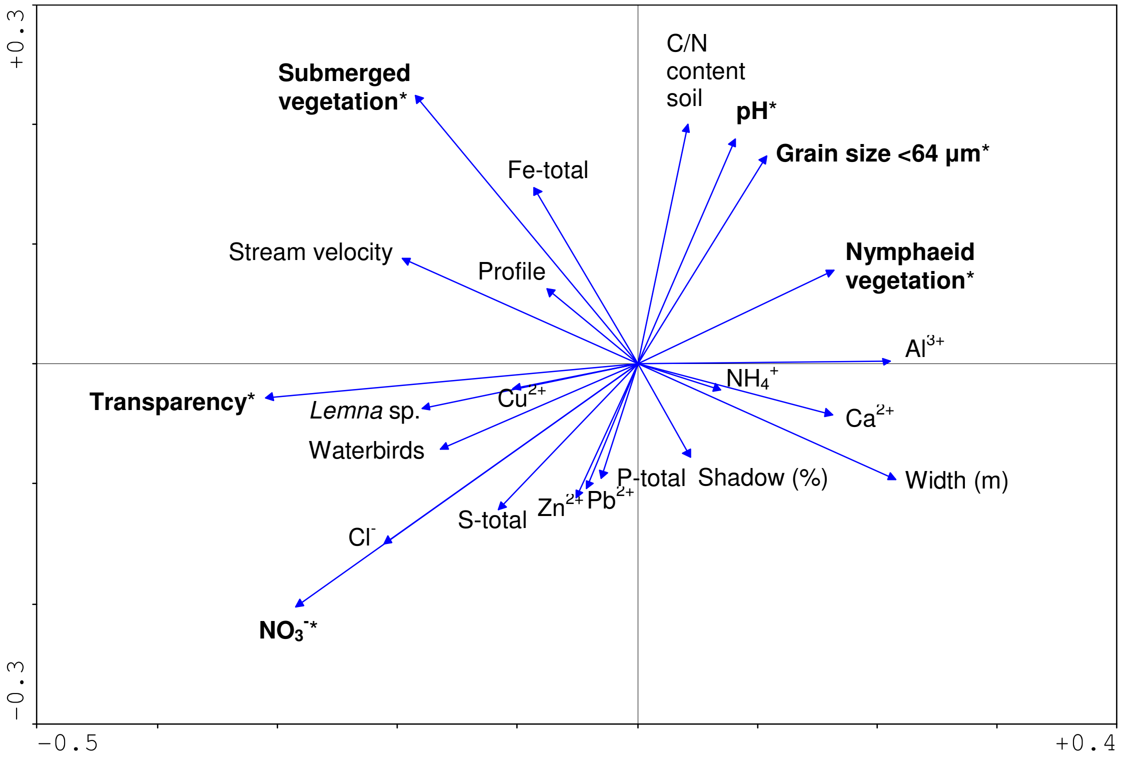

Fig. 9b Detrended correspondence analysis of environmental variables. *: environmental variables significantly explaining variation in macroinvertebrate assemblages in Canonical Correspondence analysis, 500 Monte Carlo permutations ($p<0.05$).

Type 1: turbid, taxa-poor

Type 2: nutrient-poor, taxa-rich

Type 3: richly vegetated, taxa-rich

Type 4: nutrient-rich, taxa-poor

Fig. 10 Pictures of the four types of urban water systems.

Nitrate, pH, grain size (sediment composition), transparency, nymphaeid and submerged vegetation significantly explained the variation in macroinvertebrate composition in urban water systems (Fig. 9b). The total number of species was highest in type 2 (nutrient-poor) and lowest in type 4 (nutrient-rich) (Fig. 11).

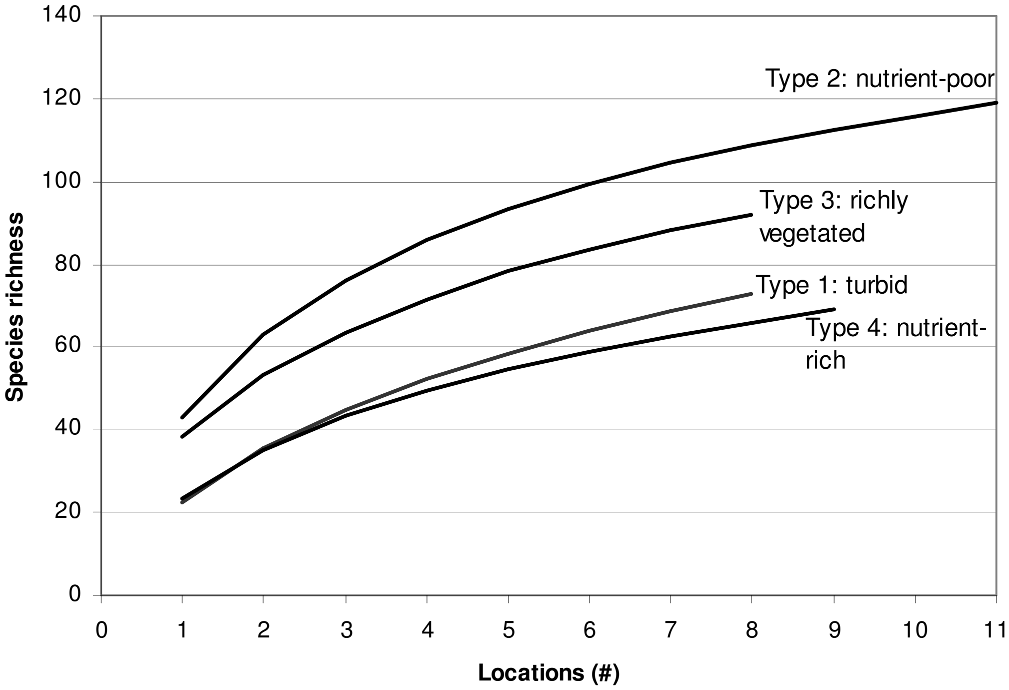

Fig. 11 Species accumulation curves for the different types of water bodies.

Table 7 Percentage of locations where characteristic (**bold**), red list and exotic macroinvertebrate species within the four different urban water types were present (number of locations in brackets).

Characteristic species	Type 1 (8): turbid, taxa-poor	Type 2 (11): nutrient-poor, taxa-rich	Type 3 (8): richly vegetated, taxa-rich	Type 4 (9): nutrient-rich, taxa-poor
Gastropoda				
Anisus vortex	0	45.5	100	44.4
Bithynia leachii	12.5	72.7	12.5	0
Gyraulus albus	25	100	100	33.3
Physa fontinalis	12.5	81.8	100	22.2
Planorbis carinatus	0	45.5	87.5	11.1
Radix ovata	0	27.3	100	22.2
Crustacea				
Asellus aquaticus	50	100	100	100
Ephemeroptera				
Caenis horaria	87.5	100	75	44.4
Trichoptera				
Triaenodes bicolor	37.5	72.7	25	0
Acari				
***Arrenurus* sp.**	37.5	90.9	25	11.1
***Limnesia* sp.**	50	90.9	25	22.2

Red list species	Type 1	Type 2	Type 3	Type 4
Tricladida				
Planaria torva	0	9.1	0	0
Trichoptera				
Leptocerus tineiformis	12.5	45.5	25	0

Exotic species	Type 1	Type 2	Type 3	Type 4
Bivalvia				
Dreissena polymorpha (PC)	12.5	63.6	87.5	55.6
Gastropoda				
*Ferrissia wautieri** (NA)	12.5	27.3	0	0
Physella acuta (NA)	0	9.1	0	11.1
Potamopyrgus antipodarum (NZ)	12.5	27.3	25	44.4
Tricladida				
Dugesia tigrina (NA)	25	45.5	25	11.1
Crustacea				
***Crangonyx pseudogracilis* (NA)**	0	9.1	62.5	77.8
***Gammarus tigrinus* (NA)**	75	27.3	12.5	11.1
Limnomysis benedeni (PC)	62.5	27.3	0	33.3
***Proasellus coxalis* (EE)**	0	36.4	25	77.8
***Proasellus meridianus* (SE)**	25	27.3	75	77.8

* possibly f. gracilis

Origin: PC = Ponto-Caspium, NA = North America, NZ = New Zealand, EE = Eastern Europe, and SE = Southern Europe

The turbid water bodies of type 1 were mostly characterized by the lack of many general species (Table 7). In the nutrient-poor water bodies of type 2 the snails *Gyraulus albus*, *Physa fontinalis*, caddis fly *Triaenodes bicolor* and mites *Arrenurus* sp. and *Limnesia* sp. were most characteristic. In the richly vegetated water bodies of type 3 the gastropods *Anisus vortex*, *Gyraulus albus*, *Physa fontinalis*, and *Radix ovata* were present in all locations. In the nutrient-rich water bodies of type 4, a lot of species were less abundant than in type 2 and 3. The exotic crustaceans *Crangonyx pseudogracilis*, *Proasellus coxalis* and *P. meridianus* were present in most of the locations of type 4.

3.2.2 Correlations between environmental variables and ecological indicators

Correlations between environmental variables and ecological indicators in urban water systems demonstrated that nitrate was negatively correlated with taxa richness, number of red list species and rareness, and positively correlated with the number of exotic species (Table 8). Rareness was positively correlated with pH. With sediment ranging from sandy to clayey, taxa richness and number of red list species increased and number of exotic species decreased. Transparency was negatively correlated with rareness. Nymphaeid vegetation was positively correlated with taxa richness and rareness, while submerged vegetation was positively correlated with taxa richness and Shannon-index values.

Table 8 Correlations between environmental variables and ecological indicators in urban water systems (Spearman's Rho correlation).

	Taxa richness	Shannon-Index	Number of red list species	Number of exotic species	Rareness
NO_3^- (mg l^{-1})	-0.29*	-0.00	-0.50***	0.30*	-0.51***
pH	0.08	0.10	0.16	-0.11	0.52***
% Grain size < 64 µm	0.43**	0.20	0.39*	-0.28*	-0.12
Transparency (Secchi (m))	0.06	0.27	-0.27	0.23	-0.48**
Nymphaeid vegetation	0.29*	-0.02	0.22	-0.15	0.40**
Submerged vegetation	0.54***	0.43**	0.14	-0.02	-0.11

* $p<0.05$
** $p<0.01$
*** $p<0.001$

3.2.3 Vegetation

The typology based on macroinvertebrates was compared with vegetation assemblages. Detrended correspondence analysis of vegetation did not distinguish the same water types based on macroinvertebrates (Fig. 12a), although the nutrient-poor urban water type 2 was similarly distinguished on the right-hand of the graph. In these nutrient-poor water bodies, *Ceratophyllum demersum* was usually present. In the other locations, *Callitriche* sp., FLAB, *Lemna minor* and the exotic species *Lemna minuta* were most characteristic.
Detrended correspondence analysis of vegetation showed that nitrate, transparency and grain size (sediment composition) were most important for explaining the variation in vegetation species assemblages (Fig. 12b). These factors were also important for the macroinvertebrate assemblages.

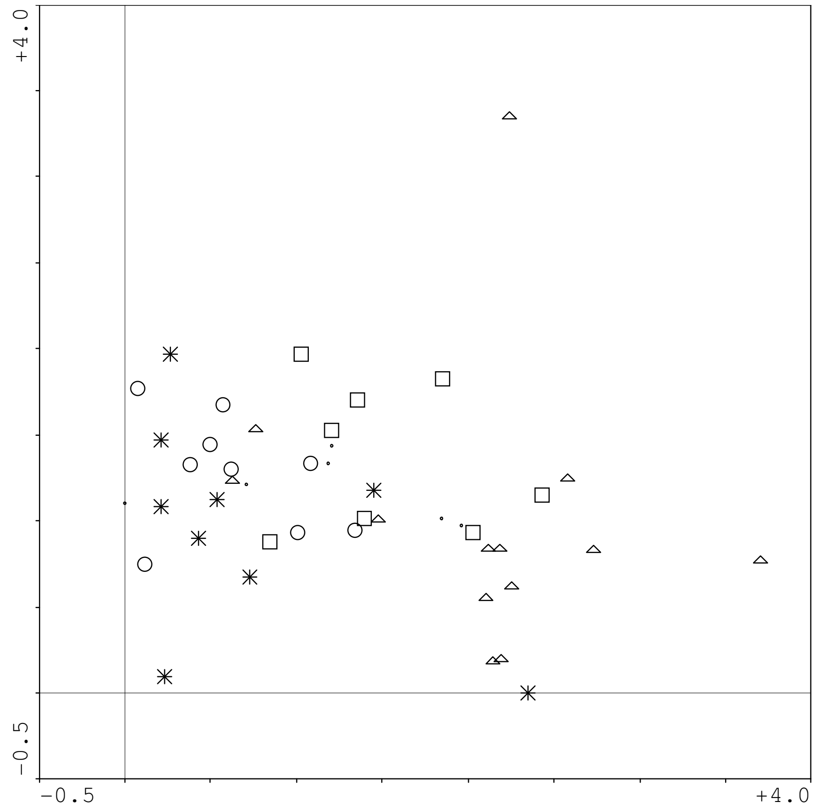

Fig. 12a Vegetation detrended correspondence analysis. Locations in- and outside the circle represent the two water types distinguished based on vegetation abundance. Symbols represent different water types based on macroinvertebrates, distinguished with TWINSPAN (squares = type 1, triangle = type 2, circle = type 3, star = type 4).

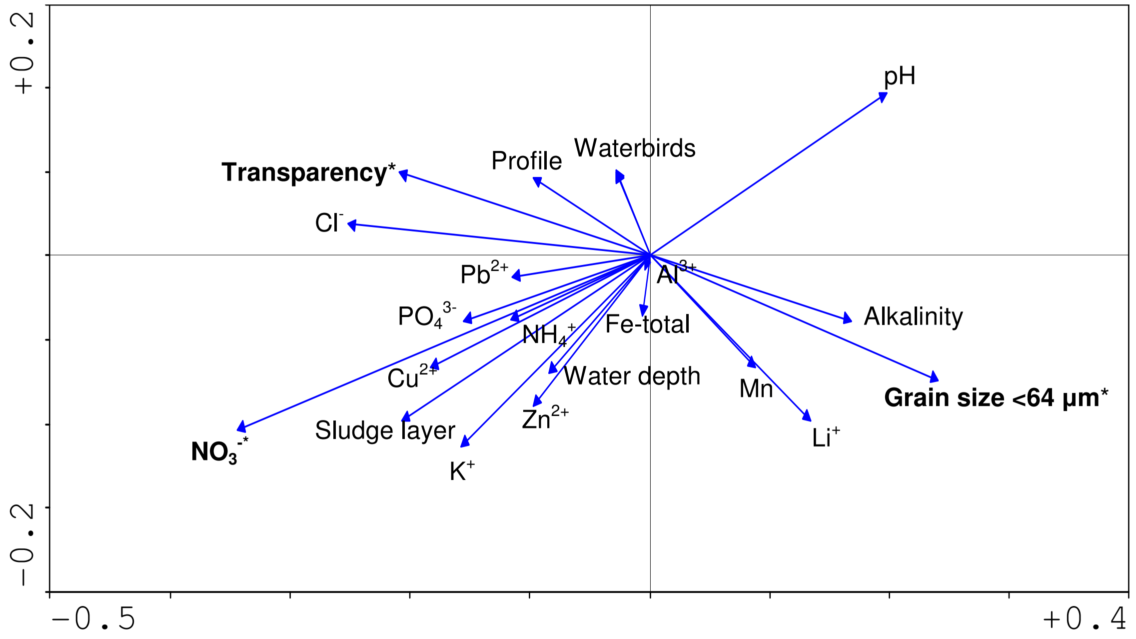

Fig. 12b Detrended correspondence analysis of environmental variables. *: environmental variables significantly explaining variation in vegetation assemblages in Canonical Correspondence analysis, 500 Monte Carlo permutations ($p<0.05$).

3.2.4 Macroinvertebrate biodiversity

Approximately 13% of the water macroinvertebrate species occurring in the Netherlands were found in the urban water systems of Nijmegen and Arnhem (Table 9). Approximately 50% of the species within the groups of Tricladida and Gastropoda were present in the urban water systems, but Plecoptera were absent.

Table 9 Number of macroinvertebrate species appearing in the urban water systems in Arnhem and Nijmegen and percentage of species in the urban water systems of the total number of species occurring in freshwater in the Netherlands.

	Urban water (#)	Urban water (%)
Tricladida	7	50[i]
Gastropoda	21	50[j]
Bivalvia[a]	4	25[j]
Hirudinea[b]	7	41[k]
Crustacea	7	14[i,l]
Odonata[c,d,e]	10	24[m,n]
Ephemeroptera	6	10[i]
Plecoptera	0	0[o]
Heteroptera[f,g]	18	33[p]
Coleoptera[h]	9	3[q]
Trichoptera	22	12[r,s]
Total	111	13

The following species were merged in one group:
[a] *Pisidium* sp., [b] *Erpobdella* sp., [c] *Aeshna* sp., [d] Libellulidae, [e] *Coenagrion puella/ pulchellum* and *Ischnura elegans,* [f] *Gerris* sp., [g] *Notonecta* sp., [h] Hydrophilidae.
References number of species in the Netherlands: [i] Mol, 1984, [j] Gittenberg et al., 1998, [k] Nederlands Soortenregister, 2008, [l] Van der Velde et al., 2000, [m] Bos and Wasscher, 1997, [n] Dijkstra et al., 2002, [o] Koese, 2008, [p] Aukema et al., 2002, [q] Drost et al., 1992, [r] Higler, 2005, [s] Higler, 2008.

Taxa richness in the nutrient-poor urban water (type 2) and the richly vegetated urban water (type 3) did not differ significantly from the other water systems (Fig. 13). Taxa richness was lowest in the turbid urban water (type 1) and the nutrient-rich urban water (type 4), although not significantly different from taxa richness in canals. The Shannon-index was highest in ditches; urban water systems had an intermediate Shannon-index. No red list species were found in the nutrient-rich urban water body type 4 and in lotic waters. The number of exotic species was highest in the nutrient-rich urban water (type 4) and lowest in lotic waters. Rareness did not differ significantly between water types.

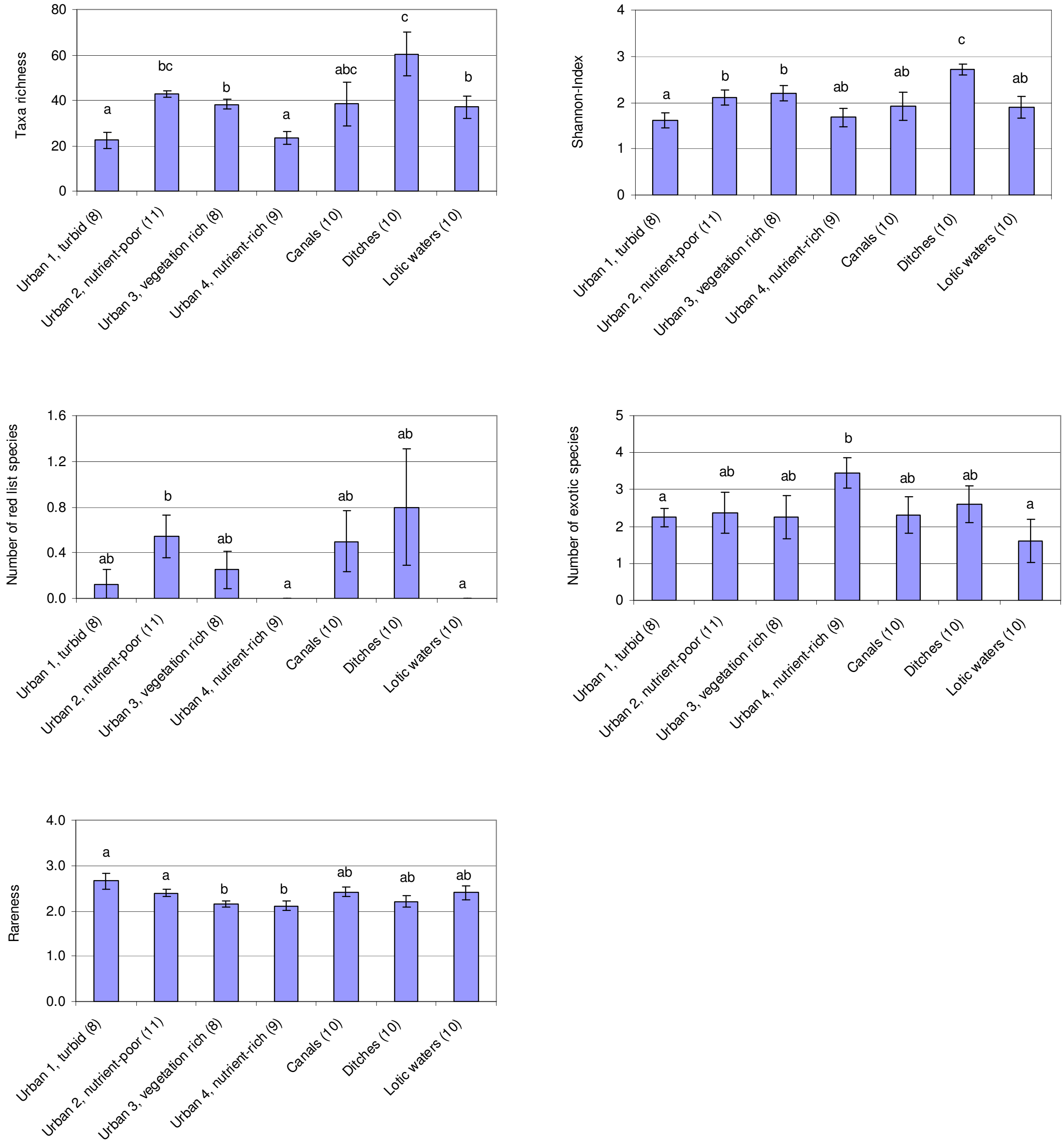

Fig. 13 Average values for ecological indicators in the four urban water systems and in drainage systems in rural areas and (semi)natural water courses. Error bars represent the standard error. Significant differences between water body types are indicated with a,b and c (Student's t-test, $p<0.05$).

Chapter 4 Influence of storm water run-off and upward seepage from rivers/ canals

4.1 Effects of urbanization on water systems

Water systems are strongly influenced by urbanization changing the hydrology, morphology, water chemistry, and flora and fauna (Ehrenfeld, 2000, Paul & Meyer, 2001, Walsh et al., 2005). Urbanization changes both the type and the magnitude of runoff processes (Booth & Jackson, 1997). Vegetation is cleared, soils compacted, ditched and drained and land surface is covered with impervious roofs and roads. The infiltration capacity is lowered and runoff is transported rapidly to stream channels.

Catchments imperviousness is one of the primary determinants of the quantity and quality of urban storm water runoff delivered to receiving water systems (Booth & Jackson, 1997, Walsh et al., 2000, Brabec et al., 2002). A distinction is made between total impervious area (TIA) and effective impervious area (EIA). TIA is the fraction of the watershed covered by constructed, non-infiltrating surfaces (Booth & Jackson, 1997). Effective imperviousness (EIA) only includes impervious surfaces that are directly connected to streams, and excludes drains onto pervious grounds. EIA is the parameter normally used to characterize urban development in hydrologic models.

Approximately 10 percent effective impervious area causes significant physical and biological effects in urban water systems (Schueler, 1995, Booth & Jackson, 1997). Scheuler (1995) summarized a number of studies that showed decreases in several ecological indicators for macroinvertebrates and fish in urban water systems with an increasing impervious area. Booth & Jackson (1997) showed that erosion of the bed and banks of channels took place when imperviousness exceeded 10 percent. Even lower levels of urban development can cause significant damage, but can not so easily be quantified (Booth & Jackson, 1997, May et al., 1997).

In Nijmegen urban water systems seem to be more strongly influenced by local upward seepage than by impervious area. People living close to the Meuse-Waal canal complain about wet basements and water quality close to the canal seems to be degraded.

4.2 Correlations water quality and effective impervious area, upward seepage and geology

Relationships between nitrate, effective impervious area, upward seepage and permeability of the soil indicated that upward seepage from the Meuse-Waal canal was much more important for nitrate concentration in the surface waters than effective impervious area (Fig. 14).

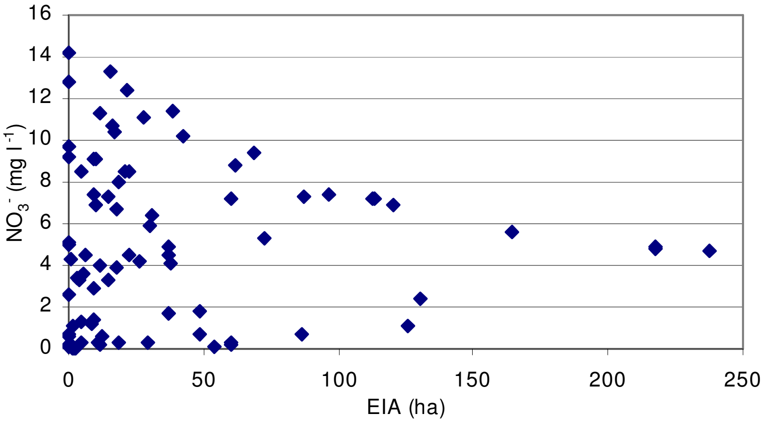

Fig. 14a Relationship between nitrate and effective impervious area in the wet period.

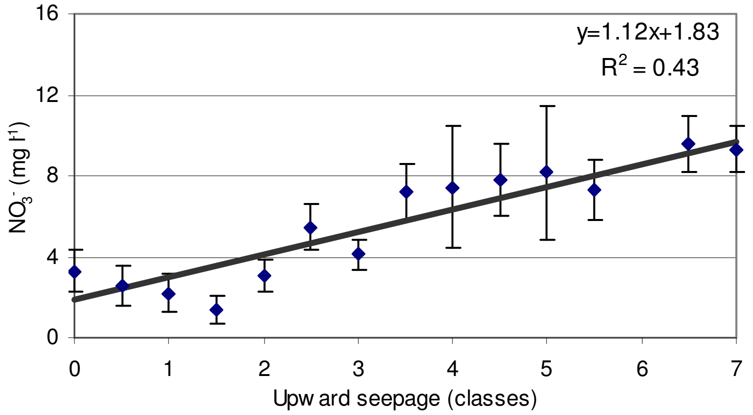

Fig. 14b Relationship between nitrate and upward seepage in the wet period (average values for each class is displayed with standard errors, the regression line is based on all measurements, instead of averages). Upward seepage is divided in seven classes, ranging from no upward seepage (0) to more than 30 mm upward seepage day^{-1} (7).

