#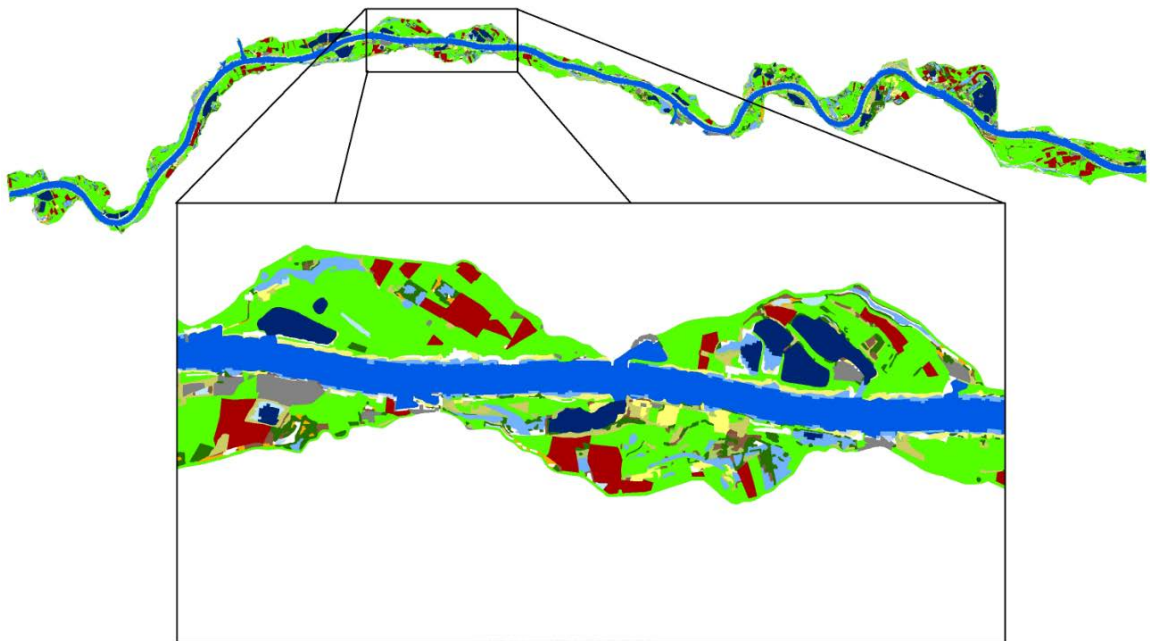 THE DEVELOPMENT OF A GIS TOOL TO ASSESS THE CHANGES IN THE RIVERINE LANDSCAPE FOR THE ECOLOGICAL QUALITY OF THE RIVER RHINE IN THE NETHERLANDS

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Deltares
Enabling Delta Life

II

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III

1 ABSTRACT

This study aims to evaluate the usability of ecotope maps to predict aquatic ecological consequences of floodplain landscape changes. If successful, this method will be applied to evaluate ecological rehabilitation measures that will be carried out in order to improve the ecological status of the large river plains. Ecological value is reflected in indicator metrics for fish, aquatic vegetation, and other qualities. There is a correlation between the composition of these indicators and ecotope types. In order to substantiate this correlation I have gathered information about changes in these indicators by comparing ecotope maps of different years. Recent maps, 1997-2004, are compared to see the effect of pilot rehabilitation measures, and these maps are compared to a reference situation, an ecotope map of 1850. 1850 is the last mapped situation before the normalisation of Dutch rivers caused the ecological quality to deteriorate.

I have explored possibilities to translate aquatic ecotope changes – derived from intervening map changes – into changes in the fish and aquatic vegetation metric scores, i.e. indicators. The metric scores on fish and aquatic vegetation can tell if the ecological status of the river flood plain as a whole is changing; they are based on the Water Framework Directive (WFD) system of scoring. For evaluation, a Geographic Information System (GIS) approach is used. In a GIS environment, I have added information about the 'ecotope – fish' and 'ecotope – aquatic' vegetation relation to the ecotope maps of different years. Through the comparison of the ecotope maps using a GIS, changes in ecotopes type and surface area and, thereby, changes in the fish and aquatic vegetation indices became apparent, which I have presented as maps, graphs and figures.

In addition to surface area related metrics, perimeter based information, too, has ecological meaning. As an indicator for the state of the river, I have chosen the shoreline index. The shoreline index can reflect whether the flow of the river is very normalised or natural. Out of the aquatic borders and shoreline type the shoreline index has been determined. This index has been divided between navigated and non-navigated waters, and furthermore into different shoreline types, such as sandy or builds up.

My conclusion is that ecotope maps can be used to reflect changes in metrics for ecological quality indicators. It is argued that, for a good comparison, the ecotope maps of different years have to be normalized for the water level during the mapping of the ecotope maps

from aerial photos. Adding height and depth information to the ecotope map will also improve resolution. It is also is argued that for a good insight into the fish population not only aquatic ecotopes but also adjacent ecotopes have to be included. By doing this the sometimes flooding patches are also incorporated – which is essential because they are important for the reproduction of some fish species.

Calculated EQR values for current years and reference years appear to be less apart than expected. Therefore it is recommended to add other factors like area ratio and diversity composition by means or the alpha beta theory.

2 ACKNOWLEDGEMENTS

This report is the result of my graduation research and it is the final part of the GIS MSc at Lund University in Sweden. The research has been carried out at Deltares in cooperation with Rijkswaterstaat in the Netherlands.

First of all I would like to thank my supervisors Tom Buijse (Deltares), Gertjan Geerling (Deltares) and Margriet Schoor (Rijkswaterstaat) for their advice, the discussions we had and for the recommendations and the corrections they made to this thesis. I would also like to thank my supervisors from the University of Lund, Petter Pilesjö and Ulrik Mårtensson for their contribution to this final document.

Apart from my supervisors and all the people of Rijkswaterstaat and Deltares that helped me to carry out this research I would like to thank some people without whom this study would have never been possible. Peter Wouters of Rijkswaterstaat for allowing me time to work at Deltares for my research. My parents for the numerous times babysitting. My father who inspired me with his own successful doctoral dissertation (Waarden 2009). And most of all my wife Willemijn for all her patience and support the past four years.

When I started this study in February 2006 we lived in Peru. I then combined the study with the care of our newborn son Pelle. In March 2007 I started to work fulltime for Rijkswaterstaat in the Netherlands. The study took then place during evening hours and in the weekends. Meanwhile the family grew in 2008 with our daughter Elin. Since February 2009 I started to work for one day a week at Deltares carrying out my graduation research. And now, a year later, I am at the end of this study. It has cost me a lot of time, but I enjoyed it and it brought me new knowledge that hopefully will help me in my further career.

Pieter van Waarden
April 2010,
Delft, The Netherlands

3 CONTENTS

4 ABBREVIATIONS AND GLOSSARY

4.1 Abbreviations

GIS   Geographic Information System

DEM   Digital Elevation Model

EQR   Ecological Quality Ratio from 0 (bad) to 1 (optimal), Figure 1
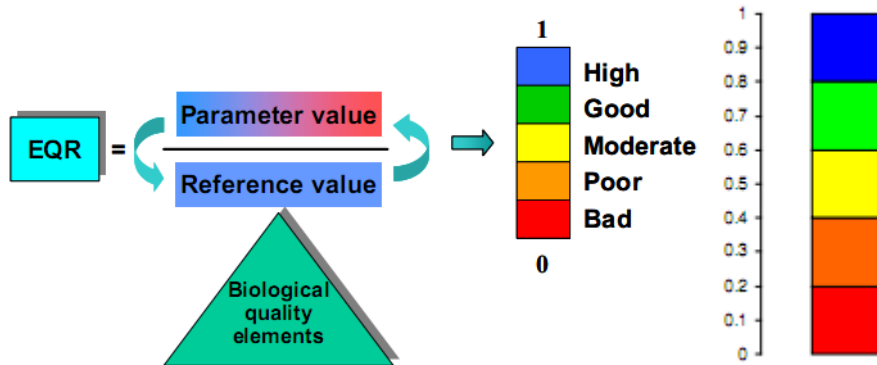
Figure 1 EQR scheme and metric bar; source Rebecca EU

WFD   EU Water Framework Directive

WEC   Water Ecotope Classification

RES   former WEC in the Netherlands used for the first Ecotope map

RWES   Rijkswateren Ecotopen Stelsels; Current WEC in the Netherlands

NAP   Normaal Amsterdams Peil; National Ordnance Datum of the Netherlands

ESRI   Environmental Systems Research Institute, Inc.; GIS software developer and supplier

USGS   United States Geological Survey; Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment

4.2 Glossary

Ecotope   The definition for ecotope used in this document is given by D.T. van der Molen et al. (2002): 'A physically limited ecological unit, whose composition and development are determined by a-biotic, biotic and anthropogenic aspect together. Ecotopes are more or less homogeneous units on the scale of the landscape, identifiable by their similarities and differences in geomorphologic and hydrological characteristics, and characterised by a vegetation structure linked to the above-mentioned a-biotic conditions in combination with land use (Figure 2).' The definition of ecotopes is closely related to the

definitions of eco-series and habitats; ecotopes differ from ecological typologies which are predominantly derived from biological data-sets.
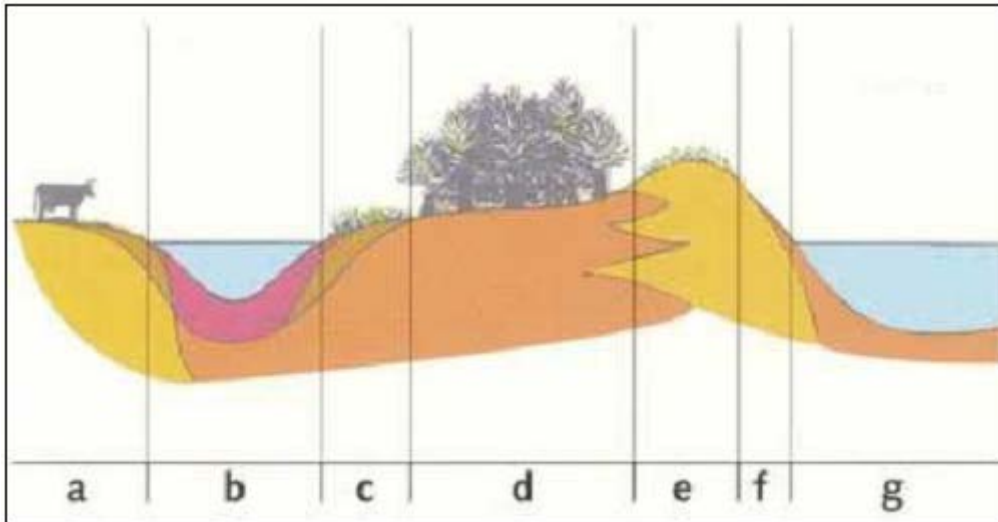
Figure 2 Examples of ecotopes in a cross-section of a river. a= Floodplain production meadow, b = Connected floodplain channel, c = Herbaceous swamp, d = Floodplain softwood forest, e = Natural levee pasture, f = Sand bar, g = Deep riverbed (D.T. van der Molen et al. 2002)

Landscape element   See Ecotope

Diadromous fish   Fish guild that migrate between marine and fresh water

Limnophilic fish   Fish guild that prefer standing waters

Rheophilic fish   Fish guild that prefer running water

Metric   Relative score on a scale from 0 (bad) to 1 (high), see also EQR

Sliver   Small polygons created when intersecting two maps on places where identical borders are mapped slightly different in each edition.

ArcGIS   GIS suite from ESRI with different license levels. For this research the ArcMap program with an ArcView license has been used.

Raster   A gridded representation of an area. Each square grid cell value represents a geographical attribute for that location in the area.

Shapefile   An ESRI file format for saving Polygon, line or point data together with the attribute data for each point. For this research Polygon and Polyline shape files have been used.

Deltares   Deltares is an acronym for Delta
Research. Deltares is the Dutch institute for applied research
and development on issues related to living and working in delta
areas. Its primary task is bringing together science and application: translating scientific
knowledge into innovative solutions needed in sustainable (clean and safe) development of
delta areas. Deltares is worldwide unique, as expertise and activities cover (and bundle) a
broad scope: water, soil, subsurface, and environment. (Source www.deltares.nl)

Rijkswaterstaat   Rijkswaterstaat is the implementation
organisation of the Ministry of Transport, Public Works and
Water Management in the Netherlands. This directorate-
general works on the protection against floods and ensuring that there is sufficient clean
water for all users. Furthermore, Rijkswaterstaat provides for the smooth, safe flow of traffic
on the country's roads and waterways. (Source www.verkeerenwaterstaat.nl/english)

4.3 Most important GIS functions used

Clip   (Analysis function within ArcGIS for extracting polygon data with its attributes
from a map within the extend of another polygon layer; Figure 3.
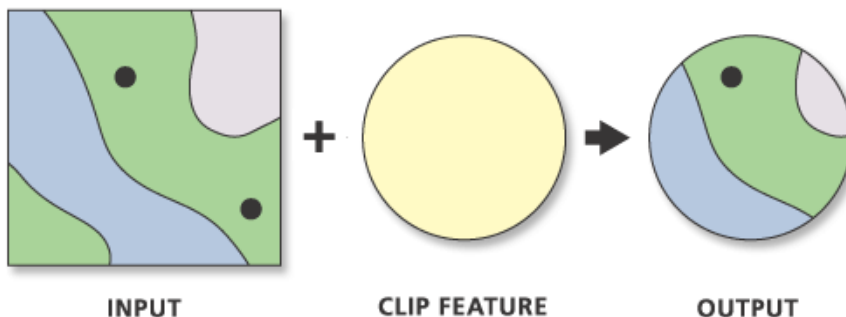
Figure 3 Clip function (source www.esri.com November 2009)

Join   (Add Join) Data management function within ArcGIS: tool for connecting
tabular (sheet/database) data to the attributes of spatial data in shape files (Figure 4).
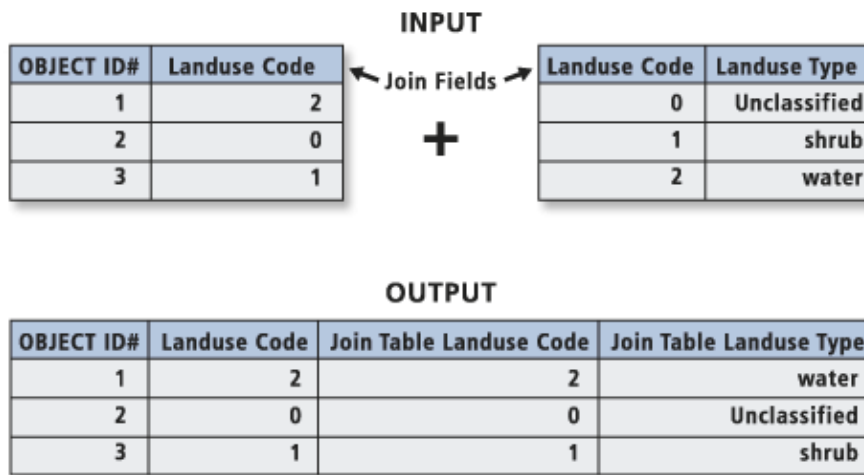
Figure 4 Join function (source: www.esri.com November 2009)

Intersect   Analysis function within ArcGIS for intersecting two Shapefiles. All attributes can be preserved and added to the newly formed features (Figure 5).
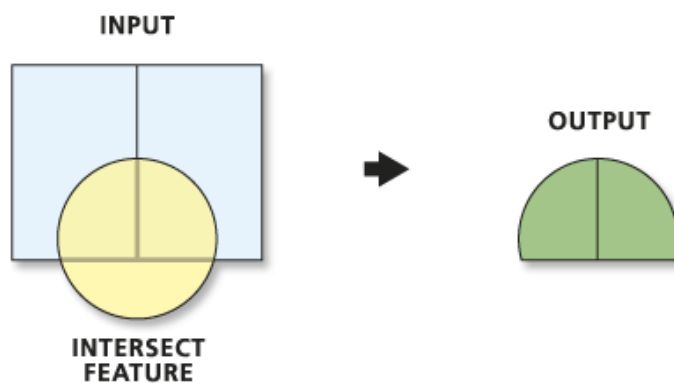
Figure 5 Intersect function (Source www.esri.com November 2009)

Summarize   Statistical analysis function within ArcGIS. Summarize is used for summarizing selected columns data for a selected category (attribute column). The summarization of the selected columns can be done as count, first, last, minimum, maximum, sum, mean, range or standard deviation and is represented in a table (database sheet).

XIII

1 INTRODUCTION

In this chapter an overview is given of the research which I have carried out in this thesis. First the background of the research objective is given in section 1.1. The motivation leads to the research objective and questions in section 1.2. In section 1.3 a short description will be given of how GIS can be used for assessing river quality. Section 1.4 describes how ecotope maps can be used for change detection. The last section, 1.5, gives an overview of the structure of the thesis.

1.1 Background

All members of the European Union are responsible for the preservation and improvements of their surface and ground waters. This is implemented in the Water Framework Directive (WFD) directive 2000/60/EC (European Parliament, Council 2000). As a result of this directive, the Netherlands have the responsibility to improve the ecological status of their large rivers. The Dutch large rivers have been heavily modified to suit the need of man (Figure 6). These modifications have had major impacts on river ecology through the destruction of important habitats and the hampering of vital processes. To improve the ecological status of the river, various measures have been proposed to restore the main channel, flood plains and riparian zone (Figure 7) (Duel and Baptist 2001; Leuven et al. 2002; Middelkoop et al. 2003; Buijse et al. 2005).

Figure 6 Ecological situation in a normalized large river; Side channels have been cut off and groins, sluices and weirs have been installed. Artist impression (Kroes et al. 2007)

Most of these measures involve a local morphological alternation, and all measures have an impact on current landscape elements. Some involve the change of an area and others the change of large stretches, for example the shoreline. All proposed measures have been designed to take place for certain amounts of area or length. Examples of measures are: fish passages near dams, weirs, sluices, the reconstruction of side channels and the lowering of flood plains (Figure 7) (see also appendix 9.1 for a list of measures).
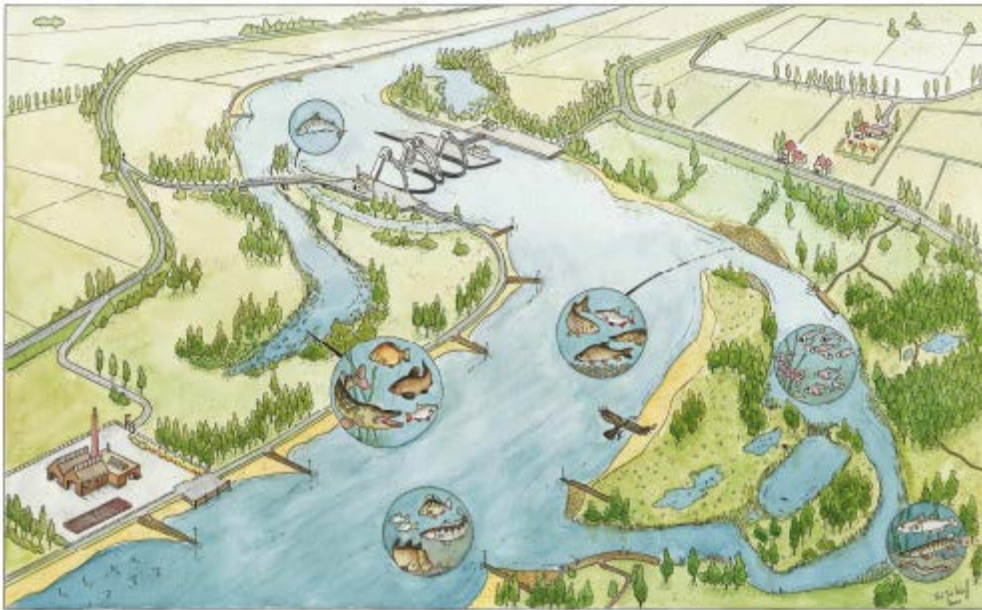
Figure 7 Ecological situation in a large river after rehabilitation measures. Side channels are restored, groins have been lowered and fish passages have been installed. Artist impression (Kroes et al. 2007)

All restoration measures are incorporated in a river basin management plan (Rijkswaterstaat 2008). This river basin management plan describes the current state of the river basin and the plans to achieve a better ecological status. To see if the measures are effective, the estimated cumulative effect of all these measures within a river basin has to be assessed (Rijkswaterstaat 2008).

A river basin is divided into several water bodies; for each of these water bodies an ecological assessment is needed. For the National Dutch water bodies the amount and type of measures have been planned based on the aggregated area of the various landscape element types. Landscape elements are also known as ecotopes (van der Molen et al. 2002). Rijkswaterstaat made an assessment of the possible ecological improvement as a result of each type of measure within large rivers (Buijse et al. 2008). The scale of

implementation for each type was based on the existing ecotope type area. All measures were compiled into a list of the total area and the river length to be reconstructed. So far no spatial information has been used to assess the influence of measures on the main channel, flood plains and riparian zone. It is thought that spatial information can improve forecasting of the benefits of restoration measures. Therefore the Ministry of Transport, Public Works and Water Management (Rijkswaterstaat), in corporation with Deltares, would like this to be investigated. This question has led to the present investigation which was performed as a thesis research for a MSc in GIS title. The outcome of this research will be used as input for incorporating large rivers in the existing tool: WFD Explorer. This is a tool from Deltares that is used for assessing the results of future measures in a river basin.

1.2 Research objective and questions

The situation described in section 1.1 has led to the following main objective and research questions for this study:

Main objective:
To develop a tool, using existing data, to use landscape elements within an ArcGIS environment to evaluate the ecological status of fish and aquatic vegetation in the river Rhine in the Netherlands.

Out of this objective, three research questions have been derived:

How can ecotopes be linked to biological quality elements (fish, aquatic vegetation) to evaluate landscape changes?
Within the ArcGIS environment at Rijkswaterstaat an instrument will be developed. The instrument should be able to represent the WFD values / WFD changes.

Is the current detail level of ecotope mapping suitable to support the assessment of fish and / or aquatic vegetation? Or should other data like height models and flooding frequency be incorporated in the model?
The existing landscape element map of Rijkswaterstaat (ecotope map) was originally designed to meet different goals such as the building of flooding models. Therefore narrow, but sometimes quite long, landscape elements which are important to biota, have not been mapped. Besides, some types of landscape elements have been generalized. Thus, two closely related ecotope types are mapped as one, resulting in a lower resolution.

The occurrence of fish and aquatic vegetation depends on a variety of factors. Possibly, the factors used for building the landscape element map are not adequate to make a good evaluation.

What is the best way of presenting results of the model?
Can the tool be used for communication purposes? Should results of queries be displayed as maps, graphs or as tables?

1.3 GIS approaches used for assessing river quality

As can be seen in the research questions, I will investigate whether biotic quality elements can be linked to ecotopes to assess the ecological quality by means of a GIS. This will be done by comparing ecotope maps of different periods. When linked with quality indicators the maps of different years will be compared with each other to see where changes have occurred. By using the biotic quality elements for each changed polygon, conclusions can be reached as to whether the change is an improvement for the river quality or not. The theory behind this comparison will be presented in chapter 2.

Besides looking at the changes within the biota patches, one can also look at the change in the area as a whole for each ecotope type. By looking at the ratios between ecotope types, indications for biological quality can be found. This is done to show the differences of the river before and after the alterations. This method is explained in section 2.4

Ecotopes can be used as patches, but quality information can also be extracted from their boundaries lines. By using this vector information on border lengths, index ratios can be computed. These ratios can be used to see the difference between the former and current state of the river. The method is explained in section 2.3

1.4 The use of ecotope maps for change detection

The research question implies the use of landscape elements. Landscape element mapping is not new, and a lot of literature can be found on the different options for mapping ecotopes out of aerial photos and remotely sensed images (Burrough and Mcdonnell 1998; Kerle et al. 2004). The production of the ecotope map used by me is covered in section 3.2.1. I will discuss the influence of some of the decisions made by the map makers later on (chapter 5). For this inquiry, change detection between two maps is important. In contrast to the production of ecotope maps, there is not much literature on change detection for these types of maps. Some landscape change discussions can be found in G. Geerling et al. (2006),

Cabezas et al. (2008) and Johnson (1997). Existing literature often fails to evaluate the results which it presents in terms of errors and their propagation in the results. In 2003 the US strategic plan for climate change already pointed this out as an area to be researched (Climate Change Science Program and Subcommittee on Global Change Research 2003), and this request is still actual as little literature is available.

In a publication which evaluates the use of maps in discussions about biodiversity Yue et al. (2004) reach the conclusion that mapping scale has a huge impact on the conclusions derived out of this map. A publication by the USGS argues the same, and gives an optimal scale for change detection for large scale applications in the USA (Congalton 1991).

There is literature on landscape change, but I did not find any evaluation on the use of coupled biological data in order to weight the impact of a change. When examining this problem, it is important that not the change itself is shown but rather its impact on the ecological quality of the area.

1.5 Thesis outline

Chapter 2 "From Water Framework Directive to quality indicators" describes how the quality of a river can be modelled. I will also explain to which reference condition these results are compared. Chapter 3 "Materials & Method" describes how the methods described in chapter 2 are applied in this study. First the research area will be described after which I will explain which base data has been used. And how, by using a GIS, maps and figures are derived to reflect the ecological condition of the river. Chapter 4 shows the outcome of all taken actions. These results are discussed in Chapter 5 'Discussion'. In the final chapter 6 'Conclusions' the final conclusion of this thesis is formulated while reflecting on the research objective and questions.

2 FROM WATER FRAMEWORK DIRECTIVE TO QUALITY INDICATORS

In this chapter an overview will be given how the use of ecotope maps can help in determining the state of a river basin. It will also explain how changes in quality can be assessed. The theory of this chapter will be used in the Chapter 3 to assess the changes in quality between different periods.

2.1 Water Framework Directive

The aim of the WFD directive is to improve the ecological quality of the European rivers. In the directive various indicators for ecological quality among others are considered (Stalzer and Bloch 2000): the chemical, the hydro-morphological and the biological condition. Rivers must be monitored and reviewed on all of these topics.

For all rivers monitoring methods are developed and improvement targets have been set. For the Netherlands we identify different parts of a river basin. One of these parts are the large rivers. Their current status has been described (Rijkswaterstaat 2008) and a reference situation has been identified (D.T van der Molen and Pot 2007). The aim is to re-establish an ecological quality closer to the level of before the human river adjustments but by leaving all social and economic functions intact. To achieve this measures have to be taken.