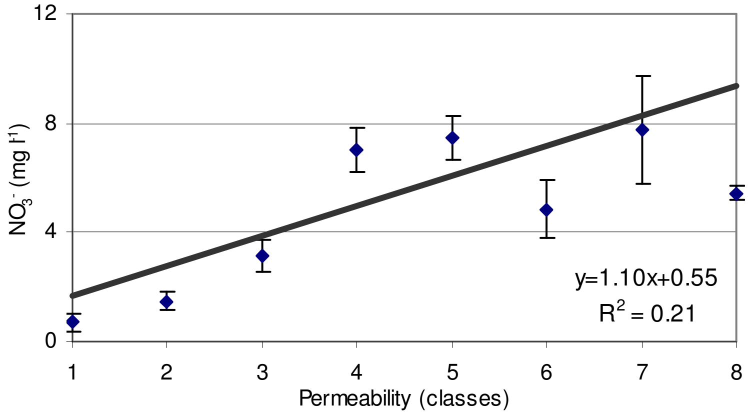

Fig. 14c Relationship between nitrate and permeability in the wet period (average values for each class is displayed with standard errors, the regression line is based on all measurements, instead of averages). Permeability ranged from least to most permeable and was classified from 1 to 8 (from heavy clay to sand/ gravel).

A summary of the correlations between EIA, upward seepage and permeability and water quality parameters was shown in table 10. Very few correlations were found between water quality parameters and EIA. Upward seepage and permeability were correlated with most water quality parameters, both in the dry period and the wet period. Correlations between water quality and permeability were very similar to correlations between water quality and upward seepage. The more permeable the soil is, the more upward seepage can flow into the urban area.

Table 10 Correlations between environmental variables and upward seepage, permeability, effective impervious area (EIA) (Spearman's correlation) in a dry and a wet period.

	Dry			Wet		
	EIA	Upward seepage	Permeability	EIA	Upward seepage	Permeability
NO_3^- (mg l^{-1})	0.09	0.65***	0.50***	0.13	0.61***	0.52***
NH_4^+ (mg l^{-1})	-0.10	-0.42***	-0.40***	0.10	0.09	0.26**
PO_4^{3-} (mg l^{-1})	0.27**	0.20*	0.17	0.06	0.40***	0.41***
Total-P (mg l^{-1})	0.05	0.06	0.13	-0.05	0.42***	0.44***
Total-S (mg l^{-1})	0.09	-0.06	0.06	0.09	-0.03	0.00
K^+ (mg l^{-1})	-0.03	0.57***	0.73***	0.09	0.50***	0.54***
Na^+ (mg l^{-1})	0.00	0.50***	0.66***	0.20*	0.31**	0.21*
Cl^- (mg l^{-1})	-0.08	0.48***	0.66***	0.15	0.19*	0.13
pH	-0.23	-0.22*	-0.06	-0.17	-0.38***	-0.31**
Alkalinity (meq l^{-1})	-0.05	-0.29**	-0.21*	0.03	-0.43***	-0.57***
Ca^{2+} (mg l^{-1})	-0.02	-0.36***	-0.24*	0.06	-0.42***	-0.61***
Mg^{2+} (mg l^{-1})	0.19*	-0.35**	-0.27**	0.14	-0.39***	-0.56***
Li^+ (µg l^{-1})	0.08	0.32**	0.10	0.06	0.31**	0.05
Total-Fe (µg l^{-1})	0.28**	-0.50***	-0.40***	0.22*	-0.29**	-0.35**
Al^{3+} (µg l^{-1})	0.02	-0.27**	-0.04	-0.15	0.18*	0.37***
Cu^{2+} (µg l^{-1})	-0.10	-0.09	-0.03	-0.14	0.48***	0.67***
Zn^{2+} (µg l^{-1})	0.18	-0.14	-0.06	-0.01	0.34**	0.42***
Pb^{2+} (µg l^{-1})	0.05	-0.24*	-0.04	-0.07	0.20*	0.40***

* $p<0.05$; ** $p<0.01$; *** $p<0.001$

Chapter 5 Assessment of ecological status

5.1 Physico-chemical quality

Physico-chemical quality was assessed based on nutrients, metals and other physico-chemical parameters (Appendix 3). In more than half of the locations in Nijmegen the target value for nitrogen was exceeded, although the Maximum Allowable Concentration (MAC) was exceeded in only once. In Arnhem the MAC for nitrogen was exceeded in one location (A14) and the MAC for phosphate was also exceeded once in location A5. Chloride concentrations were generally very low. Zinc exceeded the MAC in all locations and nickel in a few locations. Levels of cadmium and lead were complying well with standards. Transparency was lower than 40 cm in two locations in Arnhem: A5 and A8. Temperature and pH comply with standards. Physico-chemical quality was moderate to good in all locations. Metals were on average moderate to good, while nutrients and other physico-chemical parameters were on average good. The zinc (and nickel) concentrations exceeded the standards and were the most important cause for a moderate status instead of a good status.

5.2 Hydromorphological quality

Depth near the bank and the slope of the bank was used to assess the hydromorphological quality (Appendix 4). In a lot of locations the depth near the bank was more than half a metre and the slope of the bank was generally more than 30 degrees. Hydromorphological quality indicated that banks in urban water systems were generally not very natural.

5.3 Biological quality

Biological quality ratios were calculated for vegetation, macroinvertebrates and waterbirds (Appendix 5). The relative number of exotic species was generally high, especially in Lindenholt, although these species did not dominate the native species in abundance. Rareness was usually high when diversity was also high, but in a few locations diversity was low and rareness high. The number of waterbirds was generally high in urban water systems. Biological quality varied from bad to good. The two locations in Nijmegen with a dominating cover with duckweed obtained a bad status. Locations of poor status were mostly found in Nijmegen, and in one location in Arnhem (A8).

5.4 Overall ecological status

The ecological status was determined by combining the physico-chemical quality and the biological quality (table 11). Since the physico-chemical quality was moderate to good, the biological quality was usually most important for determining the final ecological status classes (waterbirds and hydromorphological quality were not included for obtaining the biological quality and ecological status respectively).

Table 11 Ecological status of the water bodies with quality ratios for physico-chemical, biological and hydromorphological parameters. Colours indicate quality classes: green = good, yellow = moderate, orange = poor and red = bad.

Locations	Ecological status	**Physico-chemical quality**	*Nutrients/ macro-ion*	*Metals*	*Other physico-chemical parameters*	**Biological**	*Flora*	*Macroinvertebrates*	*Waterbirds (#/ha)*	**Hyrdomorphological**
8*	🟧	🟨	*0.78*	*0.56*	*0.88*	🟧	*0.37*	*0.55*	*0.89*	**0.61**
9*	🟨	🟨	*0.95*	*0.48*	*0.75*	🟨	*0.50*	*0.46*	*0.78*	**0.57**
13A	🟥	🟨	*0.69*	*0.46*	*0.90*	🟥	*0.25*	*0.07*	*0.38*	**0.62**
16B	🟧	🟨	*0.82*	*0.56*	*0.90*	🟧	*0.57*	*0.29*	*0.19*	**0.48**
19A	🟩	🟩	*0.77*	*0.67*	*0.84*	🟩	*0.87*	*0.66*	*0.17*	**0.41**
21	🟧	🟨	*0.69*	*0.56*	*0.81*	🟧	*0.70*	*0.30*	*0.08*	**0.39**
24	🟨	🟨	*0.78*	*0.57*	*0.91*	🟩	*0.89*	*0.70*	*0.07*	**0.55**
26B	🟩	🟩	*0.85*	*0.61*	*0.83*	🟩	*0.90*	*0.66*	*0.84*	**0.54**
27	🟩	🟩	*0.91*	*0.63*	*0.72*	🟩	*0.80*	*0.64*	*0.76*	**0.62**
37	🟨	🟩	*0.65*	*0.68*	*0.89*	🟨	*0.56*	*0.51*	*0.18*	**0.35**
40	🟧	🟩	*0.63*	*0.62*	*0.87*	🟧	*0.77*	*0.35*	*0.19*	**0.55**
48	🟧	🟩	*0.81*	*0.60*	*0.82*	🟧	*0.37*	*0.61*	*0.55*	**0.44**
49	🟨	🟩	*0.69*	*0.60*	*0.86*	🟨	*0.90*	*0.42*	*0.85*	**0.40**
52	🟧	🟨	*0.81*	*0.46*	*0.93*	🟧	*0.44*	*0.30*	*0.70*	**0.67**
58	🟨	🟨	*0.67*	*0.48*	*0.92*	🟨	*0.69*	*0.53*	*0.84*	**0.69**
59C	🟨	🟨	*0.76*	*0.57*	*0.87*	🟩	*0.61*	*0.62*	*0.68*	**0.65**
64B	🟥	🟨	*0.80*	*0.56*	*0.92*	🟥	*0.25*	*0.14*	*0.69*	**0.58**
68	🟧	🟩	*0.79*	*0.63*	*0.92*	🟧	*0.90*	*0.34*	*0.78*	**0.73**
69	🟧	🟨	*0.72*	*0.58*	*0.92*	🟧	*0.52*	*0.27*	*0.01*	**0.68**
70	🟧	🟩	*0.70*	*0.60*	*0.93*	🟧	*0.69*	*0.35*	*0.19*	**0.53**
71	🟨	🟩	*0.81*	*0.71*	*0.84*	🟨	*0.50*	*0.51*	*0.80*	**0.45**
73	🟨	🟩	*0.93*	*0.68*	*0.74*	🟨	*0.50*	*0.48*	*0.60*	**0.36**
80	🟧	🟩	*0.80*	*0.61*	*0.91*	🟧	*0.34*	*0.50*	*0.19*	**0.40**
81A	🟨	🟨	*0.91*	*0.59*	*0.65*	🟨	*0.50*	*0.62*	*0.15*	**0.64**
81B	🟨	🟨	*0.93*	*0.57*	*0.66*	🟨	*0.50*	*0.45*	*0.60*	**0.50**
84B	🟩	🟩	*0.96*	*0.67*	*0.79*	🟩	*0.90*	*0.74*	*0.78*	**0.45**
87B	🟨	🟩	*0.99*	*0.79*	*0.80*	🟨	*0.90*	*0.59*	*1.00*	**0.81**
A1	🟨	🟩	*0.95*	*0.70*	*0.72*	🟨	*0.52*	*0.67*	*0.91*	**0.59**
A2	🟨	🟩	*0.86*	*0.71*	*0.77*	🟨	*0.90*	*0.52*	*0.74*	**0.39**
A3	🟨	🟩	*0.90*	*0.67*	*0.88*	🟨	*0.90*	*0.58*	*0.49*	**0.46**
A4	🟩	🟩	*0.85*	*0.73*	*0.71*	🟩	*0.74*	*0.71*	*0.19*	**0.34**
A5	🟨	🟩	*0.61*	*0.64*	*0.70*	🟨	*0.50*	*0.65*	*0.81*	**0.53**
A6	🟨	🟩	*0.97*	*0.79*	*0.70*	🟨	*0.80*	*0.56*	*0.17*	**0.68**
A7	🟨	🟩	*0.95*	*0.71*	*0.70*	🟨	*0.57*	*0.47*	*0.17*	**0.63**
A8	🟧	🟩	*0.84*	*0.69*	*0.65*	🟧	*0.71*	*0.24*	*0.17*	**0.53**
A9	🟩	🟩	*0.94*	*0.65*	*0.76*	🟩	*0.72*	*0.73*	*0.68*	**0.78**
A11	🟨	🟩	*0.93*	*0.72*	*0.68*	🟨	*0.72*	*0.41*	*0.75*	**0.45**
A12	🟩	🟩	*0.95*	*0.60*	*0.76*	🟩	*0.63*	*0.71*	*1.00*	**0.62**
A13*	🟨	🟨	*0.77*	*0.53*	*0.76*	🟨	*0.55*	*0.49*	*0.87*	**0.45**
A14*	🟨	🟨	*0.62*	*0.57*	*0.91*	🟩	*0.75*	*0.65*	*0.18*	**0.60**

* Locations monitored in 2007

Furthermore the ecological status was determined in the different urban water types and in the different quarters (table 12). Ecological status was moderate in the turbid urban water type and poor in the nutrient-rich urban water type. All quarters obtained a moderate ecological status, with the exception of south-west Arnhem, which obtained a good ecological status.

Table 12 Ecological status of the urban water types and the quarters with ecological quality ratios for physico-chemical and biological parameters. Colours indicate quality classes: green = good, yellow = moderate, orange = poor and red = bad.

Water types	Ecological status	**Physico-chemical quality**	*Nutrients/ macro-ion*	*Metals*	*Other physico-chemical parameters*	**Biological**	*Vegetation*	*Macroinvertebrates*	*Waterbirds (#/ha)*	**Hyrdomorphological**
Urban 1, turbid	🟨	🟩	0.85	0.65	0.75	🟨	0.58	0.53	0.51	0.51
Urban 2, nutrient-poor	🟩	🟩	0.90	0.68	0.78	🟩	0.77	0.64	0.68	0.59
Urban 3, vegetation-rich	🟩	🟩	0.78	0.63	0.85	🟩	0.72	0.49	0.44	0.48
Urban 4, nutrient-rich	🟧	🟨	0.74	0.56	0.87	🟧	0.52	0.30	0.36	0.57
Quarters										
Lindenholt	🟨	🟩	0.84	0.63	0.82	🟨	0.59	0.47	0.46	0.53
Dukenburg	🟨	🟩	0.77	0.59	0.86	🟨	0.65	0.46	0.51	0.55
Neerbosch	🟨	🟨	0.87	0.52	0.82	🟨	0.43	0.50	0.84	0.59
Arnhem south-west	🟩	🟩	0.88	0.70	0.75	🟩	0.70	0.60	0.57	0.58
Arnhem south-east	🟨	🟩	0.89	0.69	0.70	🟨	0.70	0.52	0.53	0.49
Arnhem north	🟨	🟨	0.69	0.55	0.83	🟨	0.65	0.57	0.52	0.52

Chapter 6 Effectiveness of rehabilitation measures

6.1 Effects of rehabilitation measures

6.1.1 Ecological status

Physico-chemical quality was mainly determined by metals, especially in 2006 zinc was responsible for the moderate physico-chemical status (appendix 6). The first two locations in Nijmegen (13A and 64B) changed from bad ecological status in 2005 to moderate or poor ecological status in 2006 and 2007 (table 13). The dominance of duckweed in 2005 was absent in 2006 and 2007 (appendix 8). Furthermore macroinvertebrates changed from bad status to moderate or poor status in these locations. Location 19A, where no rehabilitation measures took place, decreased slightly in ecological status, in 2006 metals caused the decrease, while in 2007 macroinvertebrates reached a moderate status.

Table 13 Comparison of ecological status, physico-chemical quality and biological quality in Nijmegen from 2005 till 2007. Similar locations with and without rehabilitation measures were sorted together.

Locations		13A	64A	19A	48	49	24	59B	71	73	81A	81B
Rehabilitation measures												
Dredging 2005-2006			X								X	X
Dredging 2006-2007								X				
Natural banks 2006-2007					X	X					X	X
Ecological status	2005	🟥	🟥	🟩	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨
	2006	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟧
	2007	🟨	🟧	🟨	🟨	🟧	🟨	🟨	🟧	🟧	🟧	🟨
Physico-chemical quality	2005	🟨	🟨	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟨	🟨
	2006	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
	2007	🟨	🟨	🟩	🟨	🟨	🟨	🟩	🟨	🟨	🟩	🟩
Nutrients/ macro-ion	2005	*0.69*	*0.80*	*0.77*	*0.81*	*0.69*	*0.78*	*0.76*	*0.81*	*0.93*	*0.91*	*0.93*
	2006	*0.50*	*0.73*	*0.75*	*0.68*	*0.68*	*0.73*	*0.61*	*0.82*	*1.00*	*0.82*	*0.91*
	2007	*0.55*	*0.82*	*0.75*	*0.72*	*0.72*	*0.71*	*0.61*	*0.83*	*0.98*	*0.93*	*0.90*
Metals	2005	*0.46*	*0.56*	*0.67*	*0.60*	*0.60*	*0.57*	*0.57*	*0.71*	*0.68*	*0.59*	*0.57*
	2006	*0.55*	*0.44*	*0.40*	*0.42*	*0.44*	*0.51*	*0.45*	*0.46*	*0.51*	*0.52*	*0.49*
	2007	*0.56*	*0.50*	*0.60*	*0.53*	*0.47*	*0.60*	*0.65*	*0.59*	*0.55*	*0.62*	*0.61*
Other physico-chemical parameters	2005	*0.90*	*0.92*	*0.84*	*0.82*	*0.86*	*0.91*	*0.87*	*0.84*	*0.74*	*0.65*	*0.66*
	2006	*0.91*	*0.93*	*0.91*	*0.93*	*0.92*	*0.87*	*0.91*	*0.72*	*0.64*	*0.77*	*0.78*
	2007	*0.89*	*0.93*	*0.91*	*0.84*	*0.88*	*0.90*	*0.91*	*0.88*	*0.79*	*0.77*	*0.74*
Biological	2005	🟥	🟥	🟩	🟧	🟨	🟩	🟩	🟨	🟨	🟨	🟨
	2006	🟨	🟨	🟩	🟨	🟨	🟨	🟩	🟨	🟨	🟨	🟧
	2007	🟨	🟧	🟨	🟨	🟧	🟩	🟨	🟧	🟧	🟧	🟨
Vegetation	2005	*0.25*	*0.25*	*0.87*	*0.37*	*0.90*	*0.89*	*0.61*	*0.50*	*0.50*	*0.50*	*0.50*
	2006	*0.48*	*0.48*	*0.84*	*0.59*	*0.82*	*0.90*	*0.69*	*0.50*	*0.50*	*0.50*	*0.50*
	2007	*0.50*	*0.47*	*0.79*	*0.76*	*0.58*	*0.83*	*0.53*	*0.51*	*0.50*	*0.50*	*0.65*
Macroinvertebrates	2005	*0.07*	*0.14*	*0.66*	*0.61*	*0.42*	*0.70*	*0.62*	*0.51*	*0.48*	*0.62*	*0.45*
	2006	*0.40*	*0.46*	*0.61*	*0.67*	*0.43*	*0.49*	*0.62*	*0.42*	*0.55*	*0.59*	*0.31*
	2007	*0.40*	*0.24*	*0.40*	*0.47*	*0.30*	*0.61*	*0.59*	*0.37*	*0.38*	*0.33*	*0.51*
Waterbirds (#/ha)	2005	*0.38*	*0.69*	*0.17*	*0.55*	*0.85*	*0.07*	*0.68*	*0.80*	*0.60*	*0.15*	*0.60*
	2006	*0.47*	*0.19*	*0.82*	*0.83*	*0.15*	*0.19*	*0.26*	*0.80*	*0.51*	*0.94*	*0.85*
	2007	*0.26*	*0.62*	*0.53*	*0.42*	*0.19*	*0.00*	*0.78*	*0.63*	*0.77*	*0.70*	*0.85*
Hyrdomorphological	2005	**0.62**	**0.58**	**0.41**	**0.44**	**0.40**	**0.55**	**0.65**	**0.45**	**0.36**	**0.64**	**0.50**
	2006	**0.74**	**0.56**	**0.72**	**0.46**	**0.55**	**0.57**	**0.70**	**0.45**	**0.30**	**0.72**	**0.55**
	2007	**0.51**	**0.49**	**0.62**	**0.45**	**0.84**	**0.50**	**0.56**	**0.60**	**0.41**	**0.95**	**0.84**

Location 48 shifted from a poor status in 2005 to a moderate status in 2006 and 2007, while the opposite happened in location 49: a shift from moderate to poor status after 2005. The development of natural banks in 48 and 49 took place just before the monitoring in spring 2007. Especially in location 49 the new design of the pond created a lot of disturbance in 2007. No apparent changes took place in location 24 and 59C between 2005 and 2007. In the locations in Lindenholt (71, 73, 81A, 81B) some shifts took place from a moderate to poor status. There was no apparent difference between the locations where dredging and development of natural banks took place and the locations where these measures did not take place.

In the first group of locations in Arnhem, location A6 shifted from moderate to good status, while location A2 shifted form good to moderate status (table 14). In both locations macroinvertebrates were responsible for the shift. In the next group of locations, A7 shifted from a moderate to poor status, due to a shift in macroinvertebrates, A9 changed from good to moderate, due to a shift in metals. Location A4 and A12 changed from a good status to a moderate status, both due to a change in metals and macroinvertebrates. Location A8 shifted from a poor to a bad status. Transparency in this water body was very low in 2007 (appendix 6).

Table 14 Comparison of ecological status, physico-chemical quality and biological quality in Arnhem between 2005 (locations were monitored in autumn 2005 and spring 2006) and 2007. Similar locations with and without rehabilitation measures were sorted together.

Locations		A6	A1	A2	A3	A5	A7	A9	A4	A11	A12	A8
Remarks						Effluent purification plant		Sewage overflow	Illicit connections			Inlet Linge
Rehabilitation measures												
Dredging 2005-2006		X	X		X	X	X	X		X		
Dredging 2006-2007				X								X
Natural banks 2005-2006							X					
Filter system 2005-2006			X	X	X							
Ecological status	2005	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟨	🟩	🟧
	2007	🟩	🟨	🟧	🟨	🟨	🟧	🟨	🟨	🟨	🟨	🟥
Physico-chemical quality	2005	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	2007	🟩	🟨	🟨	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨
Nutrients/ macro-ion	2005	*0.97*	*0.95*	*0.86*	*0.90*	*0.61*	*0.95*	*0.94*	*0.85*	*0.93*	*0.95*	*0.84*
	2007	*0.95*	*0.78*	*0.86*	*0.97*	*0.91*	*0.86*	*0.83*	*0.96*	*0.77*	*0.89*	*0.85*
Metals	2005	*0.79*	*0.70*	*0.71*	*0.67*	*0.64*	*0.71*	*0.65*	*0.73*	*0.72*	*0.60*	*0.69*
	2007	*0.67*	*0.59*	*0.56*	*0.67*	*0.66*	*0.50*	*0.52*	*0.59*	*0.46*	*0.58*	*0.52*
Other physico-chemical parameters	2005	*0.70*	*0.72*	*0.77*	*0.88*	*0.70*	*0.70*	*0.76*	*0.71*	*0.68*	*0.76*	*0.65*
	2007	*0.90*	*0.88*	*0.70*	*0.78*	*0.80*	*0.72*	*0.74*	*0.90*	*0.81*	*0.86*	*0.64*
Biological	2005	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟨	🟩	🟧
	2007	🟩	🟩	🟧	🟨	🟨	🟧	🟩	🟨	🟩	🟨	🟥
Vegetation	2005	*0.80*	*0.52*	*0.90*	*0.90*	*0.50*	*0.57*	*0.72*	*0.74*	*0.72*	*0.63*	*0.71*
	2007	*0.78*	*0.62*	*0.76*	*0.76*	*0.55*	*0.50*	*0.75*	*0.51*	*0.88*	*0.76*	*0.76*
Macroinvertebrates	2005	*0.56*	*0.67*	*0.52*	*0.58*	*0.65*	*0.47*	*0.73*	*0.71*	*0.41*	*0.71*	*0.24*
	2007	*0.72*	*0.66*	*0.31*	*0.57*	*0.55*	*0.30*	*0.62*	*0.80*	*0.65*	*0.54*	*0.18*
Waterbirds (#/ha)	2005	*0.17*	*0.91*	*0.74*	*0.49*	*0.81*	*0.17*	*0.68*	*0.19*	*0.75*	*1.00*	*0.17*
	2007	*0.51*	*0.87*	*0.60*	*0.69*	*0.36*	*0.19*	*0.55*	*0.70*	*0.75*	*0.68*	*0.15*
Hyrdomorphological	2005	**0.68**	**0.59**	**0.39**	**0.46**	**0.53**	**0.63**	**0.78**	**0.34**	**0.45**	**0.62**	**0.53**
	2007	**0.62**	**0.58**	**0.48**	**0.67**	**0.58**	**0.79**	**0.55**	**0.43**	**0.33**	**0.60**	**0.54**

6.1.2 Biological quality indicators macroinvertebrates

Appendices 9-11 shows the changes in the biological quality indicators in the following situations: effects of dredging in Nijmegen, dredging in Arnhem, effects of filter systems in Arnhem. In the reference situation in Nijmegen, taxa richness and Shannon-index seemed to increase in 2007, although not significantly. Dredging resulted in a significant increase in taxa richness in Nijmegen, although in 2006 taxa richness was still significantly lower in the dredged locations, than in the reference locations (appendix 9). The relative abundance of exotic species seemed to decrease and rareness seemed to be higher in 2007 (not significant). In Arnhem the relative abundance of exotic species also decreased in all situations, although not significantly (appendix 10-11). There was no difference between locations were filtering of storm water took place and the reference locations. Average Score Per Taxon (ASPT) was lowest in 2006 in dredged and filtered locations.

6.1.3 Macroinvertebrate taxa turnover

In the city of Nijmegen dredged locations had a significantly higher netto species gain than the locations that were not dredged (fig. 15).

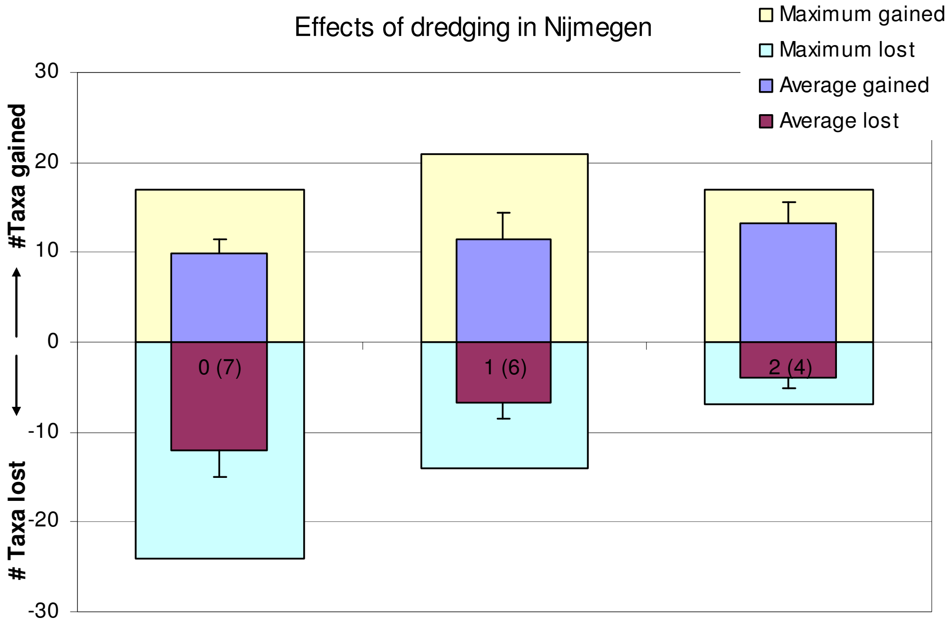

Fig. 15 Turnover of taxa without dredging (0 (7)), one year after dredging (1 (6)) and two years after dredging (2 (4)) in Nijmegen. The number in brackets indicates the number of observations.

No significant differences were found in taxa turnover after dredging, development of a natural bank or filtering of storm water in Arnhem (appendix 12).

6.1.4 Exact taxa accumulation curves

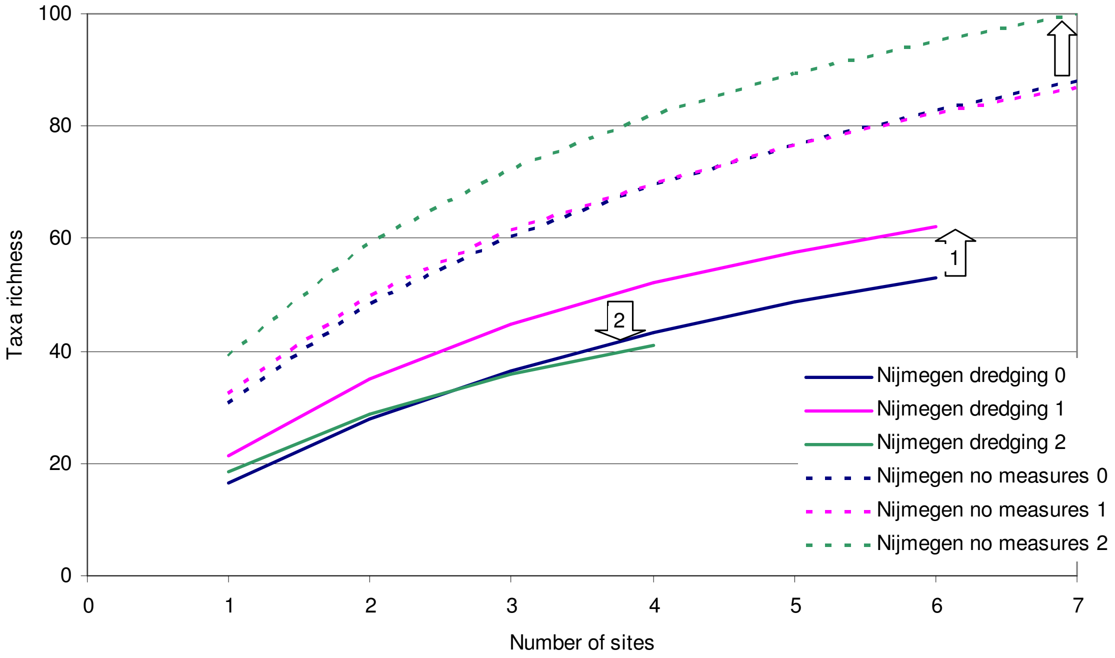

Fig. 16 Exact taxa accumulation curve for locations in Nijmegen that were dredged and locations where no rehabilitation measures took place, before any rehabilitation measures took place (0), one year after dredging 1 and two years after dredging.

In Nijmegen total taxa richness shifted in both dredged locations and locations where no rehabilitation measures took place (fig. 16). In the first year after dredging total taxa richness increased, while it decreased again in the second year. Total taxa richness increased in 2007 in the locations where no rehabilitation measures took place.

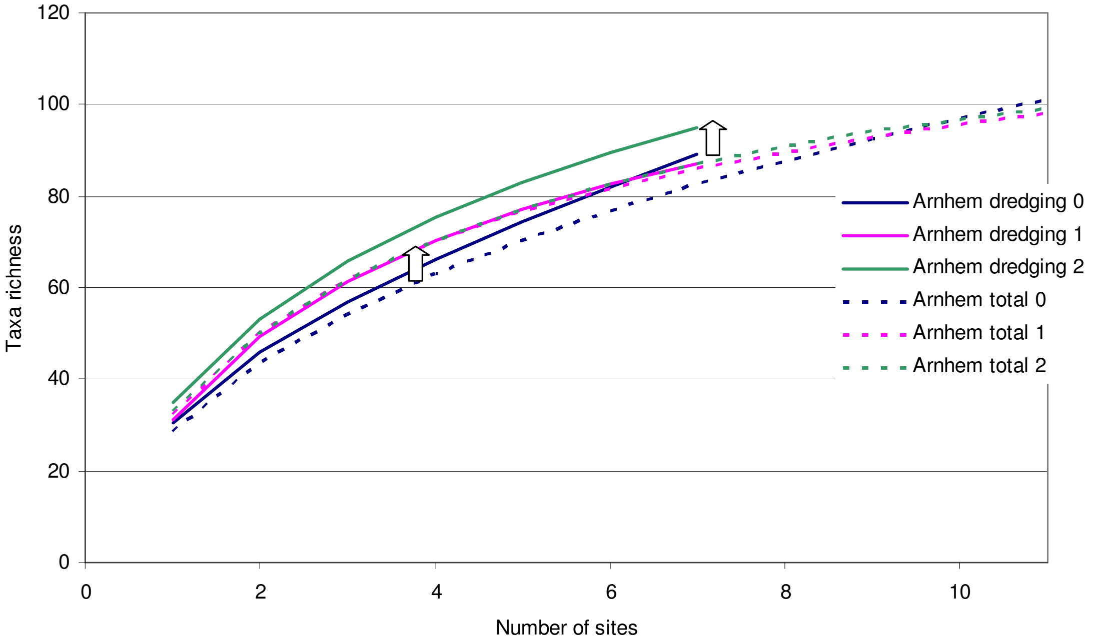

Fig. 17 Exact taxa accumulation curve for locations in Arnhem that were dredged and all locations in Arnhem, before any rehabilitation measures took place (0), one year after dredging 1 and two years after dredging.

The total taxa richness increased two years after dredging in Arnhem (Fig. 17). In all locations the taxa richness increased in the first part of the graph, when comparing 2005 with 2006 and 2007. This meant that in fewer sites more species could be found, while in total taxa richness did not increase much.

6.2 Changes in the water systems

6.2.1 Ecological status

On the water system level, very few changes were found between 2005 and 2006 in ecological status, physico-chemical quality and biological quality (table 15). The ecological status in Arnhem south-west shifted from good to moderate. Physico-chemical status changed, due to shifts in status within the metals. Macroinvertebrates in Arnhem south-west shifted from a good to moderate status.

Table 15 Comparison of ecological status, physico-chemical quality, biological quality and hydro-morphological quality in Dukenburg, Lindenholt, Arnhem south-west and Arnhem south-east in 2005, 2006 and 2007 (locations in Arnhem were monitored in autumn 2005 and spring 2006 (2005) and 2007).

		Dukenburg	Lindenholt	Arnhem south-west	Arnhem south-east
Ecological status	2005	🟨	🟨	🟩	🟨
	2006	🟨	🟨		
	2007	🟨	🟨	🟨	🟨
Physico-chemical quality	2005	🟨	🟩	🟩	🟩
	2006	🟨	🟨		
	2007	🟨	🟩	🟩	🟨
Nutrients/ macro-ion	2005	*0.76*	*0.90*	*0.88*	*0.89*
	2006	*0.67*	*0.89*		
	2007	*0.70*	*0.91*	*0.88*	*0.87*
Metals	2005	*0.58*	*0.64*	*0.70*	*0.69*
	2006	*0.46*	*0.49*		
	2007	*0.56*	*0.60*	*0.60*	*0.54*
Other physico-chemical parameters	2005	*0.88*	*0.72*	*0.75*	*0.70*
	2006	*0.91*	*0.73*		
	2007	*0.89*	*0.79*	*0.79*	*0.80*
Biological	2005	🟨	🟨	🟩	🟨
	2006	🟨	🟨		
	2007	🟨	🟨	🟨	🟨
Vegetation	2005	*0.59*	*0.50*	*0.70*	*0.70*
	2006	*0.68*	*0.50*		
	2007	*0.64*	*0.54*	*0.67*	*0.73*
Macroinvertebrates	2005	*0.46*	*0.51*	*0.60*	*0.52*
	2006	*0.53*	*0.47*		
	2007	*0.43*	*0.40*	*0.53*	*0.54*
Waterbirds (#/ha)	2005	*0.49*	*0.51*	*0.57*	*0.59*
	2006	*0.50*	*0.75*		
	2007	*0.44*	*0.68*	*0.55*	*0.53*
Hyrdomorphological	2005	**0.52**	**0.49**	**0.58**	**0.49**
	2006	**0.61**	**0.50**		
	2007	**0.57**	**0.70**	**0.61**	**0.47**

6.2.2 Biological quality indicators macroinvertebrates

In Dukenburg no significant changes took place in the biological quality indicators for macroinvertebrates (Appendix 13). The relative number of exotic species seems to decrease after 2005, although not significantly. The Shannon-index in Lindenholt was significantly lower in 2006 compared to 2005 and 2007 (Appendix 14). The relative number of exotic species increased significantly after 2005. Taxa richness seemed to increase in 2007, relative abundance of exotic species decrease after 2005 and ASPT decrease in 2007, but these changes were not significant.

Very few significant changes took place in Arnhem between the first monitoring (autumn 2005-spring 2006 and the last monitoring (Appendix 15-16). In Arnhem south-west the average score per taxon (ASPT) decreased in 2007, when compared with the first monitoring period (Appendix 15).

6.2.3 Feeding guilds macroinvertebrates

There were no apparent changes in feeding guilds divided over the different species (Appendix 17). In Dukenburg and Arnhem south-east there were generally less species in the spring seasons.

Chapter 7 Discussion

7.1 Reflection on methods

7.1.1 Monitoring macroinvertebrates

Macroinvertebrates were identified to different taxonomic levels, because some groups were difficult to identify to species level and identification was impossible for young larvae. Although species-level data might reveal more differences between locations, a higher taxa resolution can be sufficient to distinguish the larger between-site differences (Lenat and Resh, 2001). Hewlett (2000) found similar patterns when using species, family or genus level data in classifying stream sites in Australia. Furthermore, multivariate analysis on parts of the data set (for example only including Gastropoda, Crustacea, Ephemeroptera and Trichoptera, all identified to species level) did not reveal differences in typology of urban waters in comparison with analyses that included all taxa, identified to different taxonomic levels.

To avoid unreliable comparisons, the data set of the other drainage systems (STOWA, 2006), was transformed to the same taxonomic resolution as the urban water data set. In the database of the other water systems, there was not always data available on a spring and autumn season. In these cases, two other seasons were pooled for the analysis (spring and summer, summer and autumn, or two summers). Furthermore, there were slight differences in sampling techniques; macroinvertebrates were sampled over 5 m with a pond net, instead of 4 m and 3 benthic samples. We expect that such small differences in monitoring techniques did not significantly affect the comparisons of diversity indicators.

7.1.2 Effective impervious area, upward seepage and geology

Effective impervious area was calculated based on a map provided by the municipality of Nijmegen. This map delineated the impervious area connected to an inlet. Although the larger green areas were taken into account as pervious area, the smaller pervious patches, such as the gardens of the residents, were not separated from the impervious area. Probably this small amount of pervious areas did not make a substantial difference, when calculating the EIA.

Upward seepage was modelled by Witteveen+Bos (2006). Although the model was calibrated with 24 piezometers, there could be slight differences between the modelled upward seepage and the actual upward seepage. Furthermore for each location only a seepage class (for example 15-20 mm day^{-1}) could be calculated and not the actual value for upward seepage. These factors might have altered the accuracy of comparing water quality and upward seepage slightly.

Permeability was calculated based on geology maps. These geology maps gave only one soil type for each location. These vertical profiles consist of several soil types. Permeability was classified from least to most permeable, disregarding actual permeability, which was probably not evenly divided over these classes. Permeability is one of the most important factors determining the amount of upward seepage, and was therefore used to confirm relationships with upward seepage.

7.1.3 Assessment system

Physico-chemical parameters were assessed, using water quality standards from the Dutch Fourth National Document on Water Management (1998). Although the European WFD describes the elements that should be used to calculate the ecological status, the way to distinguish classes is not fixed. We considered a physico-chemical variable as poor or bad if the water quality standards were exceeded.

Biological quality should normally be assessed by comparing data with ‘natural’ reference values. For urban water systems a ‘natural’ reference was not available. A reference condition relates to a situation where no, or only very minor, anthropogenic alterations took place. The urban water systems in Arnhem and Nijmegen were designed and artificially made. As mentioned before, these urban water types differ from other water types in many ways (e.g. water quality, morphology, flora and fauna). It is therefore very difficult to compare urban water systems with a reference condition. Based on results of physico-chemical assessment and the comparison with other drainage system, an assessment system for biological quality was designed, by assuming that urban water systems are generally of a moderate/ good status. With this assumption, each parameter for determining the biological quality was divided in 4 classes, based on the median, 25th percentile and 5th percentile value.

7.1.4 Effectiveness of rehabilitation measures

In Arnhem monitoring did not take place in spring 2005. To compare ecological status with the following years autumn 2005 and spring 2006 were averaged. Since most rehabilitation measures took place in the winter of 2005/2006, this was not totally correct. Furthermore all locations in Arnhem were dredged, either before or during the monitoring period. Reference locations were not available. This limited the interpretation of the results.

7.2 Ecological function of urban water system

7.2.1 Typology

The turbid urban water bodies (type 1) harbour less submerged vegetation and very few macroinvertebrate taxa. In the absence of submerged vegetation, waves and benthivorous fish activities can cause high turbidity due to resuspension of suspended matter (Madsen et al., 2001, Gulati & Van Donk, 2002). Due to high turbidity, vegetation cannot develop fully. The lack of submerged vegetation probably caused the low number of macroinvertebrate taxa in the turbid water bodies.

In the nutrient-rich water bodies (type 4) macroinvertebrate taxa richness was also low, but the number of exotic species was highest. The increased amount of nutrients probably stimulated growth of algae and lemnids (*Lemna* sp.), inhibiting growth of submerged vegetation (Hough, 1989). Possibly the exotic species can cope better with these circumstances, filling vacant niches, left by the more sensitive native species. Brauns et al. (2007) also found more invasive species in hypertrophic lakes. Grabowski et al. (2007) argued that invasive gammarids have higher tolerances to environmental stressors (salinity, pollution, and habitat degradation) than native species, facilitating the invasion. Another explanation for the presence of these exotics in the highly eutrophic water bodies, is the much higher resource availability in such waters, increasing the probability of invasion in such waters (Van der Velde et al., 2006).

The nutrient-poor urban water bodies (type 2) sustained the highest number of macroinvertebrate taxa within the urban water systems and also the highest number of red list species. Next to submerged vegetation there was also nymphaeid vegetation present in some locations, creating more structure and a more diverse habitat for macroinvertebrate species (Den Hartog & Van der Velde, 1988).

The richly vegetated water bodies (type 3) also had a high macroinvertebrate taxa richness. This water body type had high nutrient levels, but submerged vegetation might have kept the water bodies in a ‘clear’ state (Scheffer et al., 1993). The abundant vegetation created ideal circumstances for the herbivorous gastropods that characterize the macroinvertebrate assemblage of this water type.

7.2.2 Correlations between environmental variables and ecological indicators

Correlations between environmental variables and ecological indicators in urban water systems demonstrated that nitrate was negatively correlated with taxa richness, number of red list species and rareness, and positively correlated with the number of exotic species (Table 2). Nutrients (e.g. nitrate) probably did not influence the macroinvertebrate assemblages directly, but did influence habitat availability via the vegetation composition and structure (Hough et al., 1989) and subsequently the macroinvertebrates.

Rareness was positively correlated with pH, but overall pH did not differ much between urban water types and pH-range was considered to have a minor influence in these urban water systems.

With sediment changing from sandy to clayey, taxa richness and number of red list species increased and number of exotic species decreased. In these urban water systems the water bodies with a sandy sediment were more strongly influenced by the nutrient-rich upward seepage from rivers and canals. Therefore it is expected that sediment composition only indirectly affected the ecological indicators by influencing the water quality and subsequently the type of vegetation.

Transparency was negatively correlated with rareness. Although the turbid urban water bodies sustained fewer species, these species might be more unique, because pioneer species in this type of water body were not present in many other water bodies.

Nymphaeid vegetation was positively correlated with taxa richness and rareness, while submerged vegetation was positively correlated with taxa richness and Shannon-index. Vegetation is very important for macroinvertebrates as habitat, food source, and shelter from predation (Crowder & Cooper, 1982, Dvořak & Best, 1982, Newman, 1991) and vegetation is known to influence the macroinvertebrates positively, depending on their growth form (Den Hartog & Van der Velde, 1988).

7.2.3 Vegetation

The turbid water bodies of type 1, based on macroinvertebrates, were probably not distinguished based on vegetation, because vegetation was mostly absent, and very few species occurred. Furthermore the most nutrient-rich water bodies (type 4) might not be so clearly distinguished, because vegetation was monitored in 2007 after dredging in a lot of locations and macroinvertebrates were monitored in 2005. Dredging probably reduced the growth of algae and floating plants, hereby the differences between the nutrient-rich water type and the richly vegetated water bodies became smaller.

The environmental variables important for the vegetation were also important for the macroinvertebrates: nitrate, transparency and grain size.

7.2.4 Macroinvertebrate biodiversity

A significant part of the aquatic macroinvertebrate species in the Netherlands was also present in the urban water systems of Arnhem and Nijmegen, including two red list species. Taxa richness in the nutrient-poor and richly vegetated urban water systems was comparable to the taxa richness in the other drainage systems: canals, ditches and (semi) natural lotic waters. In other studies macroinvertebrate biodiversity was always lower in urban areas (Paul and Meyer 2001, Lenat & Crawford 1994, Roy et al., 2003, Walsh et al., 2001). Possibly, the urban areas investigated in these studies were more degraded than the urban water systems studied here. Furthermore urban areas are usually situated downstream in the catchment (Walsh et al., 2001); hereby differences might be a result of the gradient from upstream to downstream, rather than the result of differences in land use only. Another reason for the contradiction could be that urban water systems were often investigated only in a natural-rural-urban gradient, disregarding any possible variation within the urban areas, while this study included an in-depth analysis of various urban water types.

7.3 Influence of upward seepage from rivers/ canals

Most water quality parameters were correlated with upward seepage and permeability. Very few were correlated with EIA. Upward seepage from the Meuse-Waal canal is much more important for the water quality in these urban water systems than the EIA. This is in contradiction to previous studies on urban water systems, where catchment imperviousness is the primary determinant of water quality and quantity in urban water system (Booth & Jackson, 1997, May et al., 1997, Walsh et al., 2000, Brabec et al., 2002).

7.4 Ecological status of urban water systems

Physico-chemical quality generally complied well with water quality standards. In more than half of the locations in Nijmegen the target value for nitrogen was exceeded, probably due to upward seepage from the Meuse-Waal canal. In Arnhem the MAC for nitrogen was exceeded in only one location (A14), where sewage overflows occurred. The MAC for phosphate was also exceeded only once, in Arnhem, where the effluent of the water purification plant is discharged. Zinc exceeded the MAC in all locations and nickel in a few locations. Zinc was probably coming from zinc gutters. Transparency was less than 40 cm in two locations in Arnhem: the location where the effluent of the water purification plant was discharged, and the location where water from the Linge was introduced in the urban area. The most important sources for water quality degradation seemed to be: local upward seepage, effluent from sewage overflows, water purification systems and inlet of rural water. Physico-chemical quality was moderate to good in all locations. The zinc (and nickel) concentrations exceeded the standards and were the most important cause for a moderate status instead of a good status.

Hydromorphological quality indicated that banks in urban water systems were generally not naturally shaped. Previously urban water systems were primarily designed to discharge water. The easiest and least space-consuming way to design these systems was with steep banks and hard wooden vertical bank protection. Deep water results in less light penetration and therefore less possibilities for submerged vegetation. In more natural water systems, banks are shallow and vegetation can expand from shallow parts. If light cannot penetrate deep enough, vegetation can be absent and waves and fish foraging activities can cause high turbidity due to resuspension of suspended matter (Madsen et al., 2001, Gulati and Van Donk, 2002).

The two locations in Nijmegen with a dominating cover with duckweeds (13A, 64A) obtained a bad status for biological quality. As mentioned previously the increased amount of nutrients probably stimulated growth of algae and lemnids (*Lemna* sp.), inhibiting growth of submerged vegetation (Hough, 1989). The permanent cover with lemnids created a harsh environment (e.g. low oxygen levels) for macroinvertebrates with little suitable habitat. Locations of poor status were mostly found in Nijmegen, and in one location in Arnhem (A8). This location in Arnhem had a very low transparency and a lot of water birds. Next to that this location received water from the Linge, which did not yet comply with water quality standards (Waterschap Rivierenland, 2007).

The nutrient-rich water type obtained the lowest score for ecological status (poor). The nutrient-poor and vegetation-rich urban water type obtained a good ecological status, while the turbid urban water bodies obtained a moderate status. This was in correspondence to what could be expected from the typology and the comparisons with the drainage systems in rural areas.

7.5 Effectiveness of rehabilitation measures

Location 13A and 64A in Nijmegen shifted from a bad ecological status to a moderate and poor ecological status in 2007, respectively. This shift could not directly be related to rehabilitation measures, because in location 13A no rehabilitation measures took place and in location 64A dredging took place.

Locations 48 and 49 in Nijmegen are situated only 40 metres apart. The physical reconstruction of the ponds took place late in the spring of 2007. Because of the short time after redesigning of the pond, shifts in ecological status could not be related to rehabilitation measures in these locations.

The shifts in Lindenholt (81A and 81B) from moderate to poor, could not be related to rehabilitation measures, because the changes also took place at locations without rehabilitation measures (71 and 73).

Location A2 shifted form good to moderate status. In both locations macroinvertebrates were responsible for the shift. Location A2 is located upstream from location A8, where water from the Linge is introduced in dry periods. Location A8 shifted from a poor to a bad status.

Possibly the effect from the Linge was larger in 2007 than in 2005/2006, although this was not clearly indicated by the physico-chemical quality. Transparency was much lower in 2007 than in 2005/2006 in location A2 and A8 (appendix 6).

There were very few locations (n=3-7) to test the effects of rehabilitation measures on biological quality parameters. Furthermore, the monitoring period after the rehabilitation measures was very short. Therefore it was very difficult to show statistically significant differences over time.
On the water system level ecological status changed very little over the period 2005-2007. Taxa richness increased in Nijmegen after dredging, while the relative abundance of exotic species seemed to decrease and rareness seemed to increase. Part of these locations shifted from a state where lemnids dominated to a state where lemnids were almost absent. In the last situation chances for (indigenous) macroinvertebrates are much better. The relative abundance of exotic species also seemed to decrease in Arnhem. Filtering of storm water did not seem to result in other effects, than when only dredging took place. Possibly this was related to the small scale of the filtering.
Taxa turnover confirmed these results: a positive netto species turnover was found in Nijmegen after dredging.
Total taxa richness changed a bit over the years in Nijmegen, but this could not be related to dredging. In Arnhem total taxa richness increased two years after dredging.
At the water system level ecological status, ecological indicators and feeding guilds did not change much in Dukenburg, Lindenholt, Arnhem south-west and Arnhem south-east.

Chapter 8 Conclusions and recommendations

8.1 Conclusions

In urban drainage systems in lowland areas along large rivers, four types of macroinvertebrate assemblages could be distuinguised, differing in environmental conditions and values for ecological indicators. Two types had low macroinvertebrate taxa richness: turbid water bodies and nutrient-rich water bodies with very poorly developed vegetation. The nutrient-rich water bodies were characterized by the highest numbers of exotic species. Two types showed high macroinvertebrate taxa richness associated with nutrient-poor water bodies and water bodies with a high cover of submerged vegetation. The highest number of red list species was found in the nutrient-poor water bodies. Herbivorous gastropods characterized the water bodies with a high cover of submerged vegetation. The most important environmental variables explaining variation in macroinvertebrate assemblages were nitrate, sediment composition, transparency, nymphaeid and submerged vegetation.

Formerly, urban water systems were considered to have a low biodiversity value. A significant part of the aquatic macroinvertebrate species in the Netherlands was also present in the urban water systems of Arnhem and Nijmegen, including two red list species. Ecological indicators did not differ significantly between urban water systems and other drainage systems. This study showed that urban water systems can sustain a high biodiversity comparable to man-made and (semi)natural rural drainage systems and can even be a habitat for several red list species.

The ecological status of the urban water systems in Nijmegen and Arnhem was generally moderate to good. Physico-chemical quality complied well with water quality standards in most cases, with the exception of zinc. Analysis of hydromorphological conditions indicated that banks in urban areas were generally very steep and often with hard wooden vertical bank protection. The biological quality in the nutrient-poor (type 2) and plant-rich (type 3) water bodies was good and in the turbid water bodies (type 1) the biological quality was moderate. The water bodies dominated by duckweeds was bad, and demanded improvement. The other nutrient-rich waterbodies (type 4) were also relatively low (poor).

The evaluation of rehabilitation measures showed that the macroinverterbate assemblages in urban water systems were quite stable. At the water system level the ecological status changed very little over the period 2005-2007. The previously lemnid-dominated water systems improved from a bad to moderate or poor status. This indicates that the removal or disappearance of lemnid vegetation has positive effects on the ecological status of water bodies. The water body that received nutrient-rich water from the Linge decreased from poor to bad. On the short term very few effects could be found from the rehabilitation measures dredging, filtering of storm water and development of natural banks. This could be caused by several reasons, e.g. the low number of locations that could be compared, and the short recovery time after measures took place. The rehabilitation measures generally disturb the water system and needs time to recover. Furthermore colonization by ‘new’ species could take several years, because of low mobility. In Nijmegen taxa richness increased significantly after dredging.

The main bottleneck for rehabilitating urban water systems in Nijmegen was the upward seepage from the Meuse-Waal canal, which introduces a lot of nutrients into the urban water systems. The upward seepage from the Meuse-Waal canal had a much larger impact on the water quality in urban water systems, than the impervious areas. Improvement of the ecological quality in the urban water systems demands reduction of nutrient loading of the rivers Meuse and Waal.

In Arnhem upward seepage from the river Rhine probably played a minor role, because the permeability of the soil was not so high. In Arnhem the main bottlenecks for rehabilitating urban water systems were the effluent of the water purification plant, effluent of sewage overflows, the inlet of water from the Linge and the (excessive feeding of) waterbirds.