2.1.1 Current river quality and quality aim

Nowadays the ecological quality of the large rivers in the Netherlands is considered to be insufficient. On a scale of 0 to 1 it is around the 0.3 (Buijse et al. 2008). Rivers nowadays are deeper, narrower, and with less side channels. The construction of locks and other man made obstructions have also influenced the condition of the rivers (Figure 6).

Until around 1850 the Dutch rivers could still flow freely. Consequently, the rivers were shallower (Middelkoop et al. 2003). The ecological state of the rivers before 1850 is thought to be around 0.8 (interview with M. Schoor, Rijkswaterstaat 2009) on the scale from 0 to 1.

2.1.2 Measures for improving quality

To improve river quality several measures have been identified. These measures vary from reconstructing the type of river bank, riparian zone and floodplains to the building of fish passages. (For a list of measures see appendix 9.1). These measures try to partially restore

former levels and diversity of, for example, biota (Figure 7), but also aim to reduce flood risk along the rivers in the Netherlands (Duel and Baptist 2001).

2.2 Measuring river quality using the Ecological Quality Ratio

As indicated in section 2.1.1, scales are being used to indicate ecological quality. Indicators have been identified to describe ecological quality. For all of these indicators metrics have been developed (D.T van der Molen and Pot 2007). There are metrics for biota, physic chemistry and hydro morphology. These metrics are expressed as Ecological Quality Ratio (EQR). To assess the quality of a river, all EQR values are separately evaluated. The lowest value of all EQR values determines the ecological quality on a scale from poor (0) to high (1) according to the one-out-all-out principle (European Parliament, Council 2000).

2.2.1 Basin/ecotopes/indicators

Indicators for describing the ecological quality have been identified and metrics have been developed. Biotic indicators are for example fish community composition and aquatic vegetation species (richness and abundance). It is difficult and expensive to monitor all of these different indicators. Counting fish and field explorations for vegetation are expensive and time consuming. Hence, it can be worthwhile to develop methods of assessing the indicators by evaluating the condition of a river on a higher level. For example, we know which type of landscape certain types of fish prefer. When you 'turn this around' you know what types of fish you will find when you are in a certain type of landscape.

The complete river floodplain can be divided into different patches of homogeneous land type. Each patch can be classified as an ecotope type. For each of these ecotopes we can assess what types of fish live in it (Kroes, Vriese, and Emmerik 2007). When this is known changes in ecotopes can be derived into changes of the fish population. The method to do this and the formulas of the metrics are explained in section 3.3.

Besides the hierarchical interaction between ecotopes, also the area size distribution between different ecotopes is important (Geerling et al. 2006). This is one of the metrics that can be calculated out of patches. Other metrics can be found for example in Dehairs et al. (2001). The size ratio permits to examine how the ecotope composition of today differs from the composition of the reference maps of before 1850. This leads to conclusions as to which ecotopes are over-represented and which are under-represented.

2.3 Measuring River quality with a shoreline index

The main concept of the shoreline index (Schiemer et al. 2001) is that a natural river is not a straight river. Normalised rivers are more straight then natural rivers. This is mostly due to improvements made for economical nautical use. The shoreline index can be calculated to assess how naturally a river flows. The length of the borders of a river is divided by the length of the river. A straightened river will have as outcome the value 2. A curved river will have a higher outcome.

Not only is the degree of meander important, but also the type of shore (Jones et al. 2006). Slower slopes and less hard paved shores give biota more possibilities to develop. The outcome of a shoreline index calculation can be specified for each type of shore to assess its attribution to the total score.

2.4 Other models for indicating river quality

River quality can be measured in different ways. Various publications can be found on researches to assess variables like the number of patches, area, diversity and configuration. A list of example researches can be found in publications of Dehairs et al. (2001) and Gergel et al. (2002)

In the present study the objective is to create a tool that can be used for assessing quality using existing Rijkswaterstaat maps and knowledge on indicators. With the available data two options have been reviewed: EQR metrics and the shoreline index.

3 MATERIALS & METHODS

In this chapter the materials and methods used for this research will be presented. First an overview of the study area will be given (section 3.1) followed by a description of all materials (section 3.2). The theory behind the tool build is described in section 3.3. After which the method used by the tool is given in section 3.4. The final section, 3.5, shows how the shoreline index is computed.

3.1 Study area

For this study the river a Dutch part of the river Rhine is used: the Waal. The river Waal is the largest of the three branches of the river Rhine after it enters the Netherlands. The Waal has no tidal influence. About two third of the water of the river Rhine flows through the river Waal (Figure 8). The remaining water flows through other two branches. The Waal runs for about 82 kilometres and has an annual flow rate of 2200 m^3/s (Mortel 2005). The minimal with for the main navigated river part is 150 metres with at least 2.80m depth. The water in the Waal comes from the river Rhine which originates in Switzerland. The melting glaciers and snow water along with the precipitation within the river basin causes the flow rate to fluctuate between 1500 $m^3\!/s$ up to 15.000 $m^3\!/s$. This fluctuation causes changes in the water level. Near Lobith, where the Rhine enters the Netherlands, the level can vary between 4.4 m NAP and 13 m NAP with exceptions up to15 m NAP high (Mortel 2005).
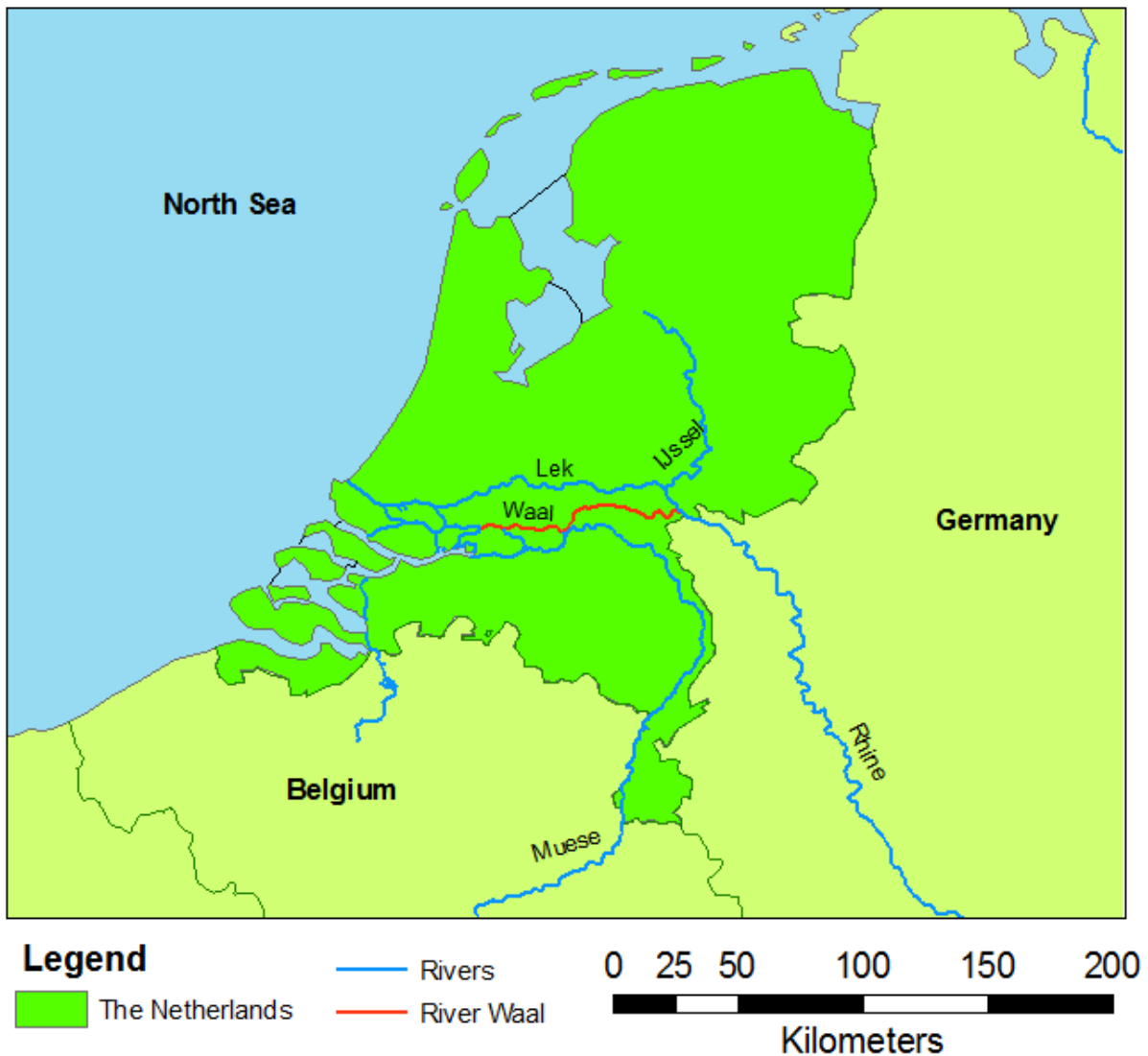
Figure 8 The research area: river Waal. When the river Rhine enters The Netherlands from Germany it splits into the river Waal, river Lek and river IJssel.

The river Waal is heavily navigated for transportation between the Dutch port of Rotterdam and Germany. To permit navigation throughout the year with large ships, it has been normalized. Originally it was a meandering river but it has been straightened by cutting off meanders and by the construction of groins. This normalization has started around 1870 (Grift 2001). The normalization has caused the river to be narrower and deeper. The negative effect of the normalization has been less variation in ecotopes and therefore a lower biodiversity. To improve the ecological situation rehabilitation measures are being executed. For example side channels are being reconnected to the mean stream.

Figure 9 River Waal around 1988. On the left a cut off side channel. (University of Utrecht; Photo by H.J.A. Berendsen)

3.2 Materials: Ecotope maps /base data

For this study the ecotope maps as produced by Rijkswaterstaat have been used. The next sections describe how these maps have been produced. In section 3.2.1 the recent maps will be discussed. The ecotope maps make use of the Water Ecotope Classification (WEC) of Rijkswaterstaat (see 3.2.1.1). To keep the maps comparable on patch level, the 'old border' technique has been used while digitizing (see 3.2.1.2).

The reference maps from before 1850 represent the river prior to the normalisation. How they were compiled and their characteristics will be described in section 3.2.2.

3.2.1 Maps 1997 2004

Since 1997 Rijkswaterstaat has produced ecotope maps. These maps are made for all large rivers in the Netherlands on a 1:10.000 scale. In the maps all ecotopes in between the winter embankments are mapped. Every six years a new edition of the map is made. For the river

Waal the map has been produced in 1997 and in 2004. The maps are based on of aerial photos and graphical information on flooding duration, land management, land use, depth and morphodynamics. All information layers are combined into one by an overlay procedure (Figure 10). When all information layers have been combined into one map, all newly formed polygons are classified into ecotopes using a conversion table. The classification is done using the WEC classification (section 3.2.1.1).
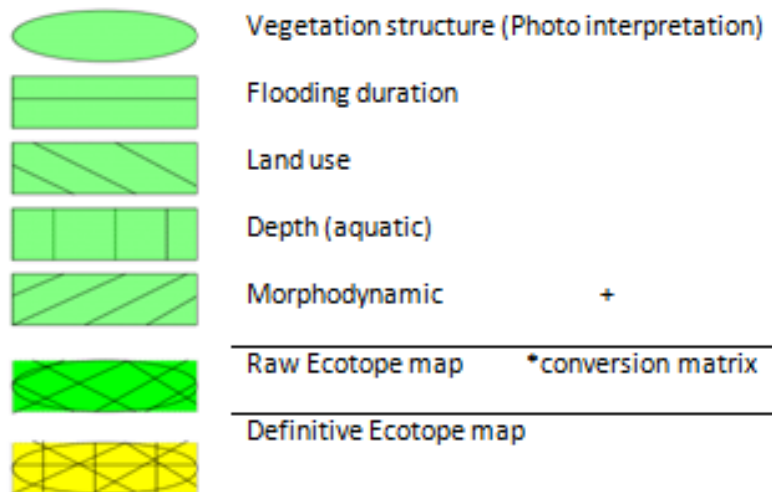

Figure 10 Overlay procedure of the Ecotope map. Five different map inputs are merged into one new map that is classified into ecototpes. (Stehman and Loveland 2005)