Main conclusions:

- Four different urban water types were found: two with a low macroinvertebrate taxa richness; turbid and nutrient-rich urban waters, two with a high macroinvertebrate taxa richness; nutrient-poor and vegetation-rich urban waters.
- The most important environmental variables explaining variation in macroinvertebrate assemblages were nitrate content of surface water, sediment composition (clayey or sandy sediment), transparency, nymphaeid and submerged vegetation.
- Biodiversity in urban water systems was relatively high and very comparable to other drainage systems and even included two protected species.
- The ecological status or urban water systems in Nijmegen and Arnhem was moderate to good.
- The evaluation of rehabilitation measures showed that the macroinvertebrate assemblages in the urban water systems of Nijmegen and Arnhem were quite stable. On the short-term significant effects of rehabilitation measures were limited. Dredging had a positive effect on locations in Nijmegen.
- The main bottlenecks for rehabilitation urban water systems in Nijmegen and Arnhem were the water quality of the rivers/canals, sewage overflows, illicit connections, discharge of effluent of the water purification system, inlet of water from the Linge and the (excessive) feeding of waterbirds

8.2 Recommendations

On the short-term significant effects of rehabilitation could not be shown very clearly. Therefore it is recommended to continue monitoring, and subsequently repeat monitoring at least every 5 years. The main environmental variables for management of these urban water systems were shown: nutrients, development of vegetation and transparency. Management should aim at lowering nutrient levels (e.g. regular dredging, avoid inlet of nutrient-rich water, avoid pollution by sewage overflows and illicit connections, decrease (excessive) feeding of waterbirds and benthivorous fish), stimulate vegetation and transparency (optimize mowing regime, development of natural banks, decrease (excessive) feeding of waterbirds and benthivorous fish) (table 16).

Table 16: Potential long-term effects of rehabilitation measures. ++ indicates a clear positive effect, + indicates a positive effect and 0 indicates no effect.

	Nutrients*	Transparency	Submerged vegetation	Nymphaeid vegetation	Floating vegetation* (*Lemna* sp.)
Dredging	++	++	+	+	++
Development of natural banks	+	+	++	0	+
Cleaning of culverts	+	+	0	0	++
Filtering of storm water**	0	0	0	0	0
Optimizing mowing regime	+	+	++	++	0
Diminish sewage overflow	++	++	+	+	++
Decrease inlet/ upward seepage of river/ canal water	++	++	+	+	++
Measures to decrease feeding of waterfowl	+	++	++	+	+

*: ++ and + in these columns indicate a decrease of nutrients, sediment pollution and floating vegetation.

** due to small scale/ relative low percentage of treatment of run-off, potential effects are not expected.

Glossary

Amsterdam Ordnance Datum (AOD; Normaal Amsterdams Peil or NAP in Dutch): a vertical datum used in large parts of western Europe, close to average sea level at the Dutch coast.

Effective impervious area: effective imperviousness (EIA) includes impervious surfaces that are *directly* connected to streams.

Lemnid vegetation: free-floating aquatic plant from the duckweed family (e.g. fig 10, type 4).

Macroinvertebrates: aquatic invertebrates including insects, crustaceans, molluscs and flatworms.

Multivariate analysis: analysis of more than one statistical variable at a time.

Nymphaeid vegetation: plant rooted in the soil, mainly floating leaves and flowers on or above the water surface (e.g. fig 10 type 2).

Shannon-index: diversity index used to measure diversity, the index increases when additional species are found or if the evenness of the species increases.

Submerged vegetation: plant totally below the water surface (exception can be flowers).

Taxon (plural taxa) is a name designating an organism or group of organisms.

Total impervious area: the fraction of the watershed covered by constructed, non-infiltrating surfaces.

Upward seepage: seepage from groundwater in the upward direction

Water Framework Directive (WFD): a European Union directive which commits European Union member states to improve water bodies to a good qualitative and quantitative status in 2015

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Appendix 1 Overview of monitoring locations

	Spring '05	Autumn '05	Spring '06	Autumn '06	Spring '07	Autumn '07	Dredging '05-'06	Dredging '06-'07	Natural banks '05-'06	Natural banks '06-'07	Filter system '05-'06	Remarks
Nijmegen												
8				x	x	x						Sewage overflow
9				x	x	x						Sewage overflow
13A	x	x	x	x	x	x						
16	x	x										Not in evaluation effects
19A	x	x	x	x	x	x						
21	x	x										Not in evaluation effects
24	x	x	x	x	x	x						
26B	x	x										Not in evaluation effects
27	x	x										Not in evaluation effects
37	x	x										Not in evaluation effects
40	x	x										Not in evaluation effects
48	x	x	x	x	x	x				x		
49	x	x	x	x	x	x				x		
52	x	x										Not in evaluation effects
58	x	x										Not in evaluation effects
59B	x	x	x	x	x	x		x				
64A	x	x	x	x	x	x	x					
68	x	x										Not in evaluation effects
69	x	x										Not in evaluation effects
71	x	x	x	x	x	x						
73	x	x	x	x	x	x						
80	x	x										Not in evaluation effects
81C	x	x	x	x	x	x	x					
81D	x	x	x	x	x	x	x					
84B	x	x										Not in evaluation effects
87B	x	x										Not in evaluation effects

Arnhem

A1		x	x	x	x	x	x				x	
A2		x	x	x	x	x		x			x	
A3		x	x	x	x	x	x				x	
A4		x	x	x	x	x						Illicit connections
A5		x	x	x	x	x	x					Effluent purification plant
A6		x	x	x	x	x	x					
A7		x	x	x	x	x	x		x			
A8		x	x	x	x	x		x				Inlet Linge
A9		x	x	x	x	x	x					Sewage overflow
A11		x	x	x	x	x	x					
A12		x	x	x	x	x						
A13				x	x	x						Sewage overflow
A14				x	x	x						Sewage overflow

Appendix 2 Environmental variables in urban water types

Average values for environmental variables in the different water body types based on macroinvertebrates (minimum and maximum values in brackets). a and b indicate significant differences between types (bold, ANOVA, post-hoc Gabriel: $p<0.05$).

	Type 1	Type 2	Type 3	Type 4
NO_3^- (mg l^{-1})	**2.0^{a} (0.5-6.8)**	**1.3^{a} (0.0-4.7)**	**5.1^{b} (0.4-7.8)**	**5.7^{b} (0.7-10.3)**
NH_4^+ (mg l^{-1})	0.18 (0.05-0.81)	0.15 (0.02-0.30)	0.11 (0.03-0.33)	0.12 (0.04-0.16)
PO_4^{3-} (mg l^{-1})	0.17 (0.03-0.93)	0.06 (0.02-0.12)	0.10 (0.02-0.37)	0.12 (0.03-0.19)
Total-P (mg l^{-1})	0.06 (0.00-0.26)	0.03 (0.01-0.08)	0.04 (0.01-0.13)	0.05 (0.01-0.08)
Total-S (mg l^{-1})	11.4 (5.3-18.8)	10.0 (3.4-18.4)	12.6 (3.7-18.2)	13.6 (7.6-19.7)
K^+ (mg l^{-1})	4.5 (2.5-5.5)	4.7 (0.8-9.7)	4.0 (2.6-4.8)	5.5 (3.9-10.6)
Na^+ (mg l^{-1})	26 (18-36)	26 (19-36)	30 (27-34)	32 (27-36)
Cl^- (mg l^{-1})	**42^{ab} (33-57)**	**40^{a} (29-55)**	**48^{ab} (42-55)**	**50^{b} (46-58)**
pH	7.8 (7.5-8.1)	7.7 (7.4-9.2)	7.6 (7.1-8.6)	7.4 (7.1-7.9)
Alkalinity (meq l^{-1})	3.0 (2.1-4.8)	3.2 (0.9-5.1)	2.5 (1.9-4.2)	2.5 (2.0-4.3)
CO_2 (mg l^{-1})	5.9 (2.2-8.9)	9.0 (0.1-15.4)	10.6 (3.9-16.3)	10.8 (5.5-16.6)
HCO_3^- (mg l^{-1})	187 (125-313)	207 (56-344)	148 (108-256)	151 (116-266)
EC (µS m^{-1})	520 (393-647)	533 (288-667)	520 (477-632)	531 (482-656)
Ca^{2+} (mg l^{-1})	67 (49-87)	63 (14-88)	57 (47-73)	58 (49-79)
Mg^{2+} (mg l^{-1})	9.3 (7.9-11.2)	9.2 (3.0-13.3)	8.1 (7.2-9.6)	8.7 (7.4-13.0)
Li^+ (µg l^{-1})	2.0 (1.0-4.1)	3.5 (1.4-6.7)	2.5 (1.1-3.6)	2.2 (0.3-6.4)
Total-Fe (µg l^{-1})	67 (35-119)	168 (50-653)	146 (55-354)	68 (25-188)
Al^{3+} (µg l^{-1})	8.4 (4.6-15.5)	7.6 (4.2-13.3)	4.7 (2.3-7.1)	15.0 (2.3-90.2)
Cu^{2+} (µg l^{-1})	1.5 (0.7-3.3)	1.9 (0.8-6.3)	1.9 (0.7-3.9)	2.3 (0.7-5.1)
Zn^{2+} (µg l^{-1})	26 (19-40)	29 (10-55)	31 (23-48)	38 (26-68)
Pb^{2+} (µg l^{-1})	0.2 (0.1-0.3)	0.4 (0.1-1.1)	0.2 (0.1-0.5)	1.0 (0.1-3.1)
C/N content soil	11 (7-20)	14 (9-20)	13 (10-17)	11 (6-15)
% Grain size < 64 µm	**12^{a} (2-63)**	**54^{b} (1-97)**	**21^{ab} (3-69)**	**11^{a} (1-60)**
Transparency (Secchi (m))	**0.6^{a} (0.4-1)**	**0.8^{ab} (0.4-1)**	**0.9^{b} (0.5-1)**	**0.9^{b} (0.4-1)**
Profile (depth (m)*slope)	14 (6-26)	11 (3-27)	16 (3-27)	11 (4-23)
Stream velocity (cm s^{-1})	4.1 (2.8-10.5)	4.8 (2.8-9.7)	13.8 (3.6-60.4)	3.1 (2.6-4.0)
Width (m)	**22^{a} (12-30)**	**14^{ab} (5-30)**	**11^{b} (6-25)**	**12^{b} (8-20)**
Shadow (%)	58 (30-80)	55 (25-80)	44 (0-80)	58 (5-95)
Nymphaeid vegetation[c]	**0.2^{ab} (0-1)**	**0.5^{a} (0-1)**	**0^{b} (0-0)**	**0^{b} (0-0)**
Submerged vegetation[d]	**0.7^{a} (0-3)**	**1.8^{ab} (0.5-3)**	**2.4^{b} (0.5-3)**	**0.8^{a} (0-2)**
Floating vegetation (*Lemna* sp.)[d]	0 (0-0)	0.2 (0-1)	0.6 (0-1.5)	1.1 (0-3)
Water birds[e]	1.9 (1-3)	1.5 (0-3)	2.2 (1-3)	2.4 (1-3)

c 0=absent, 1=present, d 0=absent, 1=<10%, 2=10-50%, 3=>50% cover, e (0=0 ha-1, 1=1-20 ha-1, 2=20-50 ha-1, 3=>50 ha-1

Appendix 3 Physico-chemical quality in locations

Quality ratios (par. 2.6); colours indicate quality classes: green = good, yellow = moderate, orange = poor, red = bad. * Locations monitored in 2007.

Locations	**Physico-chemical quality**	*Nutrients/ macro-ion*	Total nitrogen (mgN l^{-1})	Total phosphate (mgP l^{-1})	Chloride (mgCl l^{-1})	*Metals*	Cadmium (µg l^{-1})	Lead (µg l^{-1})	Nickel (µg l^{-1})	Zinc (µg l^{-1})	*Other physico-chemical parameters*	Transparency (m)	Temperature (°C)	pH
8*	🟨	*0.78*	0.46	0.93	0.97	*0.56*	0.97	0.59	0.46	0.22	*0.88*	1.00	0.85	0.80
9*	🟨	*0.95*	0.97	0.96	0.92	*0.48*	0.98	0.60	0.12	0.21	*0.75*	0.60	0.85	0.80
13A	🟨	*0.69*	0.48	0.67	0.93	*0.46*	0.71	0.59	0.49	0.06	*0.90*	1.00	0.90	0.80
16B	🟨	*0.82*	0.54	0.97	0.95	*0.56*	0.81	0.78	0.36	0.30	*0.90*	1.00	0.90	0.80
19A	🟩	*0.77*	0.52	0.85	0.96	*0.67*	0.92	0.94	0.56	0.28	*0.84*	1.00	0.72	0.80
21	🟨	*0.69*	0.56	0.58	0.94	*0.56*	0.95	0.60	0.55	0.15	*0.81*	0.80	0.83	0.80
24	🟨	*0.78*	0.51	0.88	0.95	*0.57*	0.90	0.60	0.53	0.27	*0.91*	1.00	0.94	0.80
26B	🟩	*0.85*	0.63	0.96	0.94	*0.61*	0.74	0.85	0.56	0.29	*0.83*	0.80	0.90	0.80
27	🟩	*0.91*	0.96	0.82	0.94	*0.63*	1.00	0.59	0.67	0.25	*0.72*	0.50	0.87	0.80
37	🟩	*0.65*	0.56	0.46	0.94	*0.68*	0.99	1.00	0.58	0.16	*0.89*	1.00	0.86	0.80
40	🟩	*0.63*	0.38	0.58	0.92	*0.62*	0.93	0.67	0.62	0.27	*0.87*	1.00	0.80	0.80
48	🟩	*0.81*	0.68	0.81	0.93	*0.60*	0.97	0.60	0.54	0.27	*0.82*	1.00	0.66	0.80
49	🟩	*0.69*	0.56	0.59	0.93	*0.60*	0.94	0.60	0.63	0.24	*0.86*	1.00	0.79	0.80
52	🟨	*0.81*	0.66	0.84	0.93	*0.46*	0.96	0.55	0.02	0.29	*0.93*	1.00	1.00	0.80
58	🟨	*0.67*	0.49	0.59	0.94	*0.48*	0.77	0.59	0.34	0.23	*0.92*	1.00	0.97	0.80
59C	🟨	*0.76*	0.58	0.80	0.92	*0.57*	0.93	0.63	0.45	0.29	*0.87*	1.00	0.82	0.80
64B	🟨	*0.80*	0.50	0.96	0.94	*0.56*	0.94	0.55	0.58	0.20	*0.92*	1.00	0.95	0.80
68	🟩	*0.79*	0.46	0.97	0.93	*0.63*	0.99	0.85	0.37	0.31	*0.92*	1.00	0.97	0.80
69	🟨	*0.72*	0.46	0.79	0.90	*0.58*	0.94	0.60	0.49	0.29	*0.92*	1.00	0.96	0.80
70	🟩	*0.70*	0.50	0.69	0.91	*0.60*	0.96	0.60	0.55	0.30	*0.93*	1.00	0.98	0.80
71	🟩	*0.81*	0.65	0.85	0.94	*0.71*	0.98	0.85	0.69	0.32	*0.84*	0.80	0.93	0.80
73	🟩	*0.93*	0.90	0.90	0.98	*0.68*	0.99	0.74	0.66	0.33	*0.74*	0.53	0.91	0.80
80	🟩	*0.80*	0.90	0.58	0.92	*0.61*	1.00	0.63	0.54	0.28	*0.91*	1.00	0.93	0.80
81A	🟨	*0.91*	0.88	0.92	0.94	*0.59*	0.96	0.87	0.26	0.27	*0.65*	0.45	0.70	0.80
81B	🟨	*0.93*	0.87	0.97	0.95	*0.57*	1.00	0.60	0.43	0.24	*0.66*	0.45	0.72	0.80
84B	🟩	*0.96*	0.94	0.96	0.99	*0.67*	0.98	0.76	0.60	0.34	*0.79*	0.70	0.87	0.80
87B	🟩	*0.99*	1.00	1.00	0.98	*0.79*	1.00	0.95	0.89	0.33	*0.80*	1.00	0.60	0.80
A1	🟩	*0.95*	0.90	0.98	0.98	*0.70*	0.98	0.82	0.76	0.24	*0.72*	0.45	0.93	0.80
A2	🟩	*0.86*	0.67	0.94	0.97	*0.71*	0.95	0.85	0.74	0.28	*0.77*	0.65	0.87	0.80
A3	🟩	*0.90*	0.94	0.76	1.00	*0.67*	0.97	0.59	0.88	0.23	*0.88*	1.00	0.83	0.80
A4	🟩	*0.85*	0.90	0.71	0.93	*0.73*	0.96	0.59	1.00	0.39	*0.71*	1.00	0.58	0.53
A5	🟩	*0.61*	0.65	0.18	0.98	*0.64*	0.74	0.78	0.73	0.31	*0.70*	0.34	0.95	0.80
A6	🟩	*0.97*	0.98	0.92	0.99	*0.79*	0.99	0.95	0.94	0.29	*0.70*	0.45	0.85	0.80
A7	🟩	*0.95*	0.91	0.97	0.96	*0.71*	0.99	0.87	0.79	0.20	*0.70*	0.45	0.86	0.80
A8	🟩	*0.84*	0.67	0.90	0.94	*0.69*	0.98	0.93	0.67	0.20	*0.65*	0.30	0.85	0.80
A9	🟩	*0.94*	0.89	0.97	0.97	*0.65*	0.93	0.96	0.40	0.32	*0.76*	0.68	0.82	0.80
A11	🟩	*0.93*	0.87	1.00	0.91	*0.72*	0.98	0.93	0.72	0.26	*0.68*	0.45	0.78	0.80
A12	🟩	*0.95*	0.89	0.96	0.99	*0.60*	0.97	0.59	0.72	0.13	*0.76*	0.80	0.67	0.80
A13*	🟨	*0.77*	0.56	0.81	0.94	*0.53*	0.93	0.59	0.40	0.22	*0.76*	0.63	0.86	0.80
A14*	🟨	*0.62*	0.12	0.83	0.89	*0.57*	0.90	0.71	0.49	0.17	*0.91*	1.00	0.93	0.80

Appendix 4 Hydromorphological quality in locations

Quality ratios (par. 2.6); colours indicate quality classes: green = good, yellow = moderate, orange = poor, red = bad. * Locations monitored in 2007.

Locations	**Hyrdomorphological**	Depth near bank (m)	Slope bank (°)
8*	**0.61**	0.711	0.5
9*	**0.57**	0.575	0.567
13A	**0.62**	0.44	0.80
16B	**0.48**	0.50	0.47
19A	**0.41**	0.81	0.00
21	**0.39**	0.52	0.27
25	**0.55**	0.57	0.53
26B	**0.54**	0.62	0.47
27	**0.62**	0.71	0.53
37	**0.35**	0.43	0.27
40	**0.55**	0.57	0.53
48	**0.44**	0.48	0.40
49	**0.40**	0.59	0.20
52	**0.67**	0.54	0.80
58	**0.69**	0.37	1.00
59C	**0.65**	0.50	0.80
64B	**0.58**	0.55	0.60
68	**0.73**	1.00	0.47
69	**0.68**	0.55	0.80
70	**0.53**	0.60	0.47

Locations	**Hyrdomorphological**	Depth near bank (m)	Slope bank (°)
71	**0.45**	0.50	0.40
73	**0.36**	0.45	0.27
80	**0.40**	0.60	0.20
81A	**0.64**	0.48	0.80
81B	**0.50**	0.40	0.60
84B	**0.45**	0.70	0.20
87B	**0.81**	0.81	0.80
A1	**0.59**	0.85	0.33
A2	**0.39**	0.58	0.20
A3	**0.46**	0.58	0.33
A4	**0.34**	0.42	0.27
A5	**0.53**	0.65	0.40
A6	**0.68**	0.90	0.47
A7	**0.63**	0.80	0.47
A8	**0.53**	0.73	0.33
A9	**0.78**	0.76	0.80
A11	**0.45**	0.85	0.05
A12	**0.62**	0.67	0.56
A13*	**0.45**	0.525	0.367
A14*	**0.60**	0.628	0.567

Appendix 5 Biological quality in locations

Quality ratios (par. 2.6); colours indicate quality classes: green = good, yellow = moderate, orange = poor, red = bad. * Locations monitored in 2007.

Locations	**Biological**	*Vegetation*	Submerged vegetation (%)	FLAB (%)	Floating vegetation (*Lemna* sp. (%))	*Macroinvertebrates*	Diversity	Species richness	Shannon-index	Exotic species	Relative number of exotic species (#exotic/ #native)	Relative abundance exotic species	Rareness	ASPT	*Waterbirds (#/ha)*
8*	🟧	*0.37*	0.00	0.53	0.93	*0.55*	0.62	0.60	0.65	0.73	0.69	0.77	0.66	0.18	*0.89*
9*	🟨	*0.50*	0.00	1.00	0.99	*0.46*	0.08	0.05	0.10	1.00	1.00	1.00	0.10	0.65	*0.78*
13A	🟥	*0.25*	0.00	1.00	0.00	*0.07*	0.10	0.03	0.18	0.12	0.07	0.18	0.02	0.04	*0.38*
16B	🟧	*0.57*	0.30	0.73	0.95	*0.29*	0.55	0.60	0.50	0.36	0.69	0.02	0.13	0.12	*0.19*
19A	🟩	*0.87*	0.80	0.93	0.93	*0.66*	0.78	0.80	0.76	0.68	0.67	0.70	0.60	0.57	*0.17*
21	🟧	*0.70*	0.40	1.00	1.00	*0.30*	0.53	0.20	0.86	0.42	0.65	0.18	0.10	0.16	*0.08*
24	🟩	*0.89*	0.80	0.99	0.97	*0.70*	0.87	0.78	0.96	0.75	0.77	0.72	0.60	0.58	*0.07*
26B	🟩	*0.90*	0.80	1.00	1.00	*0.66*	0.84	0.77	0.92	0.49	0.41	0.56	0.72	0.60	*0.84*
27	🟩	*0.80*	0.60	1.00	0.99	*0.64*	0.44	0.60	0.27	0.72	0.85	0.59	0.74	0.65	*0.76*
37	🟨	*0.56*	0.80	0.23	0.40	*0.51*	0.85	0.71	0.99	0.52	0.62	0.41	0.48	0.19	*0.18*
40	🟧	*0.77*	0.54	1.00	1.00	*0.35*	0.14	0.11	0.17	0.29	0.11	0.47	0.31	0.68	*0.19*
48	🟧	*0.37*	0.10	0.30	0.97	*0.61*	0.75	0.62	0.89	1.00	1.00	1.00	0.51	0.19	*0.55*
49	🟨	*0.90*	0.80	1.00	1.00	*0.42*	0.57	0.43	0.72	0.57	0.31	0.83	0.42	0.13	*0.85*
52	🟧	*0.44*	0.45	0.73	0.13	*0.30*	0.13	0.08	0.18	0.16	0.13	0.18	0.74	0.16	*0.70*
58	🟨	*0.69*	0.40	1.00	0.97	*0.53*	0.62	0.62	0.63	0.65	0.70	0.59	0.14	0.70	*0.84*
59C	🟩	*0.61*	0.24	1.00	0.97	*0.62*	0.84	0.75	0.92	0.78	0.65	0.92	0.19	0.67	*0.68*
64B	🟥	*0.25*	0.00	1.00	0.00	*0.14*	0.02	0.01	0.02	0.30	0.03	0.57	0.15	0.09	*0.69*
68	🟧	*0.90*	0.80	1.00	1.00	*0.34*	0.48	0.66	0.31	0.43	0.17	0.68	0.25	0.20	*0.78*
69	🟧	*0.52*	0.10	0.87	1.00	*0.27*	0.59	0.43	0.74	0.12	0.17	0.07	0.19	0.19	*0.01*
70	🟧	*0.69*	0.45	0.87	0.97	*0.35*	0.08	0.03	0.14	0.61	0.60	0.61	0.08	0.64	*0.19*
71	🟨	*0.50*	0.00	1.00	1.00	*0.51*	0.12	0.16	0.08	0.52	0.18	0.86	0.67	0.72	*0.80*
73	🟨	*0.50*	0.00	1.00	1.00	*0.48*	0.07	0.02	0.12	0.16	0.13	0.19	0.90	0.80	*0.60*
80	🟧	*0.34*	0.00	0.37	1.00	*0.50*	0.47	0.31	0.62	0.27	0.11	0.44	0.57	0.67	*0.19*
81A	🟨	*0.50*	0.00	1.00	1.00	*0.62*	0.09	0.04	0.14	0.52	0.16	0.88	0.95	0.91	*0.15*
81B	🟨	*0.50*	0.00	1.00	1.00	*0.45*	0.23	0.04	0.42	0.16	0.16	0.15	0.70	0.71	*0.60*
84B	🟩	*0.90*	0.80	1.00	1.00	*0.74*	0.61	0.43	0.80	0.66	0.68	0.65	0.82	0.88	*0.78*
87B	🟨	*0.90*	0.80	1.00	1.00	*0.59*	0.80	0.75	0.85	0.31	0.19	0.43	0.62	0.62	*1.00*
A1	🟨	*0.52*	0.04	1.00	1.00	*0.67*	0.63	0.66	0.61	1.00	1.00	1.00	0.65	0.40	*0.91*
A2	🟨	*0.90*	0.80	1.00	1.00	*0.52*	0.63	0.66	0.61	0.84	0.73	0.96	0.19	0.43	*0.74*
A3	🟨	*0.90*	0.80	1.00	1.00	*0.58*	0.44	0.75	0.13	0.79	0.76	0.82	0.62	0.46	*0.49*
A4	🟩	*0.74*	0.50	1.00	0.97	*0.71*	0.74	0.65	0.84	1.00	1.00	1.00	0.45	0.63	*0.19*
A5	🟨	*0.50*	0.00	1.00	1.00	*0.65*	0.68	0.68	0.68	0.51	0.60	0.41	0.64	0.76	*0.81*
A6	🟨	*0.80*	0.60	1.00	1.00	*0.56*	0.71	0.85	0.58	0.88	0.79	0.97	0.47	0.19	*0.17*
A7	🟨	*0.57*	0.14	1.00	1.00	*0.47*	0.19	0.19	0.19	0.28	0.20	0.37	0.69	0.73	*0.17*
A8	🟧	*0.71*	0.43	1.00	1.00	*0.24*	0.09	0.10	0.07	0.14	0.10	0.19	0.64	0.08	*0.17*
A9	🟩	*0.72*	0.80	0.27	1.00	*0.73*	0.86	0.95	0.77	0.68	0.43	0.92	0.71	0.69	*0.68*
A11	🟨	*0.72*	0.46	0.97	1.00	*0.41*	0.34	0.51	0.16	1.00	1.00	1.00	0.09	0.19	*0.75*
A12	🟩	*0.63*	0.26	1.00	1.00	*0.71*	0.61	0.72	0.50	0.80	0.75	0.84	0.68	0.75	*1.00*
A13*	🟨	*0.55*	0.10	1.00	1.00	*0.49*	0.45	0.72	0.18	0.93	0.88	0.98	0.39	0.19	*0.87*
A14*	🟩	*0.75*	0.58	0.93	0.93	*0.65*	0.53	0.88	0.17	1.00	1.00	1.00	0.45	0.63	*0.18*

Appendix 6 Physico-chemical quality in the period 2005-2007

Quality ratios (par. 2.6); colours indicate quality classes: green = good, yellow = moderate, orange = poor, red = bad.

Locations		**Physico-chemical quality**	*Nutrients/ macro-ion*	Total nitrogen (mgN l^{-1})	Total phosphate (mgP l^{-1})	Chloride (mgCl l^{-1})	*Metals*	Cadmium (µg l^{-1})	Lead (µg l^{-1})	Nickel (µg l^{-1})	Zinc (µg l^{-1})	*Other physico-chemical parameters*	Transparency (m)	Temperature (°C)	pH
13A	2005	🟨	*0.69*	0.48	0.67	0.93	*0.46*	0.71	0.59	0.49	0.06	*0.90*	1.00	0.90	0.80
13A	2006	🟨	*0.50*	0.15	0.48	0.87	*0.55*	0.43	1.00	0.51	0.27	*0.91*	1.00	0.94	0.80
13A	2007	🟨	*0.55*	0.33	0.41	0.91	*0.56*	0.90	0.89	0.38	0.09	*0.89*	1.00	0.88	0.80
64A	2005	🟨	*0.80*	0.50	0.96	0.94	*0.56*	0.94	0.55	0.58	0.20	*0.92*	1.00	0.95	0.80
64A	2006	🟨	*0.73*	0.30	0.91	0.97	*0.44*	0.49	0.59	0.47	0.21	*0.93*	1.00	1.00	0.80
64A	2007	🟨	*0.82*	0.54	1.00	0.93	*0.50*	0.92	0.57	0.34	0.17	*0.93*	1.00	0.98	0.80
19A	2005	🟩	*0.77*	0.52	0.85	0.96	*0.67*	0.92	0.94	0.56	0.28	*0.84*	1.00	0.72	0.80
19A	2006	🟨	*0.75*	0.36	0.89	0.99	*0.40*	0.39	0.59	0.44	0.17	*0.91*	1.00	0.94	0.80
19A	2007	🟩	*0.75*	0.46	0.88	0.91	*0.60*	0.94	0.90	0.40	0.18	*0.91*	1.00	0.92	0.80
48	2005	🟩	*0.81*	0.68	0.81	0.93	*0.60*	0.97	0.60	0.54	0.27	*0.82*	1.00	0.66	0.80
48	2006	🟨	*0.68*	0.37	0.68	0.99	*0.42*	0.53	0.56	0.54	0.06	*0.93*	1.00	0.98	0.80
48	2007	🟨	*0.72*	0.44	0.81	0.91	*0.53*	0.94	0.57	0.50	0.10	*0.84*	0.80	0.92	0.80
49	2005	🟩	*0.69*	0.56	0.59	0.93	*0.60*	0.94	0.60	0.63	0.24	*0.86*	1.00	0.79	0.80
49	2006	🟨	*0.68*	0.38	0.72	0.96	*0.44*	0.52	0.59	0.46	0.19	*0.92*	1.00	0.97	0.80
49	2007	🟨	*0.72*	0.46	0.80	0.89	*0.47*	0.91	0.60	0.15	0.20	*0.88*	0.90	0.94	0.80
24	2005	🟨	*0.78*	0.51	0.88	0.95	*0.57*	0.90	0.60	0.53	0.27	*0.91*	1.00	0.94	0.80
24	2006	🟨	*0.73*	0.38	0.84	0.97	*0.51*	0.40	0.88	0.55	0.20	*0.87*	0.90	0.92	0.80
24	2007	🟨	*0.71*	0.48	0.75	0.91	*0.60*	0.96	0.79	0.44	0.19	*0.90*	1.00	0.91	0.80
59B	2005	🟨	*0.76*	0.58	0.80	0.92	*0.57*	0.93	0.63	0.45	0.29	*0.87*	1.00	0.82	0.80
59B	2006	🟨	*0.61*	0.32	0.55	0.95	*0.45*	0.51	0.60	0.49	0.22	*0.91*	0.95	0.97	0.80
59B	2007	🟩	*0.61*	0.44	0.52	0.88	*0.65*	0.98	0.90	0.49	0.23	*0.91*	1.00	0.94	0.80
71	2005	🟩	*0.81*	0.65	0.85	0.94	*0.71*	0.98	0.85	0.69	0.32	*0.84*	0.80	0.93	0.80
71	2006	🟨	*0.82*	0.60	0.88	0.98	*0.46*	0.49	0.58	0.49	0.27	*0.72*	0.48	0.88	0.80
71	2007	🟨	*0.83*	0.70	0.88	0.91	*0.59*	0.97	0.79	0.36	0.25	*0.88*	0.90	0.94	0.80
73	2005	🟩	*0.93*	0.90	0.90	0.98	*0.68*	0.99	0.74	0.66	0.33	*0.74*	0.53	0.91	0.80
73	2006	🟨	*1.00*	1.00	1.00	1.00	*0.51*	0.58	0.72	0.49	0.27	*0.64*	0.25	0.86	0.80
73	2007	🟨	*0.98*	1.00	1.00	0.95	*0.55*	0.97	0.77	0.21	0.27	*0.79*	0.63	0.94	0.80
81A	2005	🟨	*0.91*	0.88	0.92	0.94	*0.59*	0.96	0.87	0.26	0.27	*0.65*	0.45	0.70	0.80
81A	2006	🟨	*0.82*	0.88	0.59	0.98	*0.52*	0.55	0.74	0.47	0.29	*0.77*	0.65	0.86	0.80
81A	2007	🟩	*0.93*	0.99	0.88	0.91	*0.62*	0.94	0.82	0.46	0.27	*0.77*	0.53	0.97	0.80
81B	2005	🟨	*0.93*	0.87	0.97	0.95	*0.57*	1.00	0.60	0.43	0.24	*0.66*	0.45	0.72	0.80
81B	2006	🟨	*0.91*	0.87	0.87	0.99	*0.49*	0.58	0.60	0.47	0.31	*0.78*	0.68	0.88	0.80
81B	2007	🟩	*0.90*	0.99	0.79	0.91	*0.61*	0.94	0.82	0.42	0.27	*0.74*	0.53	0.91	0.80

Locations		**Physico-chemical quality**	*Nutrients/ macro-ion*	Total nitrogen (mgN l^{-1})	Total phosphate (mgP l^{-1})	Chloride (mgCl l^{-1})	*Metals*	Cadmium (µg l^{-1})	Lead (µg l^{-1})	Nickel (µg l^{-1})	Zinc (µg l^{-1})	*Other physico-chemical parameters*	Transparency (m)	Temperature (°C)	pH
A6	2005	🟩	*0.97*	0.98	0.92	0.99	*0.79*	0.99	0.95	0.94	0.29	*0.70*	0.45	0.85	0.80
A6	2007	🟩	*0.95*	0.98	0.96	0.92	*0.67*	0.99	0.85	0.52	0.31	*0.90*	1.00	0.90	0.80
A1	2005	🟩	*0.95*	0.90	0.98	0.98	*0.70*	0.98	0.82	0.76	0.24	*0.72*	0.45	0.93	0.80
A1	2007	🟨	*0.78*	0.78	0.62	0.92	*0.59*	0.96	0.91	0.50	0.00	*0.88*	1.00	0.85	0.80
A2	2005	🟩	*0.86*	0.67	0.94	0.97	*0.71*	0.95	0.85	0.74	0.28	*0.77*	0.65	0.87	0.80
A2	2007	🟨	*0.86*	0.64	1.00	0.95	*0.56*	0.96	0.59	0.51	0.18	*0.70*	0.37	0.92	0.80
A3	2005	🟩	*0.90*	0.94	0.76	1.00	*0.67*	0.97	0.59	0.88	0.23	*0.88*	1.00	0.83	0.80
A3	2007	🟩	*0.97*	1.00	0.97	0.93	*0.67*	1.00	0.85	0.60	0.23	*0.78*	0.69	0.86	0.80
A5	2005	🟩	*0.61*	0.65	0.18	0.98	*0.64*	0.74	0.78	0.73	0.31	*0.70*	0.34	0.95	0.80
A5	2007	🟩	*0.91*	0.83	0.97	0.94	*0.66*	0.95	0.96	0.40	0.31	*0.80*	0.67	0.93	0.80
A7	2005	🟩	*0.95*	0.91	0.97	0.96	*0.71*	0.99	0.87	0.79	0.20	*0.70*	0.45	0.86	0.80
A7	2007	🟨	*0.86*	0.67	0.99	0.92	*0.50*	0.94	0.66	0.18	0.24	*0.72*	0.51	0.86	0.80
A9	2005	🟩	*0.94*	0.89	0.97	0.97	*0.65*	0.93	0.96	0.40	0.32	*0.76*	0.68	0.82	0.80
A9	2007	🟨	*0.83*	0.58	1.00	0.90	*0.52*	0.59	0.76	0.53	0.20	*0.74*	0.52	0.90	0.80
A4	2005	🟩	*0.85*	0.90	0.71	0.93	*0.73*	0.96	0.59	1.00	0.39	*0.71*	1.00	0.58	0.53
A4	2007	🟨	*0.96*	0.98	0.91	1.00	*0.59*	0.88	0.59	0.70	0.21	*0.90*	0.90	1.00	0.80
A11	2005	🟩	*0.93*	0.87	1.00	0.91	*0.72*	0.98	0.93	0.72	0.26	*0.68*	0.45	0.78	0.80
A11	2007	🟨	*0.77*	0.84	0.54	0.92	*0.46*	0.93	0.60	0.14	0.18	*0.81*	0.75	0.89	0.80
A12	2005	🟩	*0.95*	0.89	0.96	0.99	*0.60*	0.97	0.59	0.72	0.13	*0.76*	0.80	0.67	0.80
A12	2007	🟨	*0.89*	0.84	0.86	0.97	*0.58*	0.92	0.65	0.54	0.19	*0.86*	0.90	0.89	0.80
A8	2005	🟩	*0.84*	0.67	0.90	0.94	*0.69*	0.98	0.93	0.67	0.20	*0.65*	0.30	0.85	0.80
A8	2007	🟨	*0.85*	0.58	1.00	0.96	*0.52*	0.92	0.60	0.36	0.19	*0.64*	0.18	0.92	0.80

Appendix 7 Hydro-morphological quality in the period 2005-2007

Quality ratios (par. 2.6); colours indicate quality classes: green = good, yellow = moderate, orange = poor, red = bad.

Locations		**Hyrdomorphological**	Depth near bank (m)	Slope bank (°)
13A	2005	**0.62**	0.44	0.80
13A	2006	**0.74**	0.49	1.00
13A	2007	**0.51**	0.35	0.68
64A	2005	**0.58**	0.55	0.60
64A	2006	**0.56**	0.55	0.57
64A	2007	**0.49**	0.41	0.57
19A	2005	**0.41**	0.81	0.00
19A	2006	**0.72**	1.00	0.43
19A	2007	**0.62**	0.81	0.43
48	2005	**0.44**	0.48	0.40
48	2006	**0.46**	0.53	0.40
48	2007	**0.45**	0.44	0.47
49	2005	**0.40**	0.59	0.20
49	2006	**0.55**	0.57	0.53
49	2007	**0.84**	1.00	0.68
24	2005	**0.55**	0.57	0.53
24	2006	**0.57**	0.60	0.53
24	2007	**0.50**	0.46	0.53
59B	2005	**0.65**	0.50	0.80
59B	2006	**0.70**	0.39	1.00
59B	2007	**0.56**	0.66	0.47
71	2005	**0.45**	0.50	0.40
71	2006	**0.45**	0.49	0.40
71	2007	**0.60**	0.51	0.68
73	2005	**0.36**	0.45	0.27
73	2006	**0.30**	0.33	0.27
73	2007	**0.41**	0.36	0.47
81A	2005	**0.64**	0.48	0.80
81A	2006	**0.72**	0.43	1.00
81A	2007	**0.95**	0.91	1.00
81B	2005	**0.50**	0.40	0.60
81B	2006	**0.55**	0.51	0.60
81B	2007	**0.84**	0.83	0.84

Locations		**Hyrdomorphological**	Depth near bank (m)	Slope bank (°)
A6	2005	**0.68**	0.90	0.47
A6	2007	**0.62**	0.74	0.50
A1	2005	**0.59**	0.85	0.33
A1	2007	**0.58**	0.63	0.53
A2	2005	**0.39**	0.58	0.20
A2	2007	**0.48**	0.45	0.50
A3	2005	**0.46**	0.58	0.33
A3	2007	**0.67**	0.88	0.47
A5	2005	**0.53**	0.65	0.40
A5	2007	**0.58**	0.63	0.53
A7	2005	**0.63**	0.80	0.47
A7	2007	**0.79**	0.98	0.60
A9	2005	**0.78**	0.76	0.80
A9	2007	**0.55**	0.59	0.50
A4	2005	**0.34**	0.42	0.27
A4	2007	**0.43**	0.33	0.53
A11	2005	**0.45**	0.85	0.05
A11	2007	**0.33**	0.65	0.00
A12	2005	**0.62**	0.67	0.56
A12	2007	**0.60**	0.44	0.76
A8	2005	**0.53**	0.73	0.33
A8	2007	**0.54**	0.55	0.53

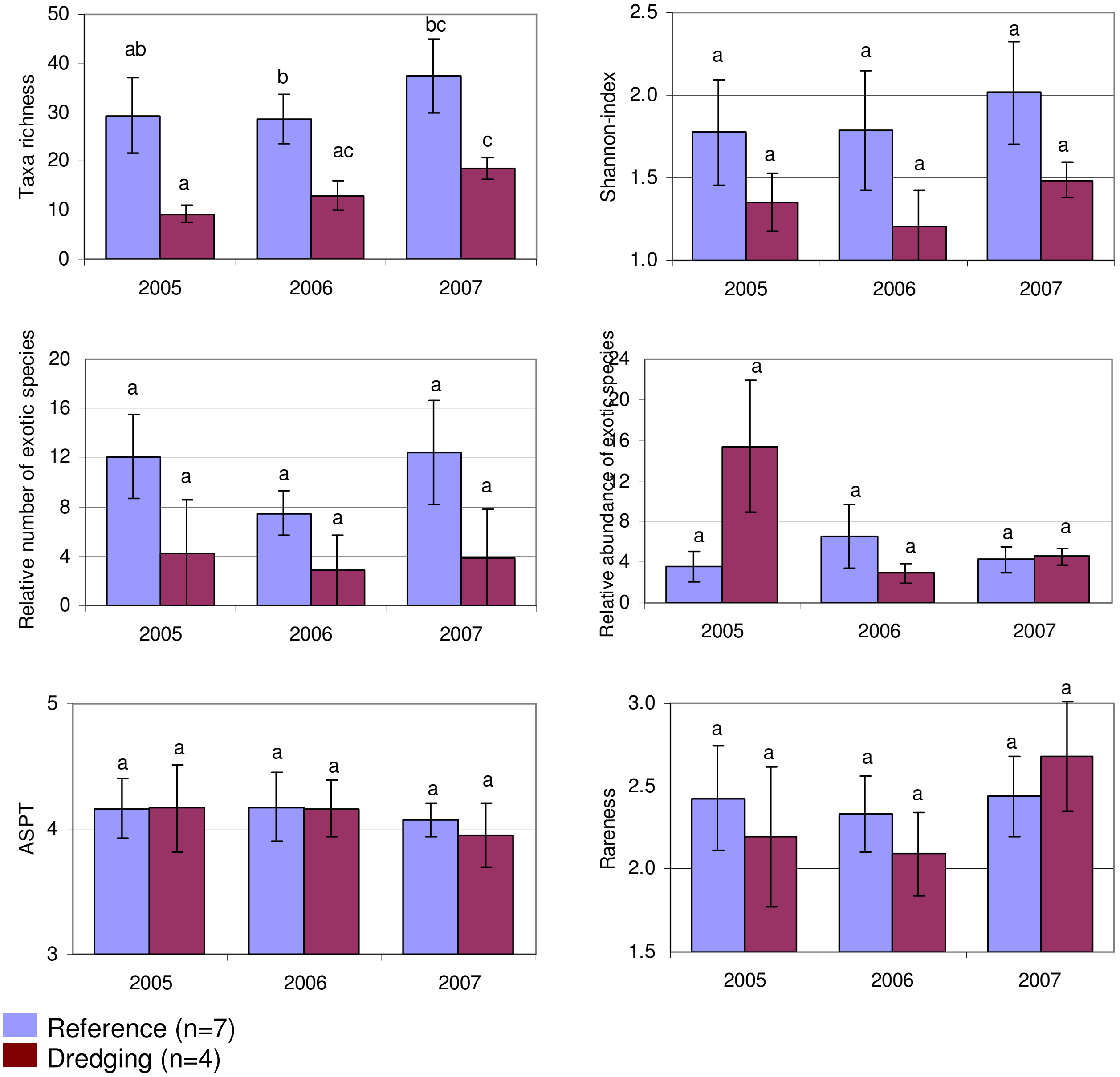
Appendix 8 Biological quality in the period 2005-2007

Quality ratios (par. 2.6); colours indicate quality classes: green = good, yellow = moderate, orange = poor, red = bad.

Locations		**Biological**	*Vegetation*	Submerged vegetation (%)	FLAB (%)	Floating vegetation (*Lemna* sp. (%))	*Macroinvertebrates*	Diversity	Taxa richness	Shannon-index	Exotic species	Relative number of exotic species (#exotic/ #native)	Relative abundance exotic species	Rareness	ASPT	*Waterbirds (#/ha)*
13A	2005	🟥	*0.25*	0.00	1.00	0.00	*0.07*	0.10	0.03	0.18	0.12	0.07	0.18	0.02	0.04	*0.38*
13A	2006	🟨	*0.48*	0.00	0.93	0.97	*0.40*	0.43	0.16	0.71	0.17	0.18	0.15	0.12	0.15	*0.47*
13A	2007	🟨	*0.50*	0.06	1.00	0.87	*0.40*	0.66	0.51	0.81	0.43	0.68	0.18	0.18	0.32	*0.26*
64A	2005	🟥	*0.25*	0.00	1.00	0.00	*0.14*	0.02	0.01	0.02	0.30	0.03	0.57	0.15	0.09	*0.69*
64A	2006	🟨	*0.48*	0.00	0.93	0.97	*0.46*	0.30	0.11	0.48	0.24	0.28	0.20	0.64	0.10	*0.19*
64A	2007	🟧	*0.47*	0.18	0.53	0.97	*0.24*	0.11	0.10	0.12	0.58	0.74	0.41	0.19	0.08	*0.62*
19A	2005	🟩	*0.87*	0.80	0.93	0.93	*0.66*	0.78	0.80	0.76	0.68	0.67	0.70	0.60	0.57	*0.17*
19A	2006	🟩	*0.84*	0.80	0.97	0.79	*0.61*	0.84	0.80	0.88	0.46	0.67	0.26	0.60	0.18	*0.82*
19A	2007	🟨	*0.79*	0.60	1.00	0.97	*0.40*	0.83	0.86	0.80	0.45	0.69	0.21	0.17	0.15	*0.53*
48	2005	🟧	*0.37*	0.10	0.30	0.97	*0.61*	0.75	0.62	0.89	1.00	1.00	1.00	0.51	0.19	*0.55*
48	2006	🟨	*0.59*	0.50	1.00	0.37	*0.67*	0.89	0.85	0.94	0.45	0.79	0.12	0.62	0.64	*0.83*
48	2007	🟨	*0.76*	0.80	1.00	0.45	*0.47*	0.97	0.95	0.98	0.44	0.73	0.16	0.19	0.26	*0.42*
49	2005	🟨	*0.90*	0.80	1.00	1.00	*0.42*	0.57	0.43	0.72	0.57	0.31	0.83	0.42	0.13	*0.85*
49	2006	🟨	*0.82*	0.80	1.00	0.67	*0.43*	0.31	0.62	0.00	0.45	0.70	0.20	0.12	0.43	*0.15*
49	2007	🟧	*0.58*	0.40	0.53	1.00	*0.30*	0.30	0.19	0.41	0.76	0.64	0.87	0.00	0.14	*0.19*
24	2005	🟩	*0.89*	0.80	0.99	0.97	*0.70*	0.87	0.78	0.96	0.75	0.77	0.72	0.60	0.58	*0.07*
24	2006	🟨	*0.90*	0.80	0.99	1.00	*0.49*	0.56	0.31	0.81	0.88	0.83	0.94	0.09	0.11	*0.19*
24	2007	🟩	*0.83*	0.80	1.00	0.73	*0.61*	0.96	0.95	0.98	0.51	0.73	0.30	0.20	0.78	*0.00*
59B	2005	🟩	*0.61*	0.24	1.00	0.97	*0.62*	0.84	0.75	0.92	0.78	0.65	0.92	0.19	0.67	*0.68*
59B	2006	🟩	*0.69*	0.48	0.93	0.89	*0.62*	0.71	0.63	0.79	0.86	0.86	0.86	0.12	0.63	*0.26*
59B	2007	🟨	*0.53*	0.06	1.00	0.99	*0.59*	0.76	0.63	0.89	0.77	0.71	0.83	0.18	0.63	*0.78*
71	2005	🟨	*0.50*	0.00	1.00	1.00	*0.51*	0.12	0.16	0.08	0.52	0.18	0.86	0.67	0.72	*0.80*
71	2006	🟨	*0.50*	0.00	1.00	1.00	*0.42*	0.11	0.12	0.10	0.47	0.76	0.17	0.84	0.00	*0.80*
71	2007	🟧	*0.51*	0.02	1.00	1.00	*0.37*	0.14	0.20	0.09	0.44	0.10	0.79	0.69	0.19	*0.63*
73	2005	🟨	*0.50*	0.00	1.00	1.00	*0.48*	0.07	0.02	0.12	0.16	0.13	0.19	0.90	0.80	*0.60*
73	2006	🟨	*0.50*	0.00	1.00	1.00	*0.55*	0.05	0.07	0.04	0.57	0.18	0.95	0.73	0.65	*0.51*
73	2007	🟧	*0.50*	0.00	1.00	1.00	*0.38*	0.11	0.06	0.17	0.31	0.05	0.57	0.95	0.16	*0.77*
81A	2005	🟨	*0.50*	0.00	1.00	1.00	*0.62*	0.09	0.04	0.14	0.52	0.16	0.88	0.95	0.91	*0.15*
81A	2006	🟨	*0.50*	0.00	1.00	1.00	*0.59*	0.06	0.04	0.08	0.65	0.63	0.67	0.72	0.79	*0.94*
81A	2007	🟧	*0.50*	0.00	1.00	1.00	*0.33*	0.08	0.03	0.14	0.13	0.07	0.20	0.92	0.19	*0.70*
81B	2005	🟨	*0.50*	0.00	1.00	1.00	*0.45*	0.23	0.04	0.42	0.16	0.16	0.15	0.70	0.71	*0.60*
81B	2006	🟧	*0.50*	0.00	1.00	1.00	*0.31*	0.03	0.00	0.06	0.32	0.10	0.53	0.05	0.65	*0.85*
81B	2007	🟨	*0.65*	0.30	1.00	1.00	*0.51*	0.16	0.13	0.18	0.16	0.13	0.19	0.92	0.82	*0.85*