Figure 11 Ecotope map at the beginning of the river Waal on false colour photo

3.2.1.1 Water Ecotope Classification

The ecotope maps are classified using the Water Ecotope Classification (WEC) of Rijkswaterstaat. For this classification ecotopes are differentiated by the factors: morphodynamics, hydrodynamics and land use. The WEC follows a hierarchical structure (Figure 12) between water systems, ecotopes and eco elements (van der Molen et al. 2000). The classification recognizes three parts of a water system: the aquatic zone, the shore or bank zone, and the terrestrial zone.
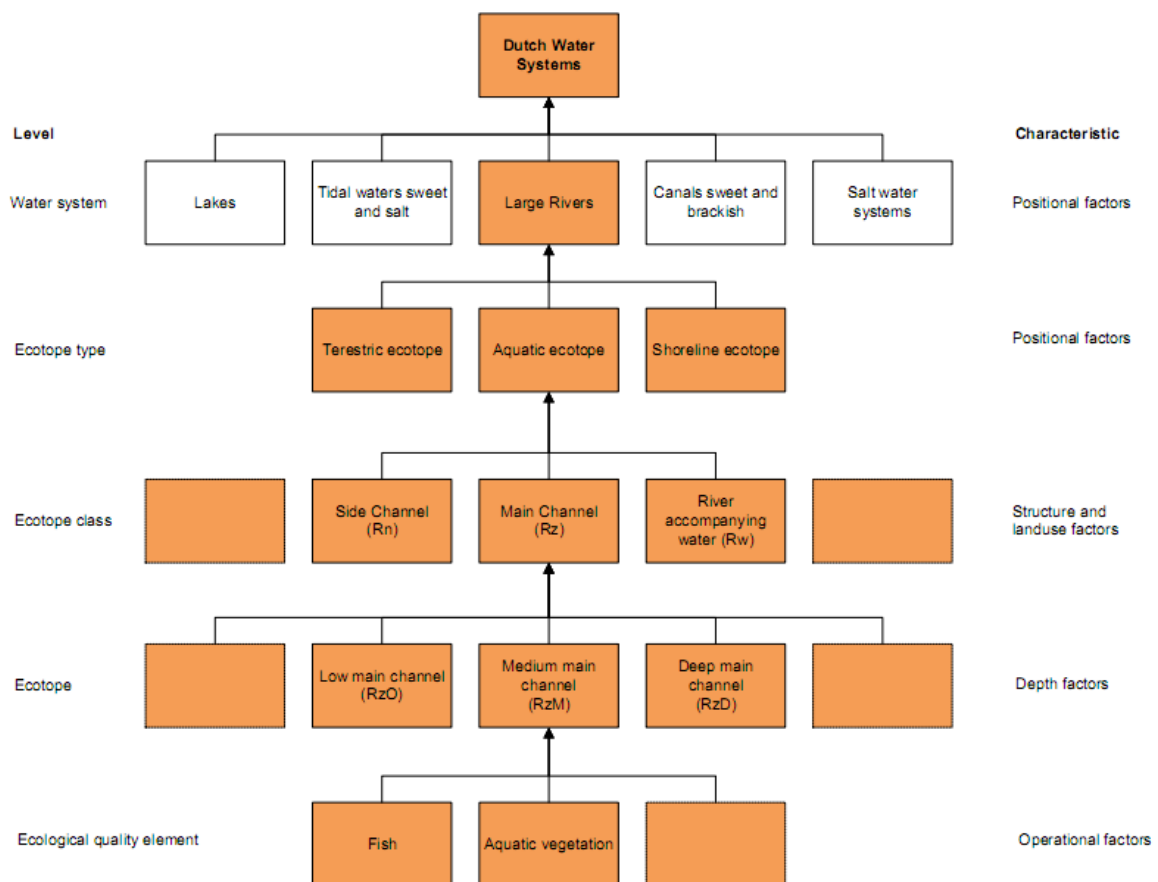
Figure 12 WEC classification with quality indicating Eco elements. Adapted from (van der Molen et al. 2002).

Originally the 1997 map was classified using the former WEC system. This map has been reclassified into the new one using a transformation table. Because of little changes in the classification some ecotopes are now merged and others should have been split into others (Willems et all. 2007). Because a split of polygons is not possible performing this conversion with a table, some ecotopes have not been split into more detailed ones. This causes a

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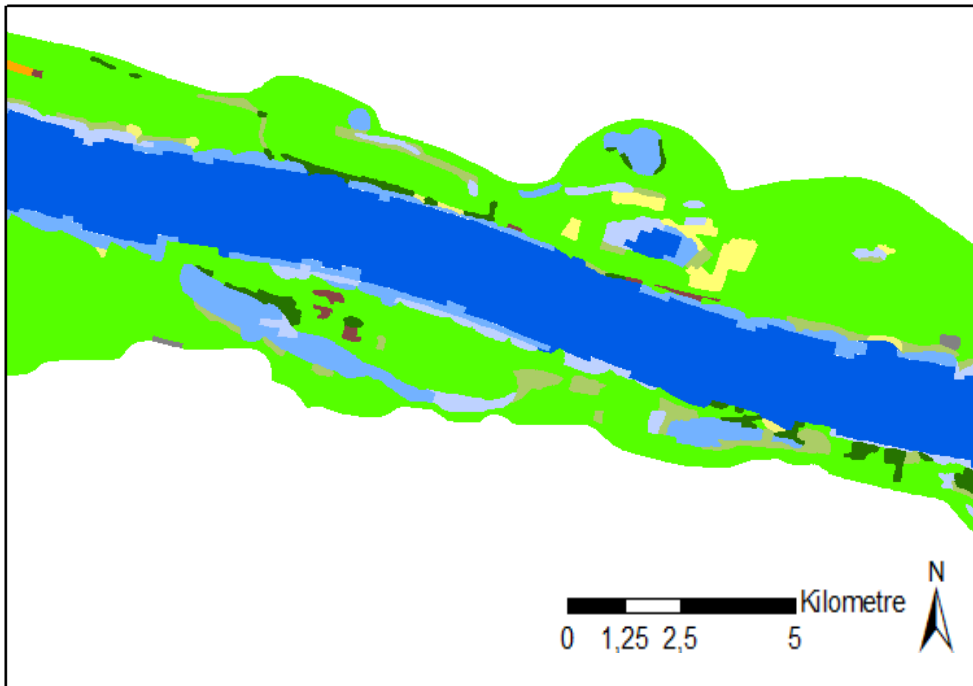lower number of polygons than there would have been if this had been mapped directly using the new WEC.

Figure 13 Ecotope map of a part of the Waal in 1997 (Same section as shown in Figure 9) . (Lower left corner at 178.5, 431.3 *km*, projection RD_new)
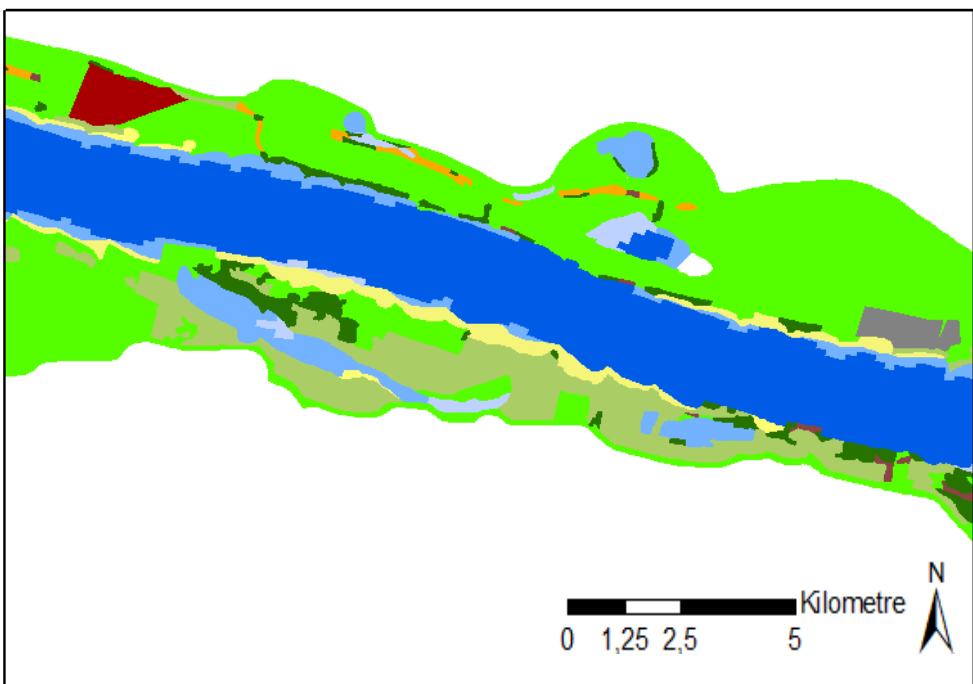

Figure 14 Ecotope map of a part of the Waal in 2004 at the same stretch as Figure 13. Notice that there are more patches. (Lower left corner at 178.5, 431.3 *km*, projection RD_new)

After the ecotope map has been classified, it can be checked for its accuracy. The Rijkswaterstaat maps are ground-thruthed using field measurements (Congalton 1991). The taken samples are then compared with the mapped ecotope values (Table 1). The results of this comparison show that the overall accuracy of the 2004 ecotope map is 70.7% (Table 2). Different ecotopes have all their own accuracy. Some ecotopes can be identified more easily than others when digitizing the aerial photos which cause these accuracy differences.

The producer accuracy is the relation between the number of samples that are equal with the mapped value and the total number of samples taken of that ecotope type in the field. For example for Sand plates (Table 1) 17 / 19 * 100% = 89.5%. Farmland, grassland and sand plates all score higher than 80%, and thus have been mapped correctly for more than 80%. This in contrast with the bare soil and scrub which both score less than 50%.

The user accuracy is the relation between the number of samples that match with the mapped values and the Total number of samples of this ecotope on the map. E.g. farmland (Table 1): 19 / 25 * 100% = 76.0%. The ecotopes farmland, grassland and sand plates all score over 80%, and bare soil is scoring lowest.

Table 1 Map accuracy, cross table map / field. Mapped ecotopes (y-axis) are compared with field measurements (x-axis) for the ecotope map 2004.

Map\Field	Others	Water	Sand plates	Hard substrate	Bare soil	Grassland	Anthropogenic	Farm and	Roughness	Scrub	Forest	Total
Water	1	0	1				1		2	5	1	11
Sand plates			17				1			2		20
Hard substrate				0			2			1		3
Bare soil					1	2						3
Grassland			1		1	119	2	2	11	2	4	142
Anthropogenic					1	3	30			3	1	38
Farmland						6		19				25
Roughness					2	9			37	6	2	57
Scrub						3	2			23	12	47
Forest					1	2	8				49	71
Total	1	0	19	0	6	144	46	21	50	52	69	417

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Table 2 Map accuracy for each ecotope (y-axis) in percentage for the Ecotope map Waal 2004. No samples where taken for water and hard substrate.

Ecotope	Producers Accuracy	Users Accuracy	Overall Accuracy
Water	0.0	0.0	
Sand plates	89.5	85.0	
Hard substrate	0.0	0.0	
Bare soil	16.7	33.3	
Grassland	82.6	83.8	
Anthropogenic	65.2	79.0	
Farmland	86.4	76.0	
Roughness	63.8	64.9	
Scrub	44.2	48.9	
Forest	71.0	69.0	
			70.7

3.2.1.2 Old border Method

An important aspect when using the Rijkswaterstaat ecotope maps is that the newer editions are always mapped using the 'Old Border Method' (Janssen and van Gennip 2000). With this method the borders and polygons of the previous ecotope map are used as base for the interpretation of the aerial photos of the new ecotope map. Thus, borders of the 1997 map formed the base for the mapping of the 2004 edition. Errors in the borders of the 1997 map have not been corrected in the new map when the errors are smaller than 10 meters in the field. Mapped at a scale of 1:10.000 this means that errors smaller then 10 mm on the map are not altered. When the difference is larger new borders will be mapped. For this 'old border method' lines in the map can be located 10 meters wrong which makes accuracy less (Table 2). An advantage of keeping lines at the same location is that there will be low difference in area calculations and less slivers when comparing maps between years.

3.2.2 Maps 1780 and 1830

The ecotope maps prior to 1850 are based on analogue maps made by different cartographers (Hebinck 2008). With these analogue maps (Figure 15) a part of the river Waal could be reconstructed at a 1:25.000 scale. These maps have been digitised and interpreted for land use and physiology (Figure 16). To be usable for this study, I have used

the original classification of the ecotopes and physiotopes to convert it into the current WEC classification (section 3.2.1.1). The conversion table has been made with expert help from Rijkswaterstaat (M. Schoor).
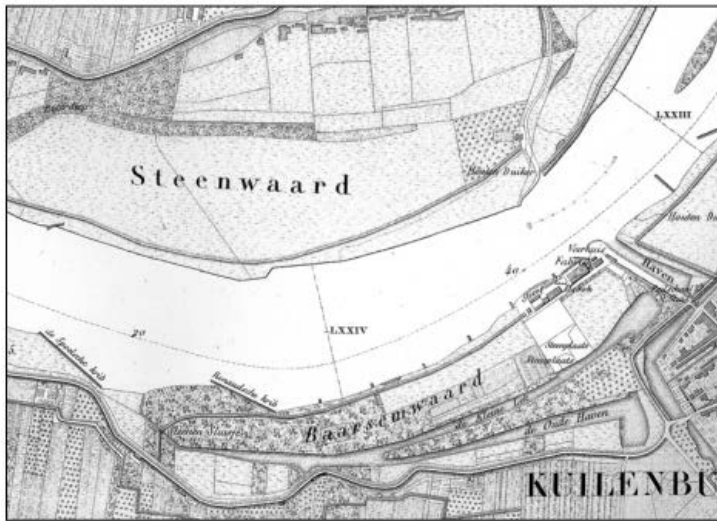

Figure 15 Fragment of the river Lek map near Culemborg around 1830 (Goudriaan, 1830-1842) (Middelkoop et al. 2003)