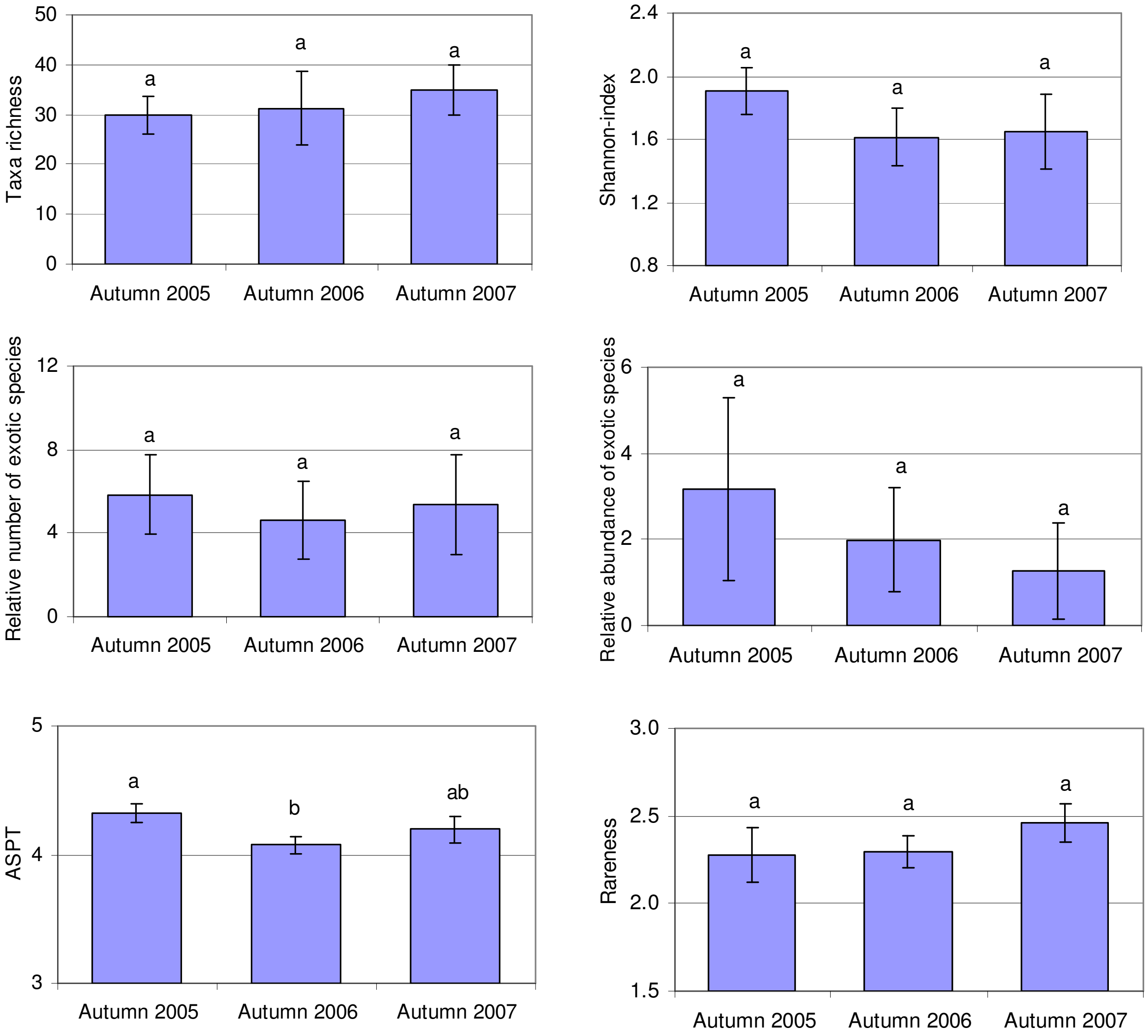
Locations		**Biological**	*Vegetation*	Submerged vegetation (%)	FLAB (%)	Floating vegetation (*Lemna* sp. (%))	*Macroinvertebrates*	Diversity	Taxa richness	Shannon-index	Exotic species	Relative number of exotic species (#exotic/ #native)	Relative abundance exotic species	Rareness	ASPT	*Waterbirds (#/ha)*
A6	2005	🟨	*0.80*	0.60	1.00	1.00	*0.56*	0.71	0.85	0.58	0.88	0.79	0.97	0.47	0.19	*0.17*
A6	2007	🟩	*0.78*	0.55	1.00	1.00	*0.72*	0.89	0.97	0.81	1.00	1.00	1.00	0.62	0.35	*0.51*
A1	2005	🟨	*0.52*	0.04	1.00	1.00	*0.67*	0.63	0.66	0.61	1.00	1.00	1.00	0.65	0.40	*0.91*
A1	2007	🟩	*0.62*	0.24	1.00	0.99	*0.66*	0.40	0.00	0.80	0.90	0.83	0.96	0.73	0.62	*0.87*
A2	2005	🟨	*0.90*	0.80	1.00	1.00	*0.52*	0.63	0.66	0.61	0.84	0.73	0.96	0.19	0.43	*0.74*
A2	2007	🟧	*0.76*	0.51	1.00	1.00	*0.31*	0.14	0.20	0.08	0.88	0.83	0.94	0.05	0.15	*0.60*
A3	2005	🟨	*0.90*	0.80	1.00	1.00	*0.58*	0.44	0.75	0.13	0.79	0.76	0.82	0.62	0.46	*0.49*
A3	2007	🟨	*0.76*	0.53	1.00	0.97	*0.57*	0.51	0.85	0.18	0.94	0.90	0.99	0.66	0.17	*0.69*
A5	2005	🟨	*0.50*	0.00	1.00	1.00	*0.65*	0.68	0.68	0.68	0.51	0.60	0.41	0.64	0.76	*0.81*
A5	2007	🟨	*0.55*	0.10	1.00	1.00	*0.55*	0.49	0.78	0.19	0.29	0.17	0.42	0.76	0.64	*0.36*
A7	2005	🟨	*0.57*	0.14	1.00	1.00	*0.47*	0.19	0.19	0.19	0.28	0.20	0.37	0.69	0.73	*0.17*
A7	2007	🟧	*0.50*	0.00	1.00	1.00	*0.30*	0.07	0.10	0.03	0.40	0.20	0.61	0.64	0.10	*0.19*
A9	2005	🟩	*0.72*	0.80	0.27	1.00	*0.73*	0.86	0.95	0.77	0.68	0.43	0.92	0.71	0.69	*0.68*
A9	2007	🟩	*0.75*	0.50	1.00	1.00	*0.62*	0.72	0.89	0.54	0.40	0.61	0.19	0.73	0.61	*0.55*
A4	2005	🟩	*0.74*	0.50	1.00	0.97	*0.71*	0.74	0.65	0.84	1.00	1.00	1.00	0.45	0.63	*0.19*
A4	2007	🟨	*0.51*	0.30	0.47	0.97	*0.80*	0.78	0.92	0.64	1.00	1.00	1.00	0.72	0.69	*0.70*
A11	2005	🟨	*0.72*	0.46	0.97	1.00	*0.41*	0.34	0.51	0.16	1.00	1.00	1.00	0.09	0.19	*0.75*
A11	2007	🟩	*0.88*	0.80	0.93	0.99	*0.65*	0.58	0.98	0.18	0.70	0.82	0.59	0.60	0.70	*0.75*
A12	2005	🟩	*0.63*	0.26	1.00	1.00	*0.71*	0.61	0.72	0.50	0.80	0.75	0.84	0.68	0.75	*1.00*
A12	2007	🟨	*0.76*	0.51	1.00	1.00	*0.54*	0.52	0.85	0.20	0.86	0.79	0.92	0.44	0.34	*0.68*
A8	2005	🟧	*0.71*	0.43	1.00	1.00	*0.24*	0.09	0.10	0.07	0.14	0.10	0.19	0.64	0.08	*0.17*
A8	2007	🟥	*0.76*	0.52	1.00	1.00	*0.18*	0.05	0.04	0.05	0.43	0.63	0.23	0.00	0.25	*0.15*

Appendix 9 Effects of rehabilitation measures on ecological indicators: dredging in Nijmegen



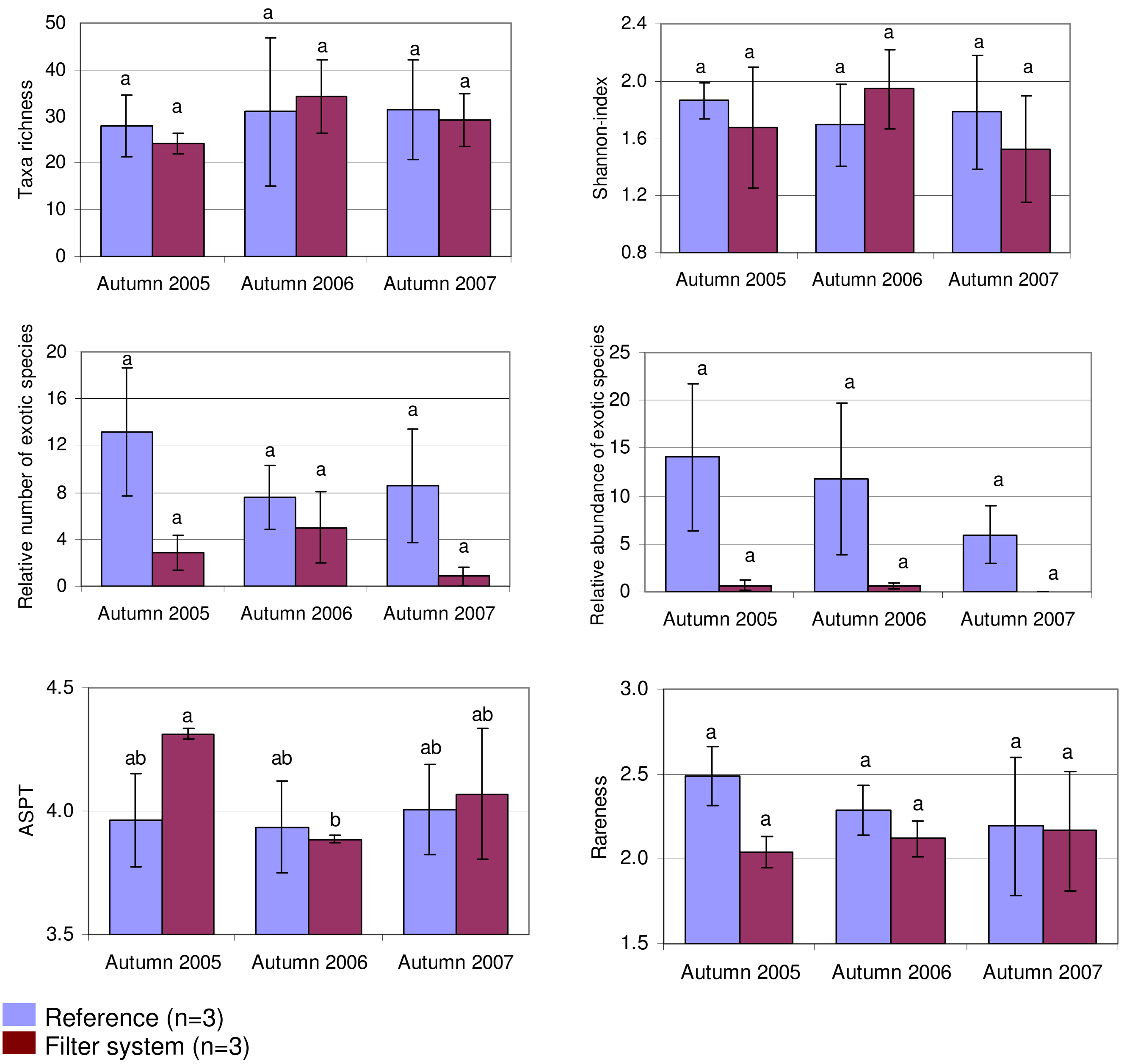
Taxa richness, Shannon-index, relative number of exotic species (%), relative abundance of exotic species (%), Average Score Per Taxon (ASPT) and rareness in locations where no rehabilitation measures took place (reference) and locations where dredging took place (dredging) in Nijmegen from 2005 till 2007. a, b and c indicate significant differences (pairwise Student's t-test, $p<0.05$; comparing reference and dredging at each time step and comparing references over time and dredging over time). Error bars represent the standard error.

Appendix 10 Effects of rehabilitation measures on ecological indicators: dredging in Arnhem



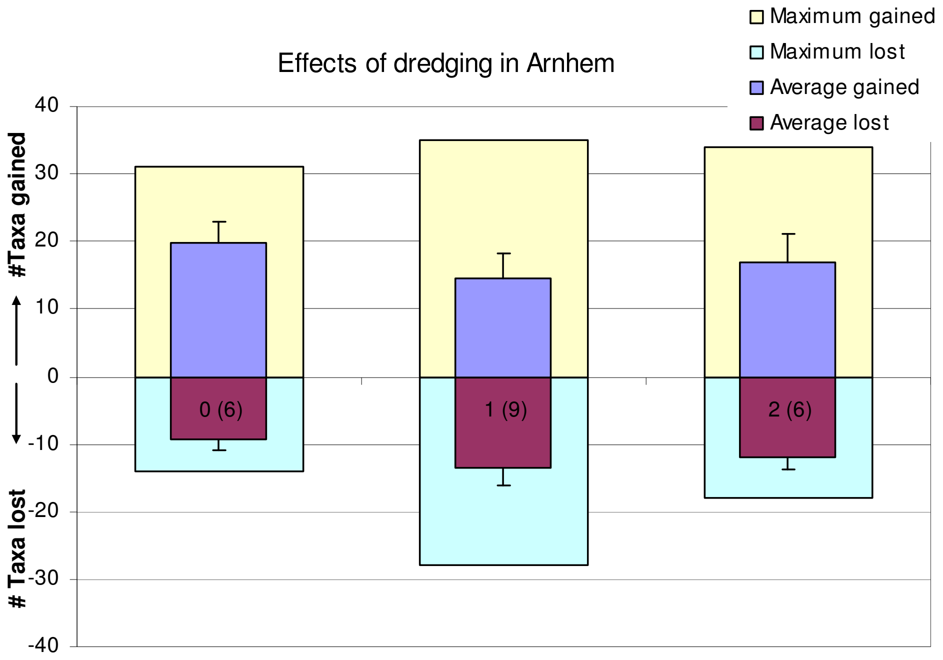
Taxa richness, Shannon-index, relative number of exotic species (%), relative abundance of exotic species (%), Average Score Per Taxon (ASPT) and rareness in locations where dredging took place in the winter of 2005/2006 in Arnhem from 2005 till 2007 (n=7). a and b indicate significant differences (pairwise Student's t-test, $p<0.05$). Error bars represent the standard error.

Appendix 11 Effects of rehabilitation measures on ecological indicators: filtering storm water Arnhem

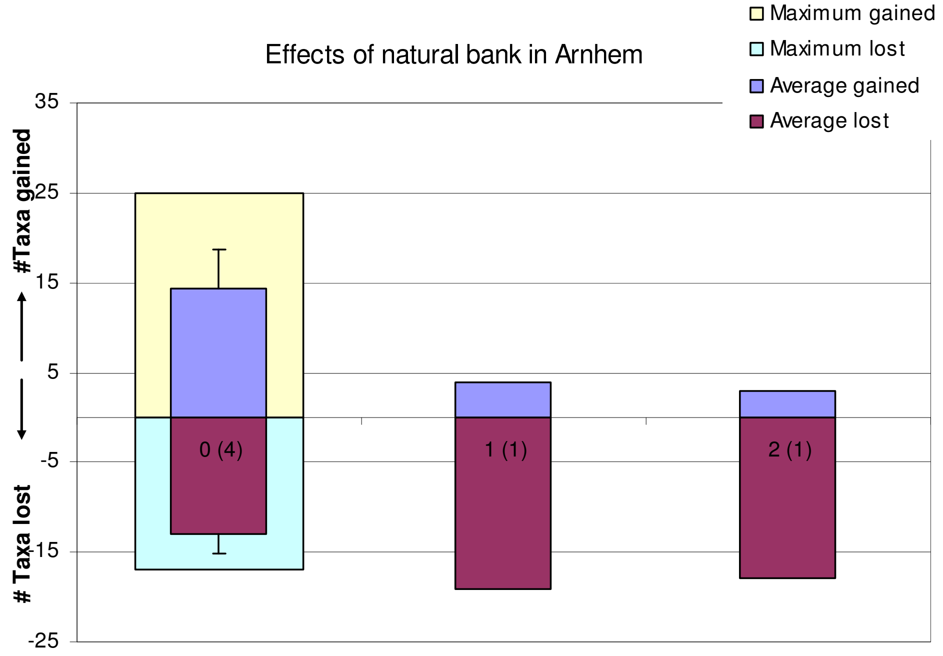


Taxa richness, Shannon-index, relative number of exotic species (%), relative abundance of exotic species (%), Average Score Per Taxon (ASPT) and rareness in locations where only dredging took place in the winter of 2005/2006 in Arnhem from 2005 till 2007 (reference) and locations where dredging was combined with the installation of filter systems. a and b indicate significant differences (pairwise Student’s t-test, $p<0.05$; comparing reference and filter at each time step and comparing references over time and filter systems over time). Error bars represent the standard error.

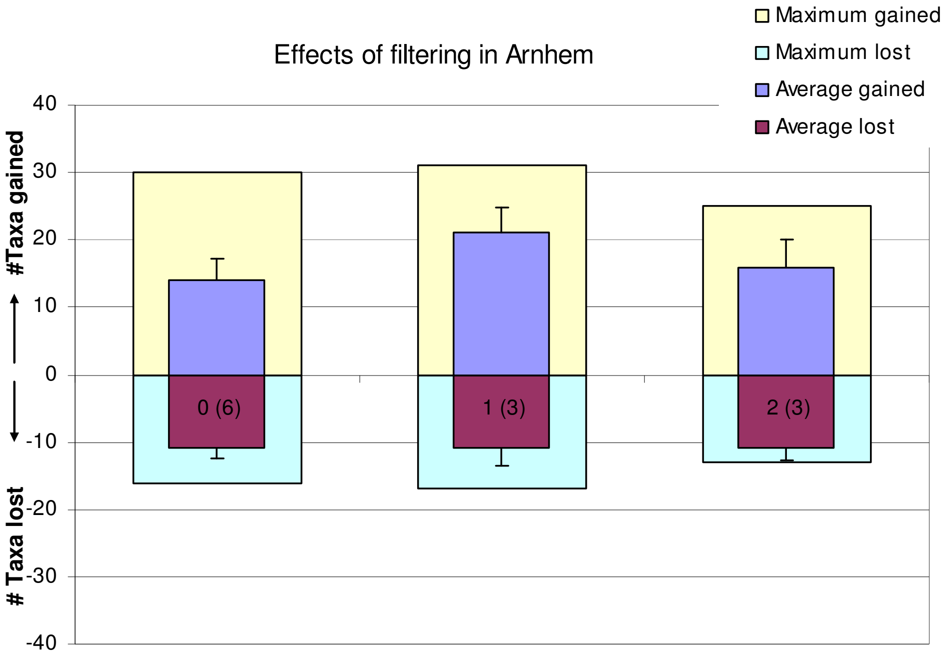
Appendix 12 Taxa turnover in Arnhem



Turnover of taxa without dredging (0 (6)), one year after dredging (1 (9)) and two years after dredging (2 (6)) in Arnhem. The number in brackets indicates the number of observations.

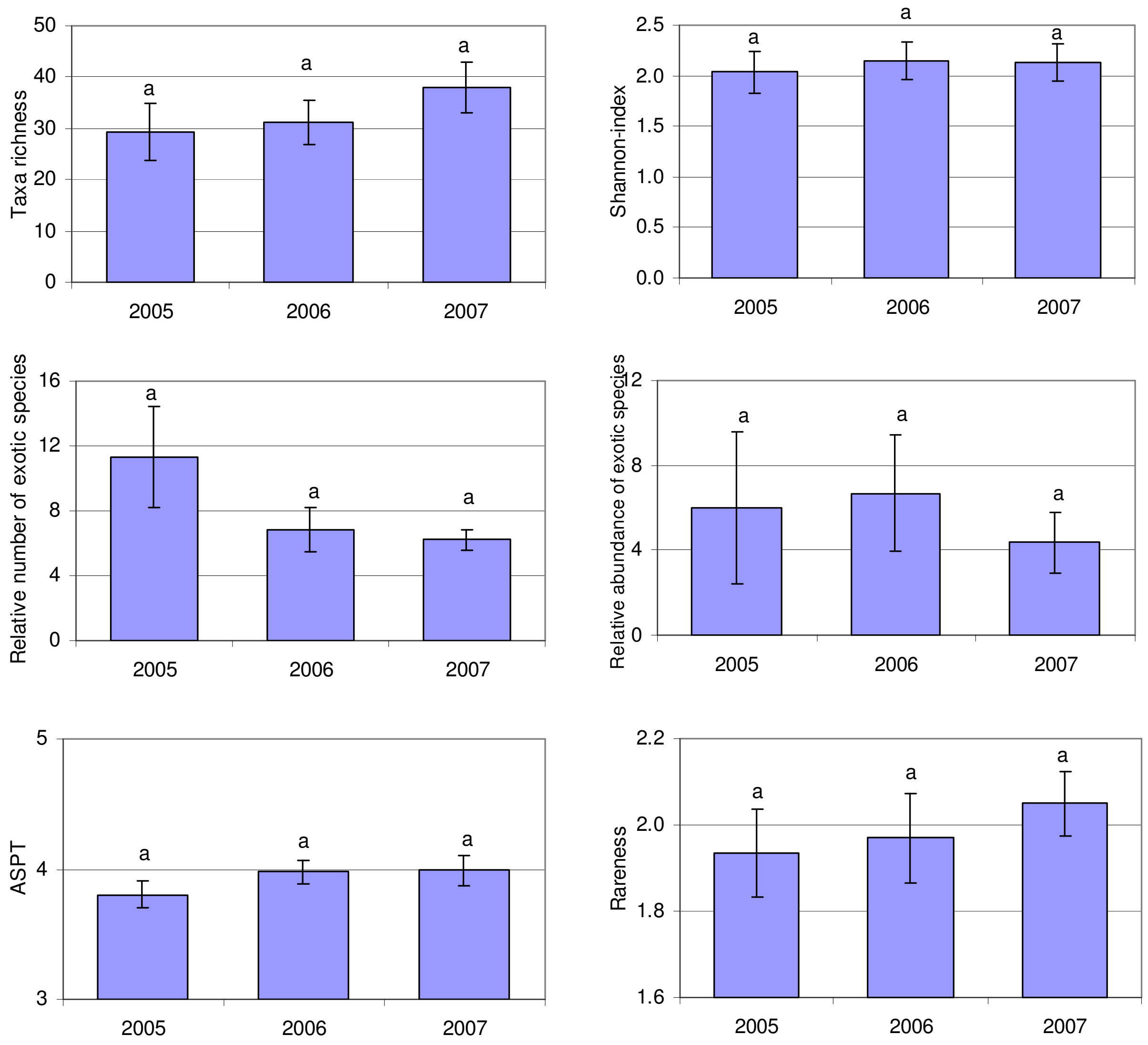


Turnover of taxa without development of natural bank (0 (4)), one year after development of the natural bank (1 (1)) and two years after development of the natural bank (2 (1)) in Arnhem. The number in brackets indicates the number of observations.



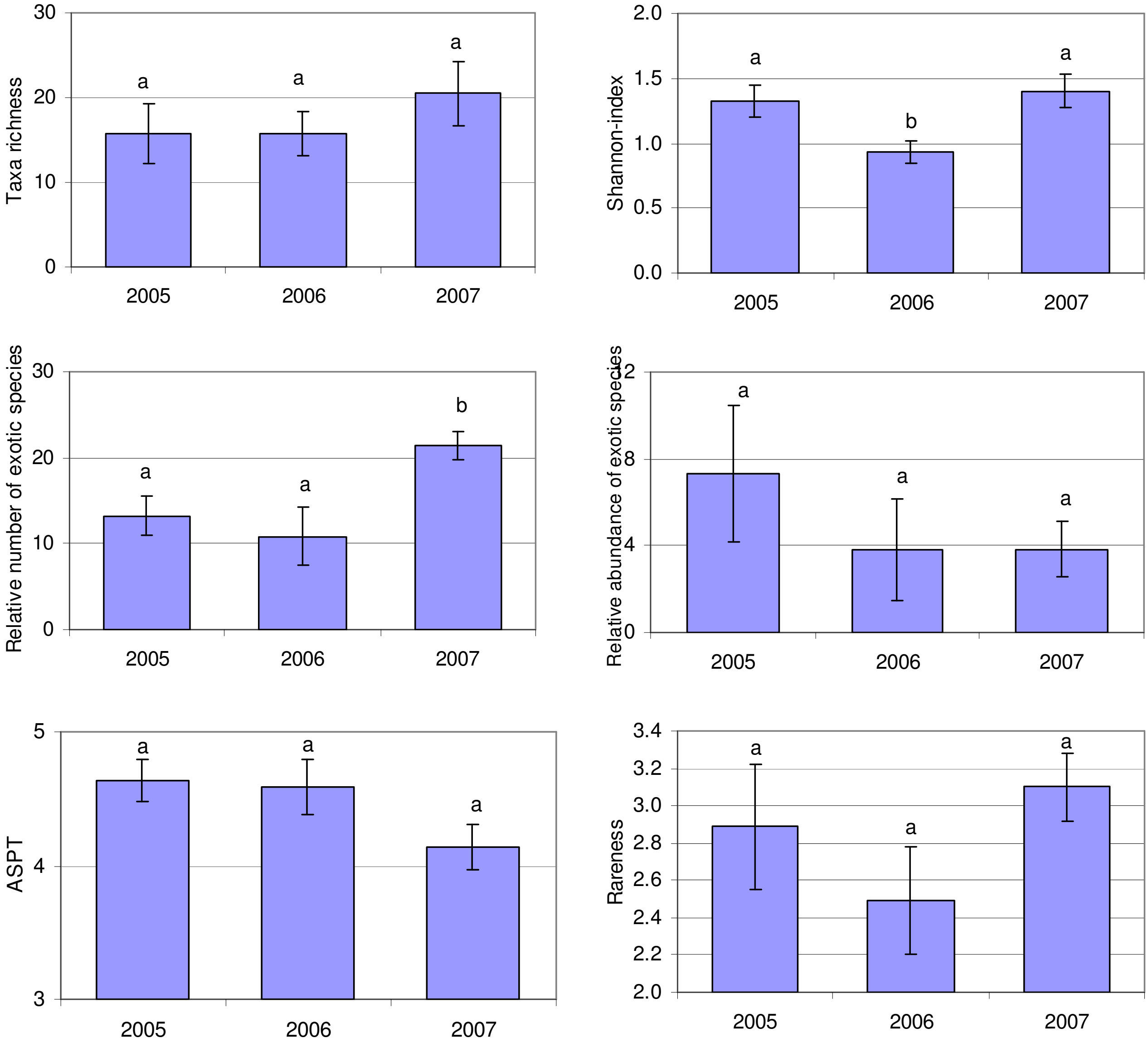
Turnover of taxa without filtering systems (0 (6)), one year after installing of the filter systems (1 (3)) and two years after installing of the filter systems (2 (3)) in Arnhem. The number in brackets indicates the number of observations.