Legend

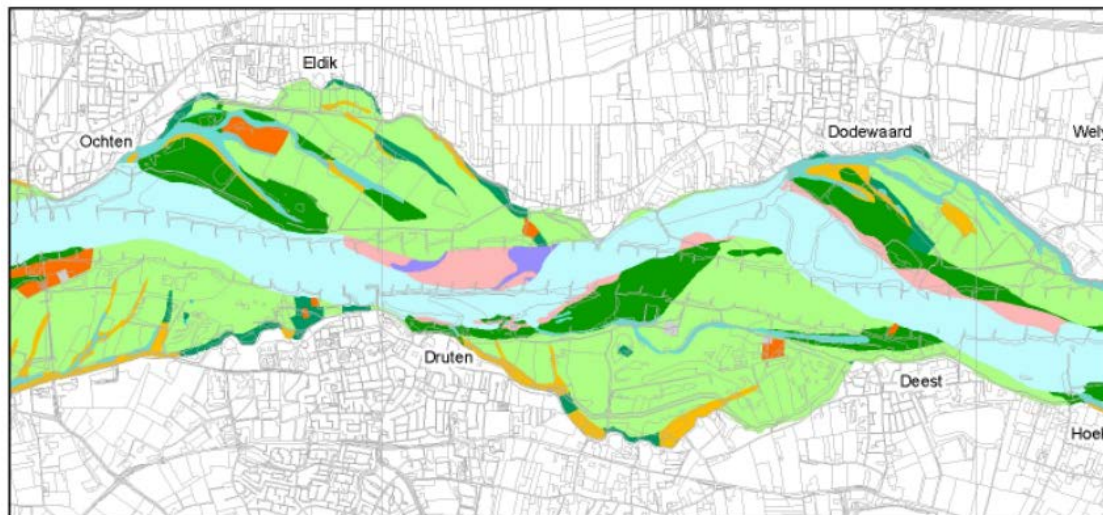|		
Summer bed	Dynamic rough	Dynamic channel
Natural shoreline	Swamp	Isolated channel
River dune	Floodplain grass	Pool
Natural hardwood	Natural floodplain grass	Farmland
Natural softwood	Production grass	Buildings
Production wood	Side channel	

Figure 16 Map of 1780 with as underground in thin gray lines a topographic vector line map of the 2008 situation (Top10 map from Kadaster) to show the difference in river shape before and after the alternations. (Lower left corner 167.0,432.7 *km*, projection RD_new)
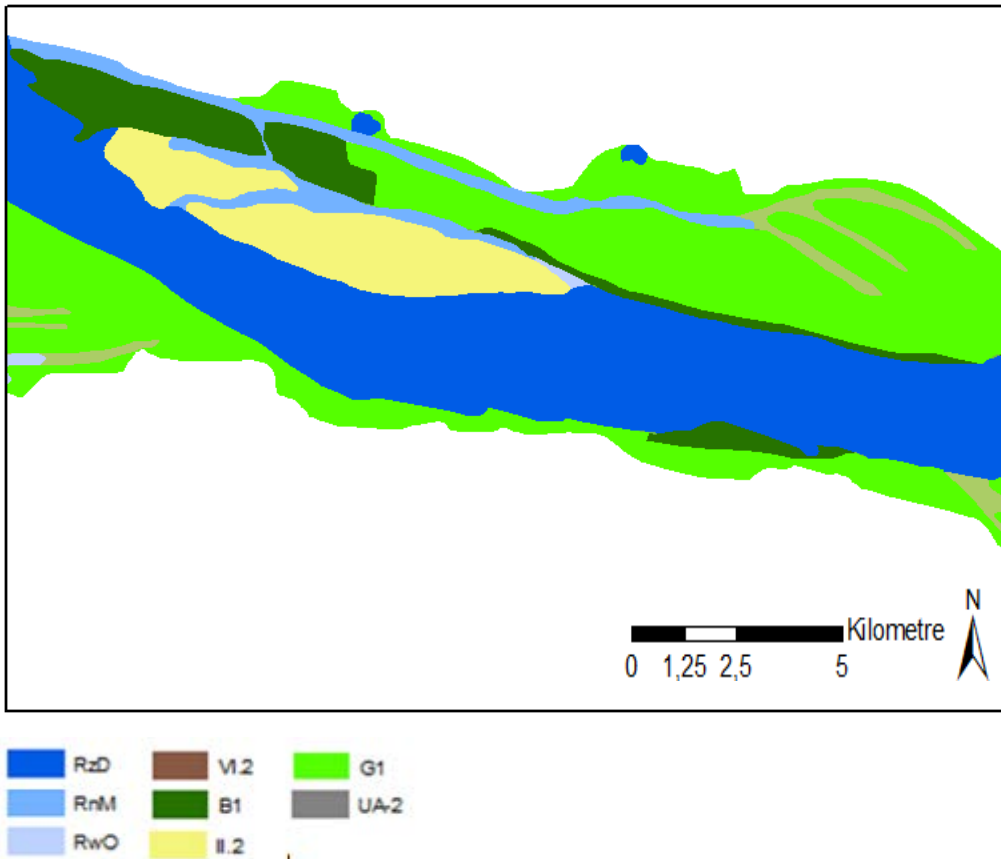
Figure 17 Ecotope map of a part of the Waal in ± 1780 with its legend given in abbreviations of the WEC system (3.2.1.1). (Lower left corner at 178.5, 431.3 km, projection RD_new)

3.2.3 Shoreline maps

The shoreline maps used for calculating the shoreline index are made by Rijkswaterstaat as a derived product of the ecotope map. All borders of aquatic ecotopes are merged and then placed on the aerial photo to interpretate the type of shoreline. It is classified into different classes like, hard, grass and sand shoreline (Appendix 9.6 for a complete list).

3.2.4 Other data

For this research other data has also been used. A shape file of the Netherlands (Rijkswaterstaat) was used for general mapping purposes. The top 10 vector map (Kadaster :Dutch land registry entity) was used for topographical purposes(Topographic 1:10.000 vector map) and a shape file of the river kilometres (Rijkswaterstaat) to calculate the shoreline index (section 3.5) and to position the depth profiles (section 3.2.5).

3.2.5 Profiles and depth DEM

To add more resolution to the ecotope classes of the 1780 map depth profiles made by Beijerink around 1800 were used (archive Rijkswaterstaat). The profiles were geo referenced within the ecotope map summer bed using the old location of a water height measurement station and the river kilometres as a reference in ArcGIS. Within the border of the summer bed the profile data has been interpolated into a 5x5 meter grid using the Digipol algorithm (van Halderen 2005) implemented in the Qloud software of QPS (software company).
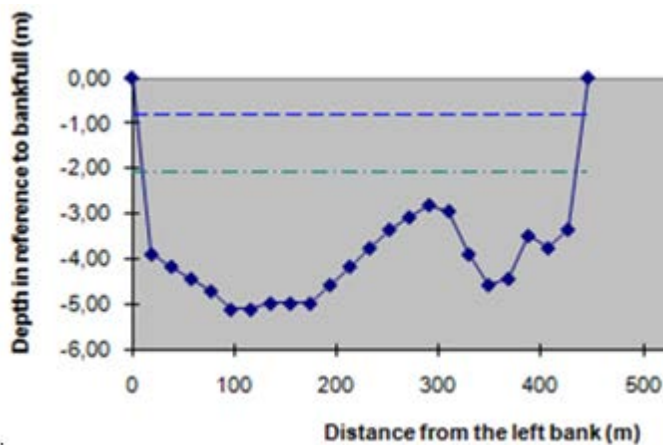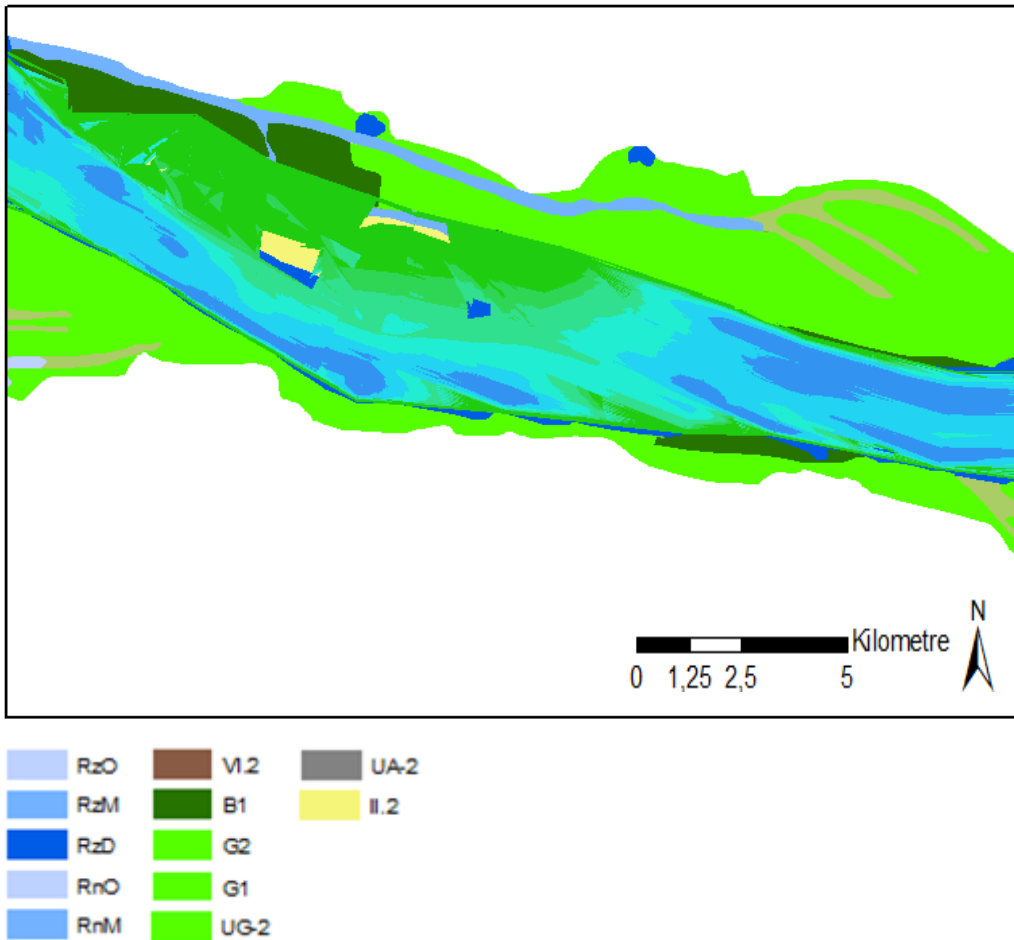

Figure 18 Example of a profile in the river Waal ±1800 used for the depth model with a low (.-.-.-.) and average (------) high water level indication (Beijerink. 1801)

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Figure 19 Ecotope map of a part of the Waal in aprox. 1780 with additional depth resolution from profiles (see Figure 18). The same map without additional resolution can be seen in Figure 17. (Lower left corner at 178.5, 431.3 *km*, projection RD_new)

The depth model was then reclassified in the three depth classes (deep, moderate and shallow) of the WEC system. Next, three depth classes were transformed into polygons. With this polygons the new EQR values were calculated (Figure 38).

3.2.6 Tables

Tables are used for connecting the information on biotic quality indicators and aquatic ecotope patches.

Fish

To relate habitat requirements of fish to ecotopes a spreadsheet has been made by Deltares.

Aquatic vegetation

For the connection between the settlements factors for aquatic vegetation and ecotopes a spreadsheet based on publication of Coops and Pot (2008) 'AMR Rekentool EKRS' has been used.

3.3 Methods: Relation EQR metrics with ecotopes

The basic idea of deducing the Ecological Quality Ratio (EQR) value from an ecotope map is to determine the habitat suitability for each species within an ecotope. Based on the species preferences and the ecotope characteristics, an expected suitability can be calculated. For each ecotope type the metrics are combined into one EQR score. For fish 13 ecotopes could be assessed and for aquatic vegetation only 6 ecotopes can be assessed, since more information was not available. This information is then added in table form (Table 3) to the overall ecotope map to see changes and to calculate the overall EQR. In Section 3.3.1 will be explained how the table has been made for fish, and in section 3.3.2 for aquatic vegetation.

Table 3 Ecotope and EQR value list for aquatic ecotopes (starting with an R) and riparian ecotopes. For some ecotopes the amount of days that they are filled with water are given.

Ecotope name	Ecotope	Fish EQR value	Aquatic vegetation Score value
RzD	Deep main channel	0.507	
RzM	Moderately deep main channel	0.454	0.050
RnM	Moderately deep side channel	0.572	0.833
RzO	Shallow main channel	0.572	0.875
RnO	Shallow side channel	0.577	5.075
RvD	(Very) deep, river accompanying water > 20 days	0.401	
RvM	Moderately deep water, river accompanying water > 20 days	0.431	0.100
RvO	Shallow water, river accompanying water > 20 days	0.463	11.250
RwD	(Very) deep water, river accompanying water < 20days	0.401	
RwM	Moderately deep water, river accompanying water < 20 days	0.431	
RwO	Shallow water, river accompanying water < 20 days	0.463	
II.1	Gravel bars	0.572	
II.2	Freshwater sand bars	0.572	
II.2-3	Freshwater sand bars / Freshwater mud banks	0.572	
IV.1	Species poor helophytes in shallow Freshwater	0.572	
IV.3-8	Species poor helophytes swanp	0.577	
VI.2-3	Softwood shrubs or pioneer softwood forest	0.577	

3.3.1 Fish

The EQR metrics for fish are divided into a metric for the species richness of fish types and a metric for species abundance (van Dam 2007). The results of the separate metrics are combined into one overall EQR per ecotope. To calculate these EQR values I have used the spreadsheet 'Ecotopen en Visgilden.xls' (Deltares) within Microsoft Excel.