Appendix 13 Effects of rehabilitation measures on the water system: Dukenburg



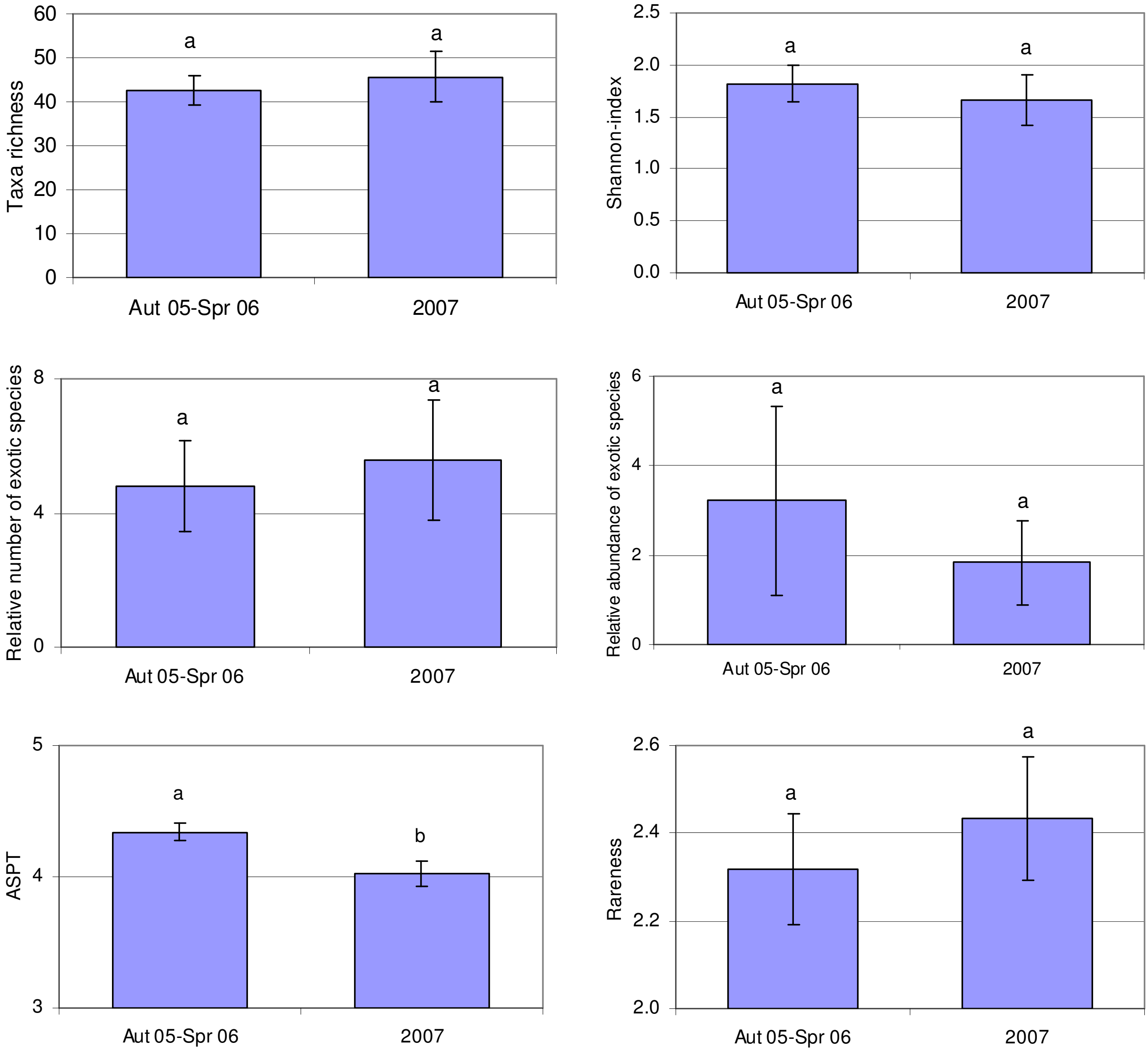
Taxa richness, Shannon-index, relative number of exotic species (%), relative abundance of exotic species (%), Average Score Per Taxon (ASPT) and rareness in Dukenburg from 2005 till 2007 (n=7). a and b indicate significant differences (pairwise Student's t-test, $p<0.05$). Error bars represent the standard error.

Appendix 14 Effects of rehabilitation measures on the water system: Lindenholt



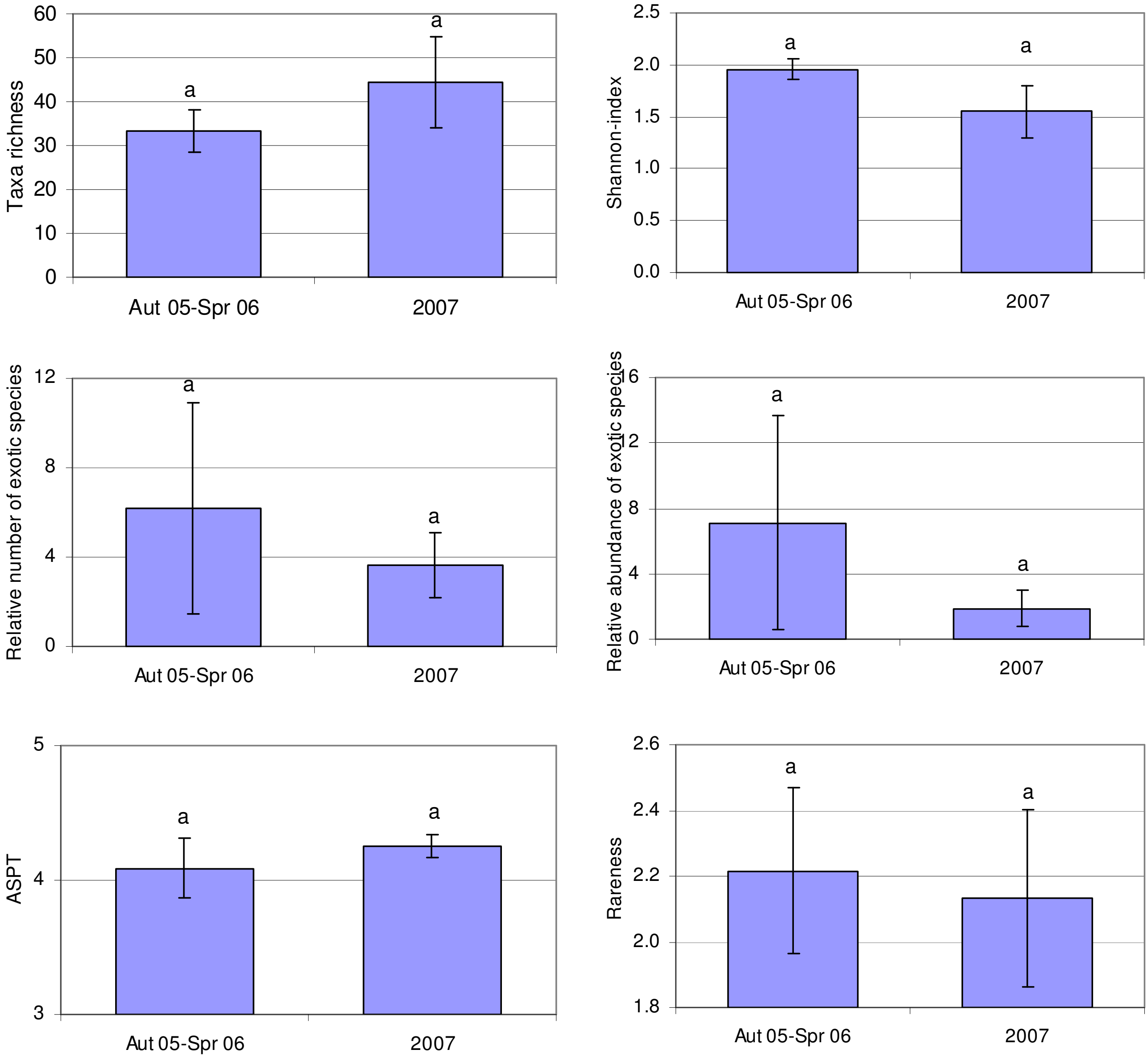
Taxa richness, Shannon-index, relative number of exotic species (%), relative abundance of exotic species (%), Average Score Per Taxon (ASPT) and rareness in Lindenholt from 2005 till 2007 (n=4). a and b indicate significant differences (pairwise Student's t-test, $p<0.05$). Error bars represent the standard error.

Appendix 15 Effects of rehabilitation measures on the water system: Arnhem south-west



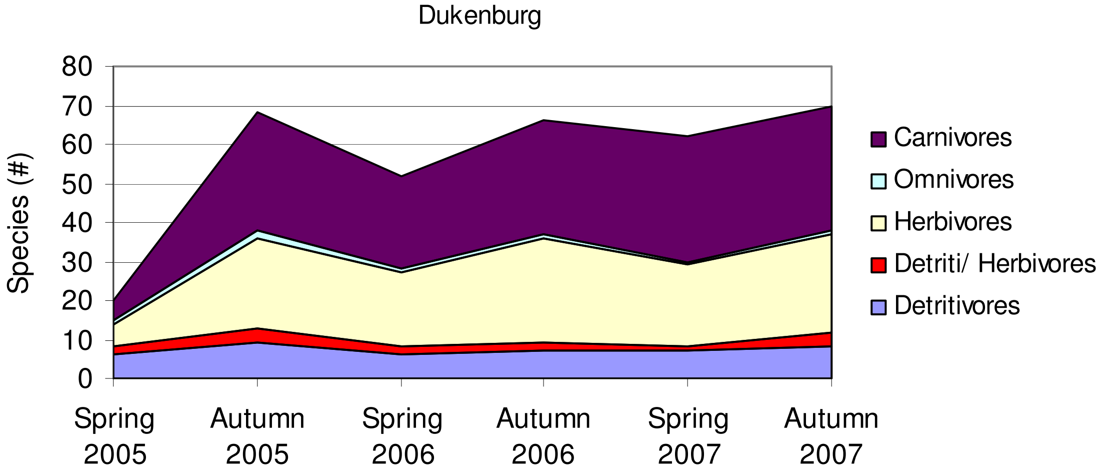
Taxa richness, Shannon-index, relative number of exotic species (%), relative abundance of exotic species (%), Average Score Per Taxon (ASPT) and rareness in Arnhem south-west from 2005 till 2007 (n=7). a and b indicate significant differences (pairwise Student’s t-test, $p<0.05$). Error bars represent the standard error.

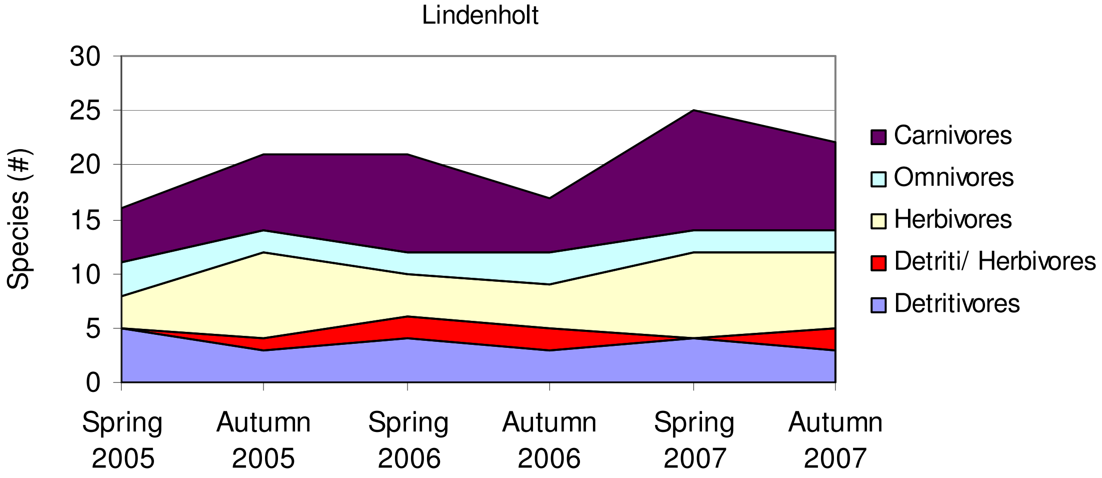
Appendix 16 Effects of rehabilitation measures on the water system: Arnhem south-east

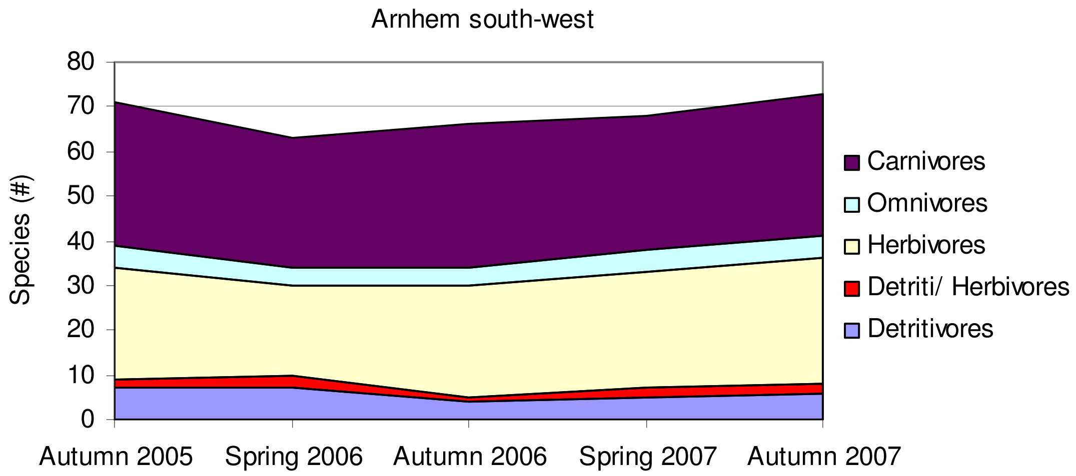


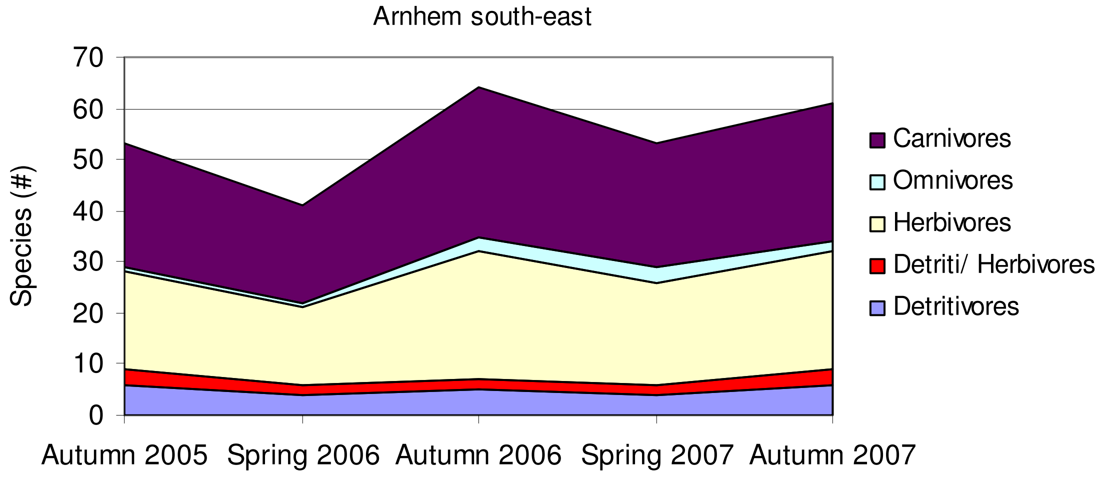
Taxa richness, Shannon-index, relative number of exotic species (%), relative abundance of exotic species (%), Average Score Per Taxon (ASPT) and rareness in Arnhem south-east from 2005 till 2007 (n=4). a and b indicate significant differences (pairwise Student's t-test, $p<0.05$). Error bars represent the standard error.

Appendix 17 Feeding guilds in the period 2005-2007 in the different water systems






Arnhem south-west
Species (#)
80
70
60
50
40
30
20
10
0
Autumn 2005
Spring 2006
Autumn 2006
Spring 2007
Autumn 2007
Carnivores
Omnivores
Herbivores
Detriti/ Herbivores
Detritivores


Arnhem south-east
Species (#)
70
60
50
40
30
20
10
0
Autumn 2005
Spring 2006
Autumn 2006
Spring 2007
Autumn 2007
Carnivores
Omnivores
Herbivores
Detriti/ Herbivores
Detritivores

Appendix 18 Occurrence of macroinvertebrate species in Arnhem and Nijmegen in the period 2005-2007

Nijmegen	8	9	24	48	49	71	73	13A	13B	19A	19B	25A	59B	59D	64A	64D	81C	81D
Acroloxus lacustris													x					
Aeshna sp.												x						
Agraylea multipunctata	x		x	x									x	x				
Agraylea sexmaculata	x																	
Agrypnia pagetana			x								x	x						
Alboglossiphonia heteroclita			x	x			x			x	x	x	x	x				
Anabolia nervosa				x									x					
Anacaena sp.																		
Anax imperator																		
Anisus vortex			x	x	x			x	x	x	x	x	x	x		x		
Anodonta anatina						x												
Anodonta cygnea zellensis																		
Arrenurus sp.	x		x	x	x	x	x			x	x	x	x	x			x	x
Asellus aquaticus	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	
Athripsodes aterrimus			x	x	x	x				x	x	x	x	x			x	x
Bathyomphalus contortus						x	x	x					x					
Bithynia leachii			x	x	x							x	x					
Bithynia tentaculata			x	x	x			x	x	x	x	x	x	x		x	x	x
Bothromesostoma essenii																		
Bothromesostoma personatum				x														
Brachypoda sp.																		
Caenis horaria		x	x	x	x	x		x		x	x	x	x	x			x	x
Caenis luctuosa		x	x			x	x						x					
Caenis robusta			x			x						x	x					
Callicorixa praesta																		
Ceratopogonidae	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Chaoboridae	x										x							
Chironomidae	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cloeon dipterum	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
Cloeon simile												x	x	x			x	
Coleoptera larvae	x		x	x	x	x		x		x	x	x	x	x	x			
Corixa punctata				x							x				x			
Crangonyx pseudogracilis				x	x			x	x	x	x	x			x	x		
Culicidae				x	x					x	x		x	x	x			
Cymatia coleoptrata																		
Cyrnus crenaticornis																		
Cyrnus flavidus			x															
Cyrnus trimaculatus						x												
Dendrocoelum lacteum				x				x	x	x								
Dixidae						x												
Dreissena polymorpha						x	x											
Dugesia polychroa	x		x	x	x			x	x	x	x	x	x	x				
Dugesia tigrina	x		x	x	x	x						x						
Enallagna cyathigerum			x	x	x					x			x					x
Eonomus tenellus																		
Ephydridae			x							x	x	x						
Erpobdella sp.	x		x	x	x	x		x	x	x	x	x	x	x	x			
Erythromma najas			x															
Erythromma viridulum																		
Eylais sp.				x	x						x		x		x			
Ferrissia wautieri																		x
Forelia sp.																		
Frontipoda musculus																		
Gammarus pulex pulex			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Gammarus tigrinus						x	x										x	x
Gerris sp.		x	x	x	x	x	x	x		x	x	x	x	x	x	x		x
Glossiphonia complanata complanata			x	x	x					x	x	x		x				
Gyraulus albus	x		x	x	x	x		x	x	x	x	x	x	x	x			
Gyraulus crista	x		x							x			x		x			
Gyrinus marinus											x							

Nijmegen	8	9	24	48	49	71	73	13A	13B	19A	19B	25A	59B	59D	64A	64D	81C	81D
Haliplus flavicollis				x						x	x							
Haliplus fluviatilis										x								
Haliplus immaculatus			x	x						x	x	x						
Haliplus laminatus																		
Haliplus lineolatus																		
Haliplus ruficollis										x								
Haliplus ruficollis groep			x	x	x					x	x	x	x	x	x	x		
Haliplus varius																		
Haliplus wehnkei			x	x	x					x	x	x	x	x	x			
Helobdella stagnalis	x	x	x	x	x	x		x		x	x	x		x	x		x	x
Hemiclepsis marginata			x	x	x						x		x	x				x
Hemimysis anomala																	x	
Hesperocorixa linnei				x	x													
Hippeutis complanatus	x		x	x	x					x	x			x				x
Holocentropus dubius										x								
Holocentropus picicornis			x	x								x						
Holocentropus stagnalis						x												
Hydrachna sp.				x														
Hydrochoreutes sp.						x				x								
Hydrodroma despiciens			x							x	x	x	x		x			
Hydrometra stagnorum																		
Hydrophilidae				x	x			x		x	x							
Hydroporus sp.			x							x	x							
Hydryphantes sp.										x								
Hygrobates sp.			x				x		x	x		x	x	x	x	x	x	x
Hygrotus inaequalis										x								
Hygrotus versicolor										x		x						
Hyphydrus ovatus			x	x						x	x	x	x					
Ilyochoris cimicoides	x		x	x						x	x	x	x	x				
Ischnura elegans / Coenagrion puella/ pulchellum	x		x	x	x	x	x	x	x	x	x	x	x	x	x			x
Laccophilus minutus													x					
Lepidoptera			x	x	x						x	x						
Leptocerus tineiformis							x	x				x						
Lestes viridis	x	x	x	x	x		x	x		x	x	x		x		x		x
Libellulidae											x	x						x
Limnephilus lunatus			x	x	x	x		x			x	x	x					
Limnesia sp.	x	x	x	x	x	x				x	x	x	x	x	x	x		x
Limnochares aquatica																		
Limnomysis benedeni						x	x						x	x			x	x
Limoniidae				x						x			x		x			
Lymnaea stagnalis	x			x	x			x										
Mesostoma sp.																		
Mesovelia furcata																		
Micronecta minutissima						x	x										x	x
Microvelia buenoi																		
Microvelia reticulata		x		x														
Mideopsis sp.		x					x					x		x			x	x
Molanna angustata																		
Musculium lacustre			x	x				x						x				
Mystacides longicornis/ nigra						x	x					x	x	x			x	x
Nemathelminthes						x	x		x						x			x
Nepa cinerea										x								
Neumania sp.	x	x	x	x	x						x	x	x	x	x		x	
Noterus clavicornis								x										
Noterus crassicornis																		
Notonecta sp.	x	x	x	x		x		x		x	x	x						
Oecetis furva																		
Oecetis lacustris			x															
Oligochaete	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Orthotrichia costalis						x											x	x
Oxus sp.																		
Oxyethira sp.																		

Nijmegen	8	9	24	48	49	71	73	13A	13B	19A	19B	25A	59B	59D	64A	64D	81C	81D
Peltodytes caesus										x	x							
Phryganea bipunctata			x															
Physa fontinalis			x	x	x				x	x	x	x	x	x				x
Physella acuta	x					x	x								x	x		
Piona sp.	x	x	x	x	x	x	x			x	x	x	x	x	x	x		
Pionacercus vatrax										x								
Pionopsis lutescens										x	x	x			x	x		
Piscicola geometra			x	x	x		x		x	x	x	x	x	x				
Pisidium sp.			x	x	x	x	x	x	x	x		x		x			x	x
Planaria torva				x														
Planorbarius corneus	x		x	x							x			x				
Planorbis carinatus			x	x	x			x	x	x	x	x	x	x				
Plea minutissima	x			x					x	x	x	x	x	x				
Polycelis nigra			x	x				x	x	x		x		x				
Polycelis tenuis			x	x		x	x	x	x	x	x	x	x	x				
Potamopyrgus antipodarum						x		x					x				x	x
Proasellus coxalis			x			x		x	x	x	x	x		x	x			
Proasellus meridianus			x	x	x	x		x	x	x	x	x	x	x		x		
Psychodidae								x										
Pyrrosoma nymphula				x	x					x								
Radix auricularia													x	x				
Radix ovata			x	x	x			x		x	x	x	x	x				
Ranatra linearis	x																	
Rhantus exsoletus										x		x						
Segmentina nitida																	x	
Sialis sp.				x	x					x	x		x					
Sigara distincta													x	x	x			
Sigara falleni	x		x		x			x	x		x	x	x	x	x		x	x
Sigara lateralis/ scotti					x										x			
Sigara striata	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Sisyridae																		
Sphaerium corneum	x		x	x	x	x		x			x	x						
Stagnicola cf. *corvus*										x		x						
Stagnicola palustris										x	x							
Stictotarsus duodecimpustulatus				x	x													
Stratiomydae			x	x	x							x						
Tabanidae																		
Theromyzon tessulatum	x		x	x	x					x		x	x					
Tinodes waeneri						x												
Tiphys sp.				x						x	x							
Tipulidae			x	x						x	x							
Triaenodes bicolor	x		x			x				x	x	x	x	x				
Unio pictorum							x										x	
Unionicola sp.						x	x					x	x					x
Valvata cristata				x						x	x							
Valvata piscinalis			x	x	x	x		x		x	x	x	x	x		x		
Viviparus contectus			x	x														

Arnhem	A1	A2	A3	A4	A5	A6	A7	A8	A9	A9B	A10	A11	A12	A13	A14
Acroloxus lacustris	x		x		x	x							x	x	
Aeshna sp.					x						x				
Agraylea multipunctata	x		x	x	x					x	x	x	x	x	x
Agraylea sexmaculata	x		x	x		x				x			x		
Agrypnia pagetana											x	x	x		
Alboglossiphonia heteroclita	x	x	x	x	x	x		x	x	x	x	x	x	x	x
Anabolia nervosa	x	x							x				x		
Anacaena sp.									x						
Anax imperator				x	x	x			x	x		x			
Anisus vortex	x	x	x	x		x				x	x	x	x		x
Anodonta anatina					x										
Anodonta cygnea zellensis									x						
Arrenurus sp.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Asellus aquaticus	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Athripsodes aterrimus	x	x		x		x			x	x	x		x		x
Bathyomphalus contortus		x		x							x			x	x
Bithynia leachii	x	x	x	x	x	x	x	x	x	x	x	x	x		x
Bithynia tentaculata	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Bothromesostoma essenii									x						
Bothromesostoma personatum			x			x			x	x		x	x		
Brachypoda sp.	x					x					x	x	x		
Caenis horaria	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Caenis luctuosa							x								
Caenis robusta	x	x				x	x			x			x		
Callicorixa praesta	x									x					
Ceratopogonidae	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Chaoboridae				x		x	x				x		x		x
Chironomidae	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cloeon dipterum	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cloeon simile				x	x	x						x			
Coleoptera larvae	x	x	x	x	x	x	x		x	x	x	x	x	x	x
Corixa punctata				x											x
Crangonyx pseudogracilis		x						x	x	x					
Culicidae				x		x			x	x	x		x	x	x
Cymatia coleoptrata	x		x	x	x	x				x					
Cyrnus crenaticornis		x											x		
Cyrnus flavidus									x						
Cyrnus trimaculatus															
Dendrocoelum lacteum	x	x	x	x									x		x
Dixidae			x	x		x								x	
Dreissena polymorpha															
Dugesia polychroa	x	x	x	x	x	x		x	x	x	x	x	x	x	x
Dugesia tigrina	x	x	x	x	x	x	x	x	x	x		x	x	x	
Enallagna cyathigerum	x	x	x	x		x	x		x				x	x	
Eonomus tenellus									x						
Ephydridae			x	x						x					x
Erpobdella sp.	x	x	x	x	x	x	x		x	x	x	x	x	x	x
Erythromma najas	x	x		x		x			x	x		x	x	x	
Erythromma viridulum	x	x	x	x		x			x	x	x		x		
Eylais sp.				x								x	x		x
Ferrissia wautieri					x	x	x		x	x		x			
Forelia sp.		x						x			x		x		
Frontipoda musculus						x									
Gammarus pulex pulex	x				x	x			x	x	x	x	x		
Gammarus tigrinus		x			x										
Gerris sp.	x		x	x	x	x	x		x	x	x	x	x	x	
Glossiphonia complanata complanata	x	x									x	x	x		x
Gyraulus albus	x	x	x	x	x	x	x		x	x	x	x	x	x	x
Gyraulus crista	x			x	x	x			x	x	x		x		x
Gyrinus marinus						x									