The spreadsheet on fish consists of a matrix of all ecotopes and of all fish species in the Rhine. The likelihood for each species to be present in an ecotope is weighted on the basis of characteristics of the ecotopes and is then represented on a scale of 0 (very unlikely) to 5 (very likely). These scores are given for the stages life: egg, juvenile and adult. These chances have been added up for each species by using Equation 1 and are reproduced as example for the deep summer bed in Table 4.

Equation 1 Species presence on a scale of 0 to 1 for fish in the river Waal (personal contact Tom Buijse)

Chance fish presence in ecotope = (chance species egg + chance species juvenile + chance species adult) / 15

Table 4 Species in the river Waal with their guild type (D=Diadromous, E= Eurytopic, L=Limnophilic, N=Neutral (not counted), R=Rheophilic and RD=Rheophilic/Diadromous) and chance on a scale of 0 to 1 for the main channel)

Specie	Guild	Chance	Species	Guild	Chance	Species	Guild	Chance
Allis shad	RD	0.20	European eel	D	0.53	Roach	E	0.33
Atlantic salmon	RD	0.20	European wels	E	0.27	Rudd	L	0.00
Atlantic sturgeon	RD	0.13	Flounder	D	0.00	Ruffe	E	0.00
Barbel	R	0.20	Gibel carp / Goldfish	E	0.00	Schneider	N	0.00
Bitterling	L	0.00	Grayling	N	0.00	Sea lamprey	RD	0.13
Bleak	R	0.00	Gudgeon	R	0.00	Sea trout	RD	0.20
Bream	E	0.00	Houting	RD	0.13	Smelt	E	0.40
Brook lamprey	N	0.00	Ide	R	0.00	Spined loach	R	0.00
Bullhead	R	0.07	Lampern	RD	0.20	Stickleback	E	0.00
Burbot	R	0.00	Moderlieschen	L	0.07	Stone loach	N	0.00
Carp	E	0.00	Nase	R	0.00	Tench	L	0.00
Chub	R	0.07	Perch	E	0.53	Ten-spinedstickleback	L	0.00
Crucian carp	L	0.00	Pike	E	0.00	Twaite shad	RD	0.00
Dace	R	0.00	Pike perch	E	0.00	Wheaterfish	L	0.00
Eurasian minnow	N	0.00	Powan	N	0.00	White bream	E	0.00

Per ecotope all possibly existing species with a chance > 0, have been counted per guild (decision from personal contact with Tom Buijse). In further studies the influence of these chances can be researched. The guild class RD fish has been counted both in the rheophilic and diadromous class. For the Deep main channel (Table 4) this results in (Table 5).

Table 5 The number and relative density of species per guild in the Deep main channel ecotope (D=Diadromous, E=Eurytopic, L=Limnophilic, R=Rheophilic and RD=Rheophilic/Diadromous)

Guild	Number of species	Relative density
R and RD	10	43%
L	1	4%
E	4	17%
D and RD	8	35%

I have deduced the metric scores for all ecotopes with (e.g. for the deep main channel) Table 5 and the metric tables for both species composition (Table 6) and guild abundance (Table 7). With these scores the final EQR per ecotope is calculated (Equation 2); the resulting EQR values per ecotope are shown in Table 3.

Table 6 Metric for species composition fish types (D.T van der Molen and Pot 2007)

	Bad	Poor	Moderate	Good	High
Rheophilic a, b species (number of species)	< 10	10 - 11	12 - 14	15 - 16	> 16
Diadromous species (number of species)	< 3	3 - 4	5 - 7	8 - 9	> 9
Limnophilic species (number of species)	0	1	2 - 3	4 - 5	> 5
Score	0.1	0.3	0.5	0.7	0.9

Table 7 Metric for fish species abundance (D.T van der Molen and Pot 2007)

	Bad	Poor	Moderate	Good	High
Rheophilic species (relative abundance)	0 - 10%	10 - 20%	20 - 30%	30 - 40%	40 - 100%
Limnophilic species (relative abundance)	0 - 1%	1 - 5%	5 - 10%	10 - 15%	15 - 100%
Score	0 - 0.2	0.2 - 0.4	0.4 - 0.6	0.6 - 0.8	0.8 - 1.0

Equation 2 EQR fish (vd Molen 2007)

EQR = [(species richness metric score Rheophilic + Diadromous + Limnophilic) / 3 + (species abundance metric score Rheophylilic + Limnophilic) / 2] / 2

3.3.2 Aquatic vegetation

The EQR values for vegetation are based on chances for the occurrence and density of vegetation. To calculate the EQR values for each type of ecotope, a spreadsheet matrix on aquatic vegetation species and ecotopes 'AMR Rekentool EKRS.xls' was used within Microsoft Excel. For each species the spreadsheet gives the chance of its occurring within an ecotope. This occurrence is based on the conditions: depth, flow rate and wave intensity. Apart from general depth classes these conditions are not incorporated in the ecotope map. Therefore the matrix uses general conditions for each ecotope type.

Coops and Pot (2008). created metrics to quantify the ecological situation For each type of aquatic ecotope they adjusted the metrics for possible coverage (Coops and Pot 2009). This is because there will be no vegetation in the deep summer bed and some in the shallower parts, up to 50% of the area. In adjacent waters this coverage can reach values up to 90 or 100%. The metrics for abundance and composition are averaged for the final score chance (Equation 3). Out of this score an EQR value per hectare for each ecotope can be calculated within the GIS by using

Equation **4**.

Equation 3 Score chance aquatic vegetation in low quality river zones (Coops and Pot 2009) The 4 in the equation is the maximum possible score in large rivers for a species chance. The "4" is a correction factor for large rivers.
Score chance = sum of chances / (sum ecotope type area / 4)

Equation 4 EQR out of the score change for aquatic vegetation in low quality river zones (Coops and Pot 2009)
EQR = score chance / 0.04

Table 8 Metric for abundance of aquatic vegetation types (% of total coverable area) (Coops and Pot 2009)

|	Bad	Poor	Moderate	Good	high	Reference value
Submers & Floating & Emergent	0 - 0.1%	0.1 - 0.5%	0.5 - 1%	1 - 5%	5 - 40%	20%

Table 9 Metric for Macrophyte composition as percentage (%) of the reference (40) and absolute score (Coops and Pot 2009)

	Bad	Poor	Moderate	Good	High
Percentage	< 10%	10 - 20%	20 - 40%	40 - 70%	> 70%
	0-3	4-7	8-15	16-27	28-40

3.4 Connect EQR with Ecotopes in Ecotope map

The map comparison has been done within the ArcGIS environment using ArcMap. The complete scheme of steps is given in the appendix 9.3 (Figure 48). Below each separate step is explained.

To be able to connect the spreadsheets with EQR values with the maps, the ecotope maps have to be prepared first. Before two ecotope maps can be compared it is important that both maps have the same extent (Figure 20). This prevents wrong comparisons of the final EQR values per area. Within ArcMap this has been done by using the clip tool (Figure 3 and Figure 21).
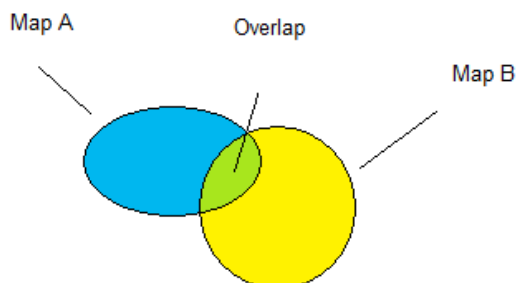
Figure 20 Only the overlap of two maps (A and B) is used for calculating changes between maps. By this the have the same extent.

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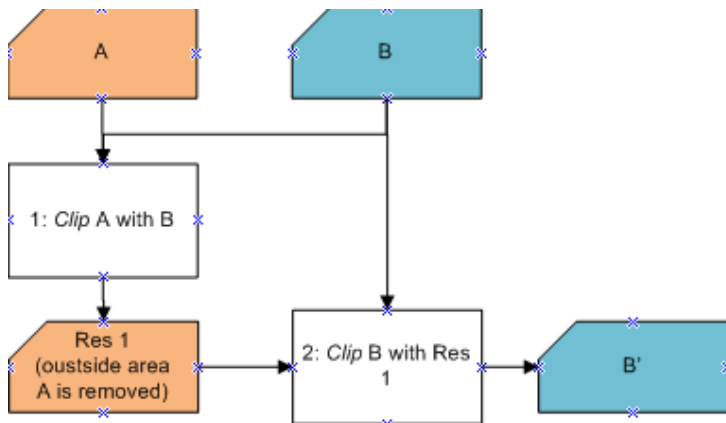
Figure 21 Step 1 Making the extents of each map equal

For the resulting maps the polygon areas are recalculated by using the Hawths tools and to these maps the EQR sheets are coupled using (Figure 22) the Join function (Figure 4). The join is being made on the columns with the ecotope name abbreviations in both the ecotope map and the made EQR table (Table 3).
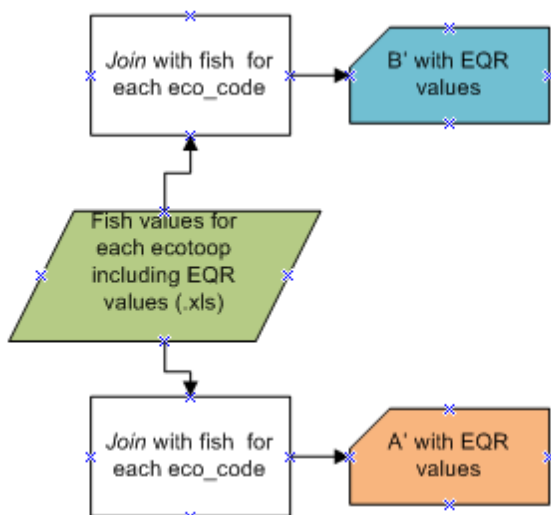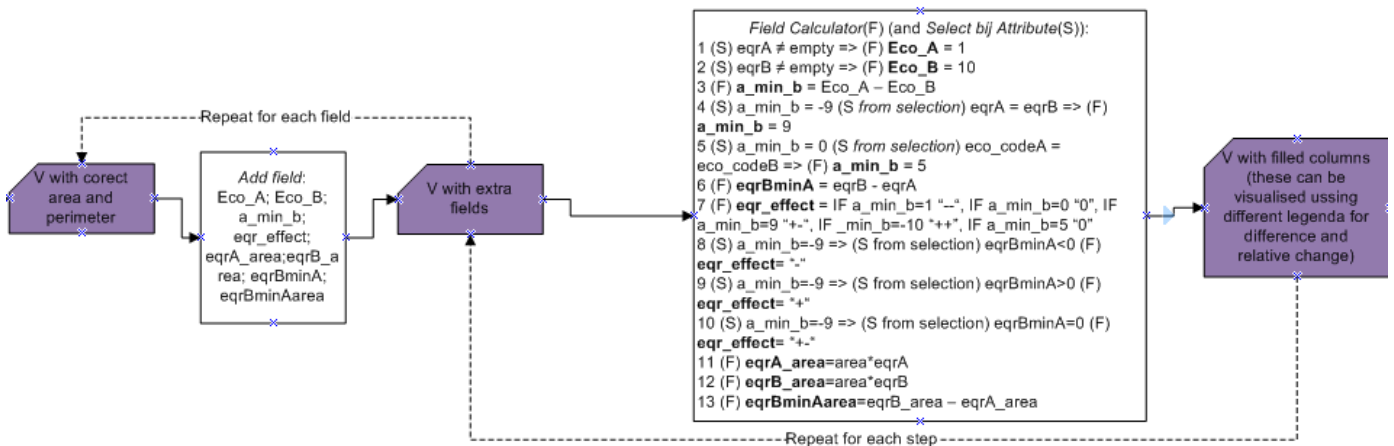

Figure 22 Step 2 Adding EQR values (Table 3) to the polygons

There are now two maps with EQR values for each ecotope map. The maps can now be confronted with each other (Figure 23) using the Intersect tool (Figure 5). This tool intersects all polygons creating new ones incorporating all borders of the two maps. The attributes of each new polygon are now the combined attributes of each originating polygon.
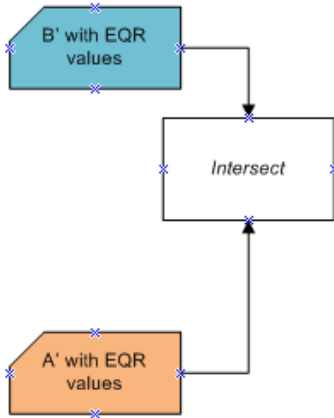
Figure 23 Step 3 Confront the two maps

After the intersection the two maps are now one. The newly formed polygons are recalculated for their area (Hawths tools). After this, new columns have to be added in the attribute table. This is done to be able to compare the EQR values within each patch from the first and second map. This process can be seen in the first part of step 4 (Figure 24)

Field Calculator(F) (and *Select bij Attribute(S)*):
1 (S) eqrA ≠ empty => (F) **Eco_A** = 1
2 (S) eqrB ≠ empty => (F) **Eco_B** = 10
3 (F) **a_min_b** = Eco_A – Eco_B
4 (S) a_min_b = -9 (S *from selection*) eqrA = eqrB => (F) **a_min_b** = 9
5 (S) a_min_b = 0 (S *from selection*) eco_codeA = eco_codeB => (F) **a_min_b** = 5
6 (F) **eqrBminA** = eqrB - eqrA
7 (F) **eqr_effect** = IF a_min_b=1 "--", IF a_min_b=0 "0", IF a_min_b=9 "+-", IF _min_b=-10 "++", IF a_min_b=5 "0"
8 (S) a_min_b=-9 => (S from selection) eqrBminA<0 (F) **eqr_effect**= "-"
9 (S) a_min_b=-9 => (S from selection) eqrBminA>0 (F) **eqr_effect**= "+"
10 (S) a_min_b=-9 => (S from selection) eqrBminA=0 (F) **eqr_effect**= "+-"
11 (F) **eqrA_area**=area*eqrA
12 (F) **eqrB_area**=area*eqrB
13 (F) **eqrBminAarea**=eqrB_area – eqrA_area

Figure 24 Step 4 Adding new columns and attributes to the table

After creating these new attribute columns, they have to be filled with attributes as shown in the right part of step 4 (Figure 24 and Figure 25)