Arnhem	A1	A2	A3	A4	A5	A6	A7	A8	A9	A9B	A10	A11	A12	A13	A14
Haliplus flavicollis					x										
Haliplus fluviatilis		x	x			x									
Haliplus immaculatus			x			x				x	x	x	x		x
Haliplus laminatus												x			x
Haliplus lineolatus		x													
Haliplus ruficollis	x									x					x
Haliplus ruficollis groep	x		x	x		x			x	x	x	x	x		x
Haliplus varius					x										
Haliplus wehnkei	x		x												x
Helobdella stagnalis	x	x	x		x	x	x	x	x	x	x	x	x	x	x
Hemiclepsis marginata	x	x	x			x				x	x	x			
Hemimysis anomala															
Hesperocorixa linnei															
Hippeutis complanatus	x	x	x	x		x	x		x						x
Holocentropus dubius	x		x												
Holocentropus picicornis	x		x	x		x					x	x			
Holocentropus stagnalis															
Hydrachna sp.	x		x	x	x				x	x	x	x		x	
Hydrochoreutes sp.	x		x			x				x		x			
Hydrodroma despiciens	x	x	x	x	x	x			x	x	x	x	x	x	
Hydrometra stagnorum				x							x	x			
Hydrophilidae										x			x		x
Hydroporus sp.															
Hydryphantes sp.															
Hygrobates sp.					x	x			x	x		x	x		x
Hygrotus inaequalis															x
Hygrotus versicolor												x			
Hyphydrus ovatus				x							x	x			
Ilyochoris cimicoides									x	x					
Ischnura elegans / Coenagrion puella/ pulchellum	x	x	x	x	x	x	x		x	x	x	x	x	x	x
Laccophilus minutus												x			
Lepidoptera	x		x	x		x		x	x	x	x	x			
Leptocerus tineiformis	x		x	x	x	x			x	x	x	x			
Lestes viridis	x		x	x		x			x	x	x				x
Libellulidae			x						x	x	x				
Limnephilus lunatus									x	x	x				x
Limnesia sp.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Limnochares aquatica						x									
Limnomysis benedeni	x	x			x		x	x	x	x		x	x		
Limoniidae			x			x	x			x					
Lymnaea stagnalis		x	x	x	x	x					x	x	x	x	x
Mesostoma sp.			x												
Mesovelia furcata			x						x			x			
Micronecta minutissima	x	x			x		x	x		x		x		x	
Microvelia buenoi									x						
Microvelia reticulata		x		x	x	x			x	x			x		
Mideopsis sp.						x			x	x					
Molanna angustata					x								x		
Musculium lacustre	x		x	x	x	x	x		x	x		x			
Mystacides longicornis/ nigra	x				x	x				x		x			
Nemathelminthes			x		x			x	x				x	x	x
Nepa cinerea															
Neumania sp.	x	x	x	x	x	x		x				x			x
Noterus clavicornis			x	x		x									
Noterus crassicornis			x	x		x									
Notonecta sp.	x		x	x					x	x	x	x	x	x	x
Oecetis furva	x	x	x	x		x	x		x	x			x		
Oecetis lacustris															
Oligochaete	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Orthotrichia costalis					x		x		x						
Oxus sp.		x	x			x					x				
Oxyethira sp.	x						x		x	x		x	x		

Arnhem	A1	A2	A3	A4	A5	A6	A7	A8	A9	A9B	A10	A11	A12	A13	A14
Peltodytes caesus				x											
Phryganea bipunctata													x		
Physa fontinalis	x	x	x	x		x		x	x		x	x	x	x	x
Physella acuta	x				x		x		x	x					
Piona sp.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Pionacercus vatrax															
Pionopsis lutescens	x		x	x	x	x	x		x		x	x			
Piscicola geometra	x	x	x			x	x		x	x	x	x	x	x	
Pisidium sp.	x	x	x		x	x				x	x	x	x	x	
Planaria torva															
Planorbarius corneus		x		x								x			x
Planorbis carinatus	x	x	x	x		x		x	x	x	x	x			x
Plea minutissima	x	x	x	x	x	x			x		x	x			x
Polycelis nigra	x											x			
Polycelis tenuis		x		x		x						x		x	x
Potamopyrgus antipodarum					x				x						x
Proasellus coxalis			x			x		x							
Proasellus meridianus													x		
Psychodidae															
Pyrrosoma nymphula															
Radix auricularia	x	x	x		x	x		x	x	x			x	x	x
Radix ovata					x	x			x		x	x			x
Ranatra linearis			x	x	x	x								x	
Rhantus exsoletus															
Segmentina nitida															
Sialis sp.	x	x						x	x	x	x	x	x	x	
Sigara distincta	x														
Sigara falleni	x	x		x	x	x	x		x	x	x	x		x	
Sigara lateralis/ scotti	x														x
Sigara striata	x	x		x		x	x	x	x	x	x	x	x	x	x
Sisyridae													x		
Sphaerium corneum	x	x	x	x		x	x	x		x	x	x	x		x
Stagnicola cf. *corvus*															
Stagnicola palustris						x			x						
Stictotarsus duodecimpustulatus															
Stratiomydae						x			x						
Tabanidae					x						x	x			
Theromyzon tessulatum	x	x	x	x		x	x			x	x	x	x		x
Tinodes waeneri															
Tiphys sp.	x		x	x		x	x		x	x					x
Tipulidae												x			
Triaenodes bicolor	x	x	x	x	x	x			x	x	x	x	x	x	x
Unio pictorum					x										
Unionicola sp.	x	x			x		x	x	x			x	x	x	
Valvata cristata	x	x	x	x	x	x				x	x	x	x		x
Valvata piscinalis	x	x	x		x	x		x	x	x	x	x	x	x	x
Viviparus contectus				x											x

Appendix 19 Physico-chemical quality in Arnhem and Nijmegen in the period 2005-2007

Loc.	NO_3^- (mg l^{-1})			NH_4^+ (mg l^{-1})			PO_4^{3-} (mg l^{-1})			Total-P (mg l^{-1})		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
8	6.5	1.7	12.9	0.22	0.06	0.46	0.04	0.01	0.07	0.02	0.01	0.03
9	0.5	0.3	1.1	0.09	0.08	0.10	0.03	0.03	0.03	0.02	0.01	0.02
24	7.8	3.2	13.2	0.12	0.01	0.30	0.08	0.04	0.14	0.03	0.01	0.05
48	7.0	0.5	14.0	0.22	0.02	0.52	0.10	0.05	0.15	0.04	0.01	0.06
49	7.6	4.0	13.6	0.19	0.04	0.28	0.12	0.08	0.21	0.04	0.02	0.06
71	3.5	1.3	5.2	0.13	0.06	0.21	0.06	0.03	0.10	0.02	0.01	0.05
73	0.9	0.0	2.6	0.13	0.01	0.23	0.03	0.01	0.07	0.02	0.01	0.02
13A	14.4	3.1	35.1	0.13	0.04	0.25	0.30	0.09	0.54	0.11	0.05	0.18
13B	14.8	10.9	21.6	0.11	0.06	0.13	0.45	0.37	0.54	0.16	0.11	0.19
19A	8.4	2.1	15.1	0.12	0.01	0.26	0.07	0.03	0.09	0.03	0.01	0.06
19B	8.1	3.5	15.1	0.20	0.12	0.25	0.10	0.06	0.18	0.03	0.02	0.04
25A	6.1	5.0	6.9	0.15	0.07	0.27	0.09	0.02	0.18	0.03	0.01	0.07
59B	9.6	6.9	17.1	0.13	0.04	0.27	0.20	0.06	0.34	0.07	0.05	0.10
59D	8.2	5.0	15.9	0.26	0.05	0.65	0.23	0.08	0.36	0.08	0.07	0.11
64A	8.6	2.8	20.3	0.11	0.05	0.20	0.05	0.02	0.10	0.02	0.01	0.06
64D	7.0	1.6	18.5	0.12	0.04	0.21	0.05	0.01	0.10	0.02	0.00	0.05
81C	1.3	0.0	3.2	0.09	0.04	0.23	0.09	0.01	0.26	0.04	0.02	0.09
81D	1.3	0.0	3.6	0.11	0.03	0.24	0.06	0.02	0.15	0.03	0.02	0.06
A1	1.3	0.1	3.3	0.19	0.07	0.49	0.08	0.02	0.24	0.02	0.00	0.08
A2	2.7	1.0	5.3	0.31	0.12	0.96	0.03	0.02	0.04	0.02	0.01	0.02
A3	0.3	0.2	0.7	0.16	0.07	0.26	0.06	0.02	0.15	0.04	0.02	0.09
A4	0.4	0.1	1.0	0.24	0.04	0.48	0.09	0.04	0.14	0.05	0.04	0.06
A5	1.6	0.0	2.9	0.36	0.05	1.54	0.39	0.02	1.82	0.12	0.01	0.51
A6	0.5	0.0	1.6	0.11	0.08	0.19	0.04	0.02	0.05	0.02	0.00	0.03
A7	1.4	0.5	3.1	0.33	0.09	0.90	0.03	0.01	0.03	0.00	0.00	0.02
A8	3.2	1.4	4.9	0.27	0.06	0.82	0.03	0.01	0.08	0.01	0.00	0.02
A9	1.7	0.1	4.2	0.33	0.08	0.73	0.03	0.02	0.04	0.02	0.01	0.02
A9B	1.7	0.1	4.1	0.21	0.08	0.62	0.12	0.01	0.43	0.05	0.00	0.14
A10	1.3	0.0	3.0	0.19	0.07	0.49	0.05	0.01	0.09	0.02	0.01	0.04
A11	1.2	0.0	2.3	0.21	0.07	0.58	0.11	0.01	0.44	0.04	0.00	0.17
A12	1.5	0.1	2.3	0.12	0.09	0.17	0.04	0.02	0.11	0.01	0.00	0.04
A13	3.5	0.7	7.7	0.40	0.19	0.76	0.09	0.05	0.12	0.04	0.02	0.05
A14	18.9	3.8	27.7	0.34	0.14	0.75	0.17	0.02	0.36	0.08	0.02	0.19

Loc.	Total-S (mg l^{-1})			K^+ (mg l^{-1})			Na^+ (mg l^{-1})			Cl^- (mg l^{-1})		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
8	3.6	0.6	8.9	2.1	0.6	5.0	15.3	1.4	39.9	21.6	3.9	55.3
9	10.6	6.5	17.0	3.5	2.6	5.1	23.9	15.1	36.8	38.2	26.9	60.5
24	17.6	16.3	19.1	3.9	3.6	4.3	30.6	27.0	35.1	47.0	43.3	49.6
48	15.1	7.7	20.6	4.2	3.1	4.9	30.5	21.1	33.2	46.7	35.3	52.3
49	17.1	7.8	20.8	4.7	4.1	5.5	34.4	28.7	38.7	52.2	47.0	59.2
71	13.4	1.6	19.5	4.1	3.4	4.9	28.0	21.4	34.9	46.8	37.2	58.3
73	12.1	0.0	19.9	3.4	3.0	3.9	21.2	17.9	29.6	36.9	31.6	48.6
13A	17.8	12.8	21.1	5.6	4.4	8.5	39.8	31.3	70.6	58.1	47.5	96.7
13B	18.6	16.8	21.7	5.2	4.4	6.3	35.9	31.5	41.6	51.6	46.6	54.5
19A	15.6	6.3	19.4	3.8	3.4	4.1	29.2	24.7	35.1	44.8	40.2	48.3
19B	16.6	14.0	20.2	3.8	3.3	4.3	29.0	24.0	34.2	45.5	40.6	50.7
25A	17.3	15.8	19.3	4.2	3.7	5.1	33.7	26.4	42.8	52.3	45.2	65.2
59B	16.9	6.2	21.3	4.6	4.3	5.1	35.8	28.7	38.9	55.3	51.1	57.5
59D	17.0	9.6	20.2	4.5	2.8	6.2	33.6	18.6	50.2	51.9	30.1	70.9
64A	16.9	9.6	20.0	4.9	2.7	5.7	31.5	17.1	37.9	47.4	24.9	58.6
64D	17.6	12.7	20.9	4.9	3.6	6.0	31.9	22.4	38.7	48.3	32.4	58.6
81C	16.5	13.1	20.0	4.7	3.8	5.2	25.6	24.1	28.2	46.7	43.7	48.2
81D	15.0	6.8	18.2	4.8	3.9	5.6	24.9	23.1	26.5	45.7	43.0	48.5
A1	8.3	0.0	18.8	4.3	2.3	5.9	22.8	16.4	34.6	37.0	25.7	61.0
A2	13.3	7.9	16.0	6.1	4.3	10.7	23.5	18.4	27.8	36.7	25.3	48.3
A3	9.2	2.8	16.0	3.9	1.7	5.3	19.9	9.1	28.5	33.4	13.6	48.3
A4	2.6	1.4	5.3	0.9	0.6	1.6	22.6	7.6	63.2	30.3	6.3	90.8
A5	9.4	5.9	16.3	4.3	2.0	8.0	21.8	13.7	30.6	33.4	21.1	53.1
A6	8.4	0.0	19.6	4.0	2.4	5.6	21.8	14.4	30.9	35.7	21.3	54.0
A7	7.8	0.0	15.6	4.9	4.4	6.4	23.4	16.8	34.7	40.2	26.6	58.6
A8	13.5	0.2	18.6	7.3	5.0	15.3	25.0	18.9	34.8	38.6	25.9	56.2
A9	12.1	6.3	18.3	5.5	2.5	9.4	25.6	15.9	40.5	41.2	26.3	74.1
A9B	11.5	6.4	18.8	4.2	2.4	5.3	25.0	16.1	40.3	40.5	25.5	73.1
A10	10.6	7.7	12.4	3.4	1.8	4.7	27.6	16.8	53.5	41.3	24.5	78.0
A11	6.1	0.0	16.7	3.0	1.6	5.1	28.2	17.0	40.6	46.4	28.3	68.1
A12	9.5	0.0	16.3	6.4	3.1	14.0	22.2	17.1	26.1	31.4	27.7	37.4
A13	11.3	6.2	14.3	3.8	3.0	4.9	23.5	22.0	25.1	39.2	37.3	42.2
A14	16.3	12.5	20.1	8.2	7.7	9.2	35.3	30.4	41.6	51.0	45.9	57.3

Loc.	pH			Alkalinity (eq l^{-1})			CO_2 (µmol l^{-1})			HCO_3 (µmol l^{-1})		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
8	7.1	6.6	7.8	0.0	0.7	2.2	119.7	101.7	154.3	1056	190	2497
9	7.8	7.3	8.2	0.0	1.6	2.6	92.1	20.2	144.5	1752	1287	2573
24	7.1	6.8	7.5	0.0	2.2	2.6	454.3	176.5	853.3	2114	1674	2590
48	7.6	6.7	9.7	0.0	1.6	2.5	287.4	3.3	586.3	1894	1351	2394
49	7.3	6.8	7.6	0.0	2.3	2.6	317.6	169.1	676.9	2260	1837	2523
71	7.7	7.5	7.9	0.0	2.3	2.7	137.4	94.7	195.7	2691	2338	3394
73	7.8	7.6	8.0	0.0	2.3	2.8	101.3	65.1	135.4	2588	2259	2862
13A	7.2	6.8	7.5	0.0	2.3	2.8	387.3	145.6	709.9	2196	1951	2515
13B	7.3	7.1	7.6	0.0	2.3	2.6	295.6	132.6	464.3	2366	2041	2623
19A	7.3	6.7	8.8	0.0	2.0	2.6	446.2	10.7	804.4	2123	1614	2497
19B	7.0	6.8	7.6	0.0	2.3	2.9	586.4	161.8	944.1	2045	1677	2466
25A	7.1	6.7	7.6	0.0	2.5	2.8	477.8	127.8	774.9	2242	1754	2631
59B	7.4	6.9	7.9	0.0	2.2	2.5	284.6	93.3	628.1	2372	1845	2734
59D	7.3	6.8	7.8	0.0	2.2	2.5	269.6	94.5	601.9	2227	1191	2758
64A	7.3	6.9	7.9	0.0	2.1	2.4	297.2	78.4	547.0	1935	965	2476
64D	7.3	6.9	7.8	0.0	2.0	2.4	243.4	91.3	489.2	1943	1329	2469
81C	7.9	7.4	8.5	0.0	3.1	3.5	130.5	25.0	302.3	3250	3032	3507
81D	7.9	7.5	8.4	0.0	3.0	3.5	124.9	33.1	234.0	3332	2878	4009
A1	7.6	7.4	7.9	0.0	2.9	4.8	221.9	125.5	261.4	3731	2660	5213
A2	7.5	7.3	7.6	0.0	3.1	4.5	318.9	172.8	423.2	3959	3190	4548
A3	7.5	7.1	7.9	0.0	1.5	5.3	266.0	152.7	392.7	3696	1347	5289
A4	7.9	6.6	9.3	0.0	0.4	9.0	122.1	1.1	358.6	932	541	1514
A5	7.7	7.5	8.0	0.0	2.6	3.8	152.7	60.4	228.6	2972	2457	4281
A6	7.6	7.2	7.9	0.0	2.3	5.8	227.1	127.4	400.0	4015	2429	5855
A7	7.6	7.4	7.8	0.0	2.9	5.8	248.8	155.1	420.1	4356	2950	6109
A8	7.8	7.6	8.1	0.0	3.1	4.8	167.7	97.2	250.8	3977	3275	4965
A9	7.7	7.5	8.0	0.0	2.4	5.5	222.0	52.4	435.5	3984	2317	5954
A9B	7.7	7.5	7.7	0.0	2.5	5.4	189.7	105.1	284.2	3416	2389	5561
A10	7.7	7.6	7.9	0.0	3.2	5.9	174.2	114.8	236.4	3907	2586	6063
A11	7.7	7.4	7.9	0.0	2.4	6.0	210.5	93.9	290.4	3753	2452	5942
A12	7.7	7.6	7.8	0.0	2.8	5.6	196.6	99.7	272.1	3966	2604	5679
A13	7.5	7.2	8.1	0.0	1.8	3.1	184.3	51.1	309.9	2240	1175	2901
A14	7.8	7.7	8.0	0.0	4.2	4.5	179.1	90.3	225.9	4268	4008	4491

Loc.	Ca^{2+} (mg l^{-1})			Mg^{2+} (mg l^{-1})			Li^{+} (µg l^{-1})			Total-Fe (µg l^{-1})		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
8	19.4	3.9	44.0	3.0	0.3	8.2	3.3	0.5	8.1	151.1	32.1	262.6
9	40.3	29.4	61.8	4.8	3.0	7.9	3.0	1.4	4.8	46.7	38.6	58.8
24	55.8	49.9	62.1	8.2	7.5	9.0	3.5	2.9	5.3	135.3	83.2	215.8
48	50.0	39.4	62.3	7.4	5.3	8.8	1.9	1.2	2.6	80.5	39.9	157.0
49	55.7	49.3	60.5	8.3	7.5	9.0	1.6	0.9	2.5	59.0	45.3	71.7
71	57.9	50.5	65.1	8.6	7.7	9.6	2.5	1.3	5.6	39.5	24.6	58.7
73	56.6	44.9	67.8	8.3	6.9	10.1	1.6	0.9	3.3	68.0	27.8	121.9
13A	57.0	52.6	58.9	8.6	7.4	9.5	4.0	2.9	7.2	22.3	10.8	37.2
13B	57.7	51.8	63.1	8.6	7.3	9.5	4.4	3.0	7.0	18.2	10.2	28.3
19A	55.2	45.7	62.6	7.9	6.5	9.0	3.6	2.5	4.9	177.6	112.7	259.1
19B	56.4	49.3	63.1	8.1	7.2	9.0	3.7	3.3	4.4	166.6	96.4	202.9
25A	57.4	51.3	63.3	8.4	7.6	9.1	3.6	3.2	4.4	129.9	63.1	179.4
59B	55.9	49.4	60.1	9.0	8.0	9.6	2.0	1.7	3.2	37.9	33.8	42.2
59D	53.1	28.9	68.1	8.3	4.4	9.9	2.0	1.2	2.8	44.0	23.6	63.2
64A	52.8	27.3	65.6	7.3	3.7	8.8	1.4	0.2	6.9	21.6	14.6	28.9
64D	53.3	36.8	66.8	7.3	5.1	8.5	0.6	0.2	1.9	32.8	20.3	52.7
81C	76.2	64.2	89.6	10.1	8.8	11.5	1.8	0.7	6.0	59.4	26.4	115.1
81D	72.7	61.5	87.1	9.7	8.5	11.2	1.3	0.6	3.7	50.4	20.9	112.0
A1	70.5	50.2	93.5	9.6	6.2	15.1	4.6	2.7	8.2	87.1	39.8	193.2
A2	79.7	68.7	90.6	12.2	9.9	14.0	6.4	5.3	8.1	96.7	29.8	173.9
A3	70.3	31.7	99.2	9.5	3.7	14.5	3.8	1.9	4.8	369.4	89.2	1108.8
A4	17.9	9.6	25.4	2.2	1.0	4.9	2.0	1.4	2.5	209.3	98.9	343.2
A5	65.0	46.3	78.9	8.5	5.3	12.2	4.8	3.5	7.6	39.7	30.5	63.3
A6	73.5	38.6	101.5	10.0	5.2	14.5	4.3	1.6	5.9	118.1	45.4	180.9
A7	79.4	63.7	109.5	10.4	9.1	13.3	4.9	3.0	7.7	113.4	20.6	303.5
A8	77.1	68.6	84.1	12.3	10.5	13.6	6.2	4.2	8.6	43.2	21.3	83.5
A9	72.8	41.3	90.8	10.8	6.0	14.3	6.6	4.5	10.8	42.6	19.4	66.4
A9B	71.3	44.5	93.8	9.9	5.9	12.1	6.2	4.5	10.6	43.7	18.0	90.0
A10	79.1	61.3	125.4	10.6	9.9	12.2	4.2	2.9	5.3	50.6	34.1	60.7
A11	73.8	41.2	105.1	9.8	6.4	12.7	4.0	2.1	6.0	96.2	39.8	184.0
A12	78.0	57.9	88.2	11.6	7.4	13.1	5.3	4.3	6.1	56.1	18.8	100.4
A13	49.1	35.9	56.0	6.2	6.1	6.3	2.5	1.7	3.2	50.7	34.4	60.4
A14	90.7	79.8	97.9	9.6	8.7	10.5	4.4	4.1	4.6	80.1	9.3	128.9

Loc.	Al^{3+} (µg l^{-1})			Cu^{2+} (µg l^{-1})			Zn^{2+} (µg l^{-1})			Pb^{2+} (µg l^{-1})		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
8	11.4	3.6	15.7	3.2	2.6	4.1	39.5	36.0	44.6	4.27	0.85	10.72
9	38.0	19.3	69.8	2.1	1.7	2.6	31.5	17.2	41.5	0.52	0.24	0.76
24	4.0	0.8	6.1	1.6	1.1	2.6	37.1	22.0	52.4	0.29	0.10	0.43
48	6.7	4.0	10.3	2.4	1.6	5.6	52.7	16.6	93.2	1.45	0.00	4.03
49	8.1	3.0	16.8	1.6	1.3	2.2	38.9	27.7	54.7	0.64	0.15	1.64
71	4.9	2.5	6.7	1.1	0.0	1.6	27.8	10.1	45.5	0.49	0.07	2.04
73	11.5	4.7	25.3	1.1	0.5	1.4	26.3	13.0	37.9	0.23	0.06	0.38
13A	4.3	1.0	9.0	2.1	1.3	3.8	52.9	23.0	77.1	0.31	0.00	1.25
13B	3.6	0.0	6.6	2.0	1.4	2.9	29.7	23.8	35.1	0.20	0.00	0.52
19A	3.1	0.0	5.9	1.5	0.1	3.4	38.9	21.4	69.6	0.30	0.02	1.14
19B	5.9	0.5	8.9	1.6	0.7	2.2	35.1	26.8	42.2	0.66	0.20	1.48
25A	2.9	0.0	5.2	1.5	0.8	2.4	35.3	25.6	42.5	0.20	0.06	0.43
59B	4.7	0.7	12.0	1.7	1.2	3.2	34.6	19.8	55.7	0.20	0.00	0.53
59D	9.5	3.1	35.3	1.9	1.5	2.6	36.3	14.0	58.8	1.22	0.18	4.75
64A	5.1	3.4	6.5	2.4	1.3	3.4	38.0	17.9	58.3	1.15	0.00	3.36
64D	6.4	4.3	9.3	3.2	1.3	10.0	38.6	25.5	57.2	0.84	0.00	1.53
81C	10.5	7.3	13.2	1.2	0.7	1.5	27.8	20.5	32.8	0.21	0.07	0.32
81D	9.3	3.3	15.0	1.3	0.7	1.7	25.3	19.0	30.4	0.18	0.00	0.38
A1	6.9	0.0	10.9	1.4	1.0	1.6	72.7	18.3	229.6	0.17	0.09	0.27
A2	7.7	4.3	14.2	1.3	0.1	2.1	34.2	18.6	52.6	0.38	0.00	1.00
A3	5.3	0.9	9.5	1.5	0.9	2.6	34.4	13.9	56.7	0.33	0.00	0.83
A4	12.2	6.4	15.6	4.6	1.5	6.7	25.0	6.5	39.6	0.78	0.38	1.37
A5	8.4	4.9	12.3	1.8	0.7	3.9	27.1	13.4	42.4	0.17	0.02	0.28
A6	4.8	0.0	8.3	0.9	0.0	2.0	28.5	10.1	43.8	0.17	0.00	0.39
A7	6.0	0.2	9.7	1.0	0.1	1.3	36.0	21.7	59.3	0.19	0.14	0.38
A8	11.3	4.7	29.6	1.3	0.0	2.0	38.5	18.5	62.0	0.19	0.00	0.49
A9	5.6	3.1	8.6	1.8	1.0	2.4	27.6	12.5	43.2	0.34	0.05	1.08
A9B	6.5	5.4	8.0	1.7	1.1	2.0	36.2	14.8	50.2	0.10	0.03	0.15
A10	4.1	2.1	5.7	2.1	1.4	3.2	31.8	16.4	45.8	0.23	0.07	0.52
A11	4.7	3.3	6.1	1.3	0.1	2.6	37.0	13.9	59.5	0.25	0.09	0.71
A12	6.1	4.2	7.7	1.4	0.7	2.2	45.3	30.9	60.4	0.38	0.08	1.07
A13	13.7	6.9	23.0	1.7	1.2	2.0	34.5	24.4	49.9	0.47	0.09	0.85
A14	3.8	3.2	4.6	1.2	0.7	1.4	37.6	21.3	59.7	0.20	0.14	0.28