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```
          Field Calculator(F) (and Select bij Attribute(S)):
1 (S) eqrA ≠ empty => (F) Eco_A = 1
2 (S) eqrB ≠ empty => (F) Eco_B = 10
3 (F) a_min_b = Eco_A – Eco_B
4 (S) a_min_b = -9 (S from selection) eqrA = eqrB => (F)
a_min_b = 9
5 (S) a_min_b = 0 (S from selection) eco_codeA =
eco_codeB => (F) a_min_b = 5
6 (F) eqrBminA = eqrB - eqrA
7 (F) eqr_effect = IF a_min_b=1 "--", IF a_min_b=0 "0", IF
a_min_b=9 "+-", IF _min_b=-10 "++", IF a_min_b=5 "0"
8 (S) a_min_b=-9 => (S from selection) eqrBminA<0 (F)
eqr_effect= "-"
9 (S) a_min_b=-9 => (S from selection) eqrBminA>0 (F)
eqr_effect= "+"
10 (S) a_min_b=-9 => (S from selection) eqrBminA=0 (F)
eqr_effect= "+-"
11 (F) eqrA_area=area*eqrA
12 (F) eqrB_area=area*eqrB
13 (F) eqrBminAarea=eqrB_area – eqrA_area
```

Figure 25 Adding attribute values to the newly created columns in 13 steps.

In this step the new columns are filled (see also table Figure 26). Because only the aquatic ecotopes have an EQR value connected to them, this is first shown in the columns Eco_A for map A and in Eco_B for the second map B. When there is a EQR value the first map A is assigned the value 1 and the second map B the value 10 (Step 1 and 2). a_min_b is then calculated subtracting columns Eco_A min Eco_B (step 3). The column a_min_b is now filled with the numbers 1, -9 or -10 which can be used to interpret the changes. 1 means that existing aquatic ecotopes have vanished for that location, -9 means that both in the first ecotope map and in the second an aquatic ecotope is present and -10 means that there is an aquatic ecotope in the second map only. To make the difference more distinctive between the two maps the numbers have been altered for polygon locations where the EQR value of the polygon on a location in map A is the same as the one in map B. For these locations the value -9 has been changed into 9 (step 4). The same has been done for locations where the value is 0, locations with non aquatic ecotopes that did not change, have been changed into the value 5 (step 5). Having now the values 0, 1, 5, 9, -9 and -10 in the column a_min_b changes between the ecotope maps can be visualized (Figure 32).

Map A	Map B	a_min_b	eqr_effect
T	A	-10	++
a	A	-9	+
A	A	9	+-
A	a	-9	-
A	T	1	- -
T	T	5	0
T	t	0	0
t	T	0	0

A / a	Aquatic ecotope (A=high EQR, a=low EQR)
T / t	Terrestric ecotope (T=high EQR, t=low EQR)

Figure 26 Attribute values for changes between Aquatic and Terrestric ecotopes. Terrestric ecotopes score a "0" for they are not of interest for this research.

To see whether the change in ecotopes between the two ecotope maps is a positive or negative one steps 6 to 10 are taken. In step 6 column eqrBminA is filled with the difference in EQR value of each polygon by subtracting the EQR value of map B with the value of map A. In step 7 eqr_effect is filled with the values "- -" were eqrBminA shows that for that location there was first an aquatic ecotope where in the second map there is none. "++" is assigned for locations where non-aquatic ecotopes changed into aquatic ecotopes, "0" is added for locations where there were and are no aquatic ecotopes. "+-" has been assigned to eqr_gevolg where a_min_b has the value 9. In steps 8 till 10 the values "-" for a worst EQR value in the new map, "+" for a better EQR value and "+-" for locations with the same aquatic ecotope in both map editions. Using the values ranging from "—" till "++" it is possible to visualize how the EQR values changed relatively (Figure 33).

To calculate overall EQR values for the complete area, steps 11 till 13 are performed. The resulting EQR value is multiplied with the area of each polygon. The results of this step are

exported to Microsoft Excel by making dbase tables using the Summarize command on the column a_min_b and eqr-effect. Within Microsoft Excel the total EQR has been calculated.

To compare the present day map with the map of before 1850 the same process is applied, but an extra step has to be taken to give the old map the same WEC classification (Figure 27).
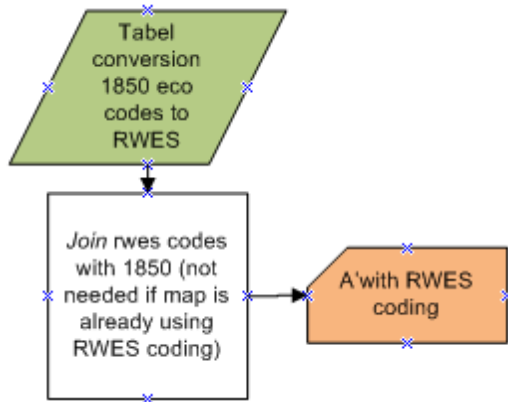
Figure 27 Adding WEC classification to the 1850 map

3.5 Calculation of a shoreline index
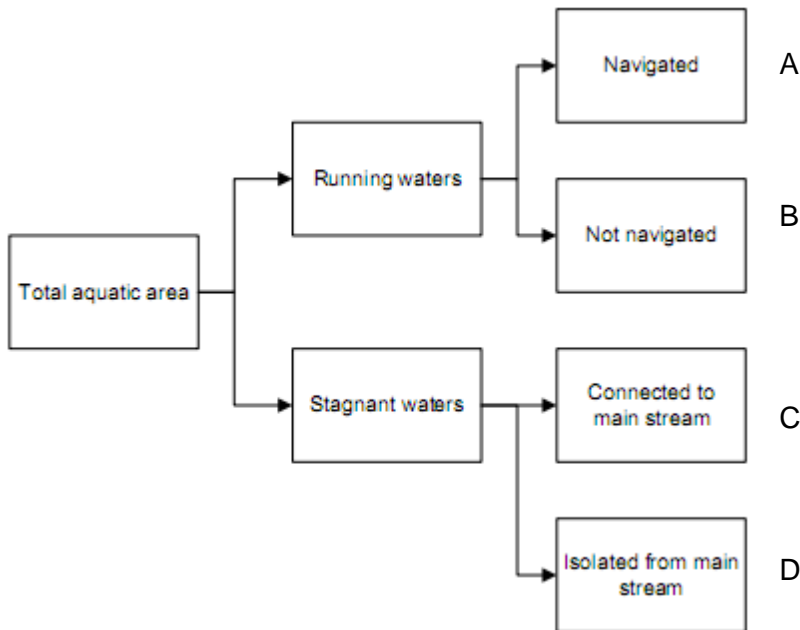
Figure 28 Shoreline index. An index has been calculated for the Total aquatic area and for the four separate river parts (A to D) (Figure 29) in the rightmost column of the figure.
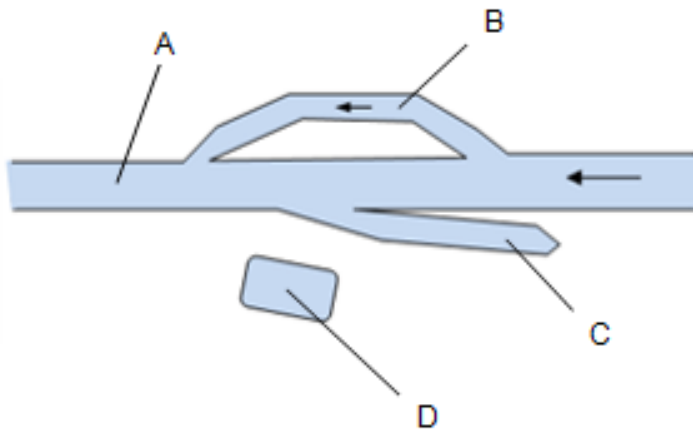
Figure 29 Four different river parts: A: navigated main channel, B: Not navigated side channel, C: Not navigated downstream connected backwater without current, D: Floodplain waterbody isolated from the main channel.

The complete flow diagram of the steps taken for calculating the shoreline index is appendix 9.3, Figure 49. The shoreline index has been calculated for the complete river, and for four different parts of the river with their own characteristics (Figure 28).

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The shoreline shapefile polylines have been divided into several classes by using the clip function. The input for this clip function came from the dissolved ecotope polygon patches of the ecotope map for each river part (Figure 30). After completing these clip actions for each class, the total length of polylines was summarized per class. By dividing the cumulative lengths by the total river length, a river index was calculated that can be used to compare rivers (Figure 31). This is done in Microsoft Excel. The resulting data is represented in bar graphs for between-year comparison (Figure 40 and Figure 41).
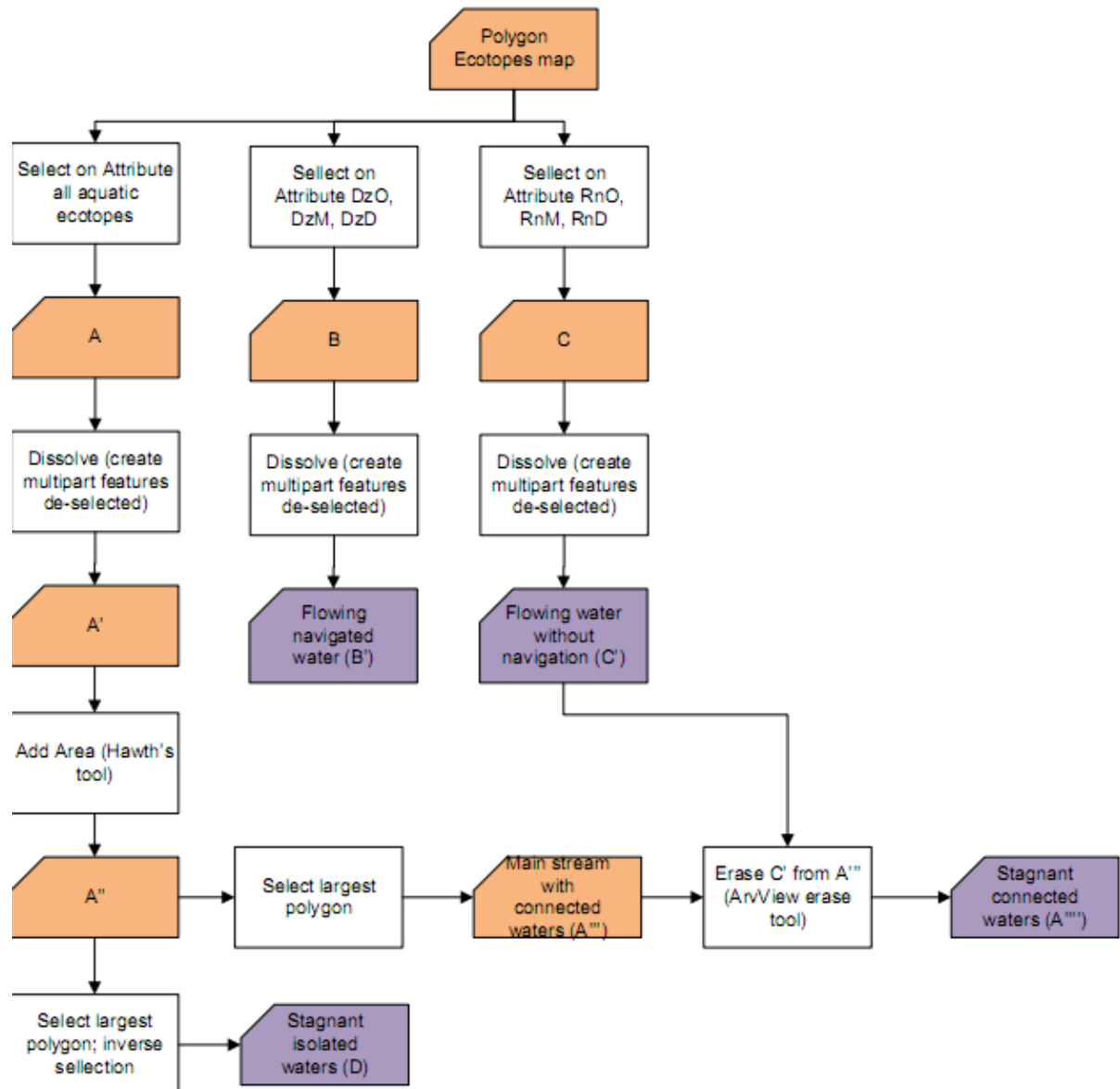
Figure 30 Flow chart part 1 shoreline index; making clip polygons for each distinct river part.
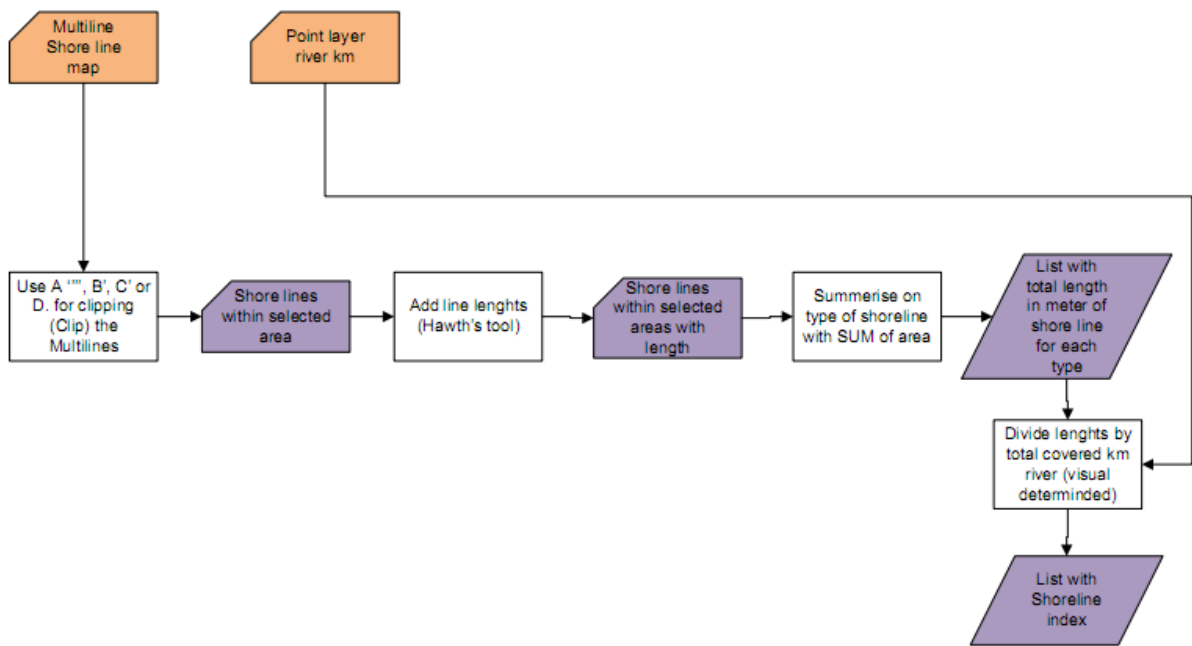
Figure 31 Flow chart part 2 shoreline index; The shorelines are clipped and divided by the river length.

4 RESULTS

In this chapter the results will be shown of the methods described in chapter 3.

First the results will be given of the tool that compares ecotope maps. The results are shown as maps, tables and graphs. In section 4.1 the recent maps will be compared, and in section 4.2 the results of a recent map compared with a map of before the normalization. Section 4.3 shows the results of the extra resolution from depth profiles.

After these ecotope map comparisons, the shoreline index results are given in section 4.4. For aquatic vegetation only information for 6 ecotope types was available. Therefore the results are not shown. All results for aquatic ecotopes and the discussion are similar to that of fish.

4.1 Comparison of ecotope maps 1997-2004

Maps

The comparison of the ecotope maps of 1997 and 2004 using the described method resulted in maps showing where changes in ecotopes have occurred. The first map (Figure 32) shows the ecotope changes between the two periods for a part of the river Waal. The dotted polygons did not change. Green patches represent the aquatic ecotopes and the yellow and red the non-aquatic ecotopes. Bright green means a new area of aquatic ecotope where there was none. Red means that an aquatic ecotope area was transformed into a non-aquatic ecotope.
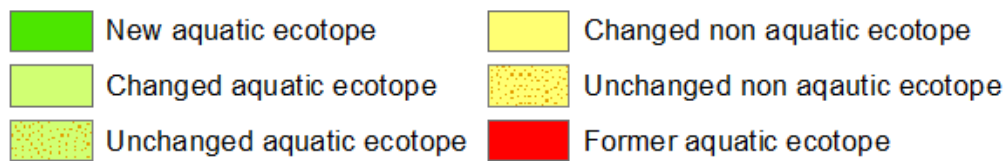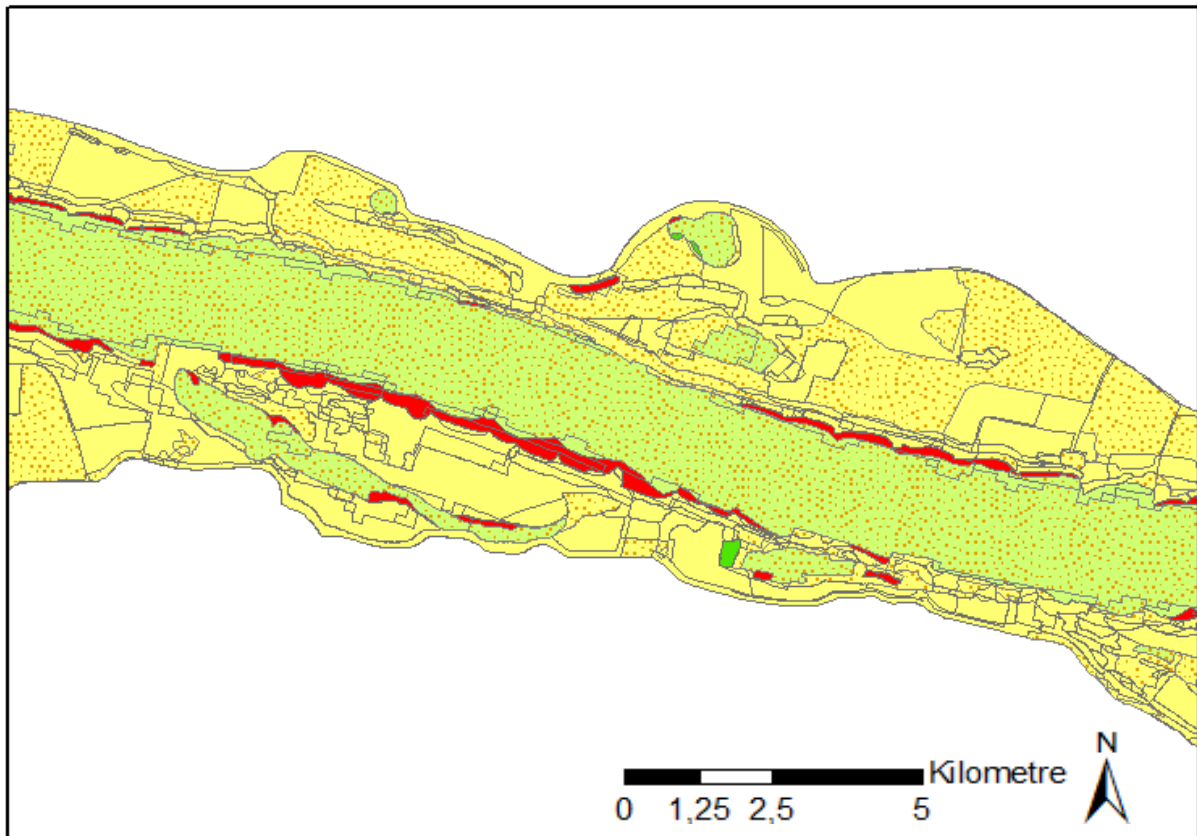
Figure 32 Map change of ecotope suitability for fish between 1997 and 2004. (Lower left corner at 178.5, 431.3 *km*, projection RD_new)

It is also possible to demonstrate whether the changes shown in Figure 32 had a positive or negative effect on the EQR value. This is shown in Figure 33. In bright red the parts that had an EQR value and now not anymore. In red the parts where the EQR value decreased, yellow are the patches where the EQR value was stable, in light green the parts where the EQR value improved and in bright green the parts where there was no EQR value in the older map. In 'salmon pink' the non-aquatic ecotopes.

Figure 33 The relative change in EQR values for 1997-2004. (Lower left corner at 178.5, 431.3 *km*, projection RD_new)

Tables

The results of the ecotope comparison can also be represented in tables. Two tables that belong to the shown maps in section 4.8. are given. Table 10 shows the amount of area that changed and the mean difference in EQR for the complete area per m^2. In this case the mean change was -0.026 m^2. In Table 11 the EQR value for the area has been calculated. This has been done for the complete water basin, and for the aquatic ecotopes only. It appears that the overall EQR value for the basin is lower in 2004, but the EQR for the aquatic ecotopes is almost unchanged. The polygon sizes are smaller in 2004 and the total amount of patches has risen.

Table 10 Values belonging to Figure 32 and Figure 33. The overall EQR value is lower for 2004

fish EQR ecotoop change (values from Arcmap Table => eqr*area / polygon area)							Waal
1997-2004 fish EQR	# polygons	Tot. Area (Ha)	mean area	mean EQR 1997	mean EQR 2004	change mean EQR	mean EQR*area
New aquatic ecotope	1133	97	0.1	0.000	0.449	0.449	41
Changed aquatic ecotope	535	332	0.6	0.489	0.482	-0.006	-3
Changed non aquatic ecotope	13438	5183	0.4	0.000	0.000	0.000	0
Former aquatic ecotope	2688	330	0.1	0.466	0.000	-0.466	-155
Unchanged aquatic ectope	2415	2794	1.2	0.000	0.000	0.000	0
Unchanged non aquatic ecotope	388	4034	10.4	0.450	0.450	0.000	0
Total	20597	12770	0.6		mean EQR change / m2		-0.026

fish EQR relative ecotoop change (values from Arcmap Table => eqr*area / polygon area)							Waal
1997-2004 fish EQR	# polygons	Tot. Area (Ha)	mean area	mean EQR 1997	mean EQR 2004	change mean EQR	mean EQR*area
++	1133	97	0.1	0.000	0.449	0.449	41
+	229	108	0.5	0.454	0.523	0.069	7
+-	407	4110	10.1	0.449	0.449	0.000	0
-	287	148	0.5	0.521	0.454	-0.067	-10
--	2688	330	0.1	0.466	0.000	-0.466	-155
0	15853	7977	0.5	0.000	0.000	0.000	0
Total	20597	12770	0.6		mean EQR change / m2		-0.026

Table 11 EQR values per area per year for 1997 and 2004. There is less area of aquatic ecotopes in 2004; The aquatic ecotopes itself did not change substantially.

fish EQR value / area / year			Waal
	1997	2004	2004min 1997
sum eqr*area	2243	2130	-113
sum area	12770	12770	0
gem eqr	**0.176**	**0.167**	**-0.009**
sum eqr*area	2243	2130	-113
sum area_EQR	4699	4473	-225
mean EQR	**0.477**	**0.476**	**-0.001**
number of polygons	4972	5966	994
mean area of a polygon	2.6	2.1	-0.4
number of EQR polygons	555	486	-69
mean area of EQR polygons	**8.5**	**9.2**	**0.7**

Another possibility to show how the ecotopes have changed is in a pivot table. In this way we can see what the ecotopes changed into, e.g. RnM in 2004 is formed for 100% out of area that was RzM in 1997, and what the new ecotopes where created from (Table 12), e.g.

18% of the total I.1 area in 1997 stayed I.1 the rest changed for 3% into II.2, 8% RwD, 19% RwM, 3% RwO, 2% into VI.2-3 and 46% other ecotopes.

Table 12 1997-2004 ecotope area change as percentage. On the diagonal the not changed area percentage. It shows what the ecotopes of 2004 are formed from. The 'other' row and column represent non aquatic ecotopes.

2004	I.1	II.2	RnM	RvD	RvM	RvO	RwD	RwM	RwO	RzD	RzM	RzO	VI.2-3	other	Total
1997 I.1	59%	2%			2%		5%	7%	13%				4%		1%
II.2		7%													
RvD		4%		95%	6%		18%	4%					1%		5%
RvM					70%			3%	1%						
RvO						47%			3%						
RwD							60%	1%							1%
RwM	2%				18%		7%	76%	7%				4%		3%
RwO	2%							2%	72%				1%		
RzD		10%		4%	4%	1%	3%			98%	27%	12%	4%		23%
RzM		34%	100%			4%				2%	65%	57%	4%		3%
RzO	1%	12%				7%					7%	31%	1%		
VI.2-3		2%											30%	1%	
other	34%	27%				41%	7%	5%	2%				50%	96%	61%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Total area (ha)	50	278	6	586	61	4	271	442	31	2823	202	38	83	7896	12770

Table 13 1997-2004 ecotope area change as percentage. On the diagonal the not changed area percentage. It shows what the 1997 parts changed into. The 'other row and column represent non aquatic ecotopes.

2004	I.1	II.2	RnM	RvD	RvM	RvO	RwD	RwM	RwO	RzD	RzM	RzO	VI.2-3	other	Total	Total area (ha)
1997 I.1	18%	3%					8%	19%	3%				2%	46%	100%	163
II.2		55%					1%						2%	42%	100%	37
RvD		2%		85%			7%	3%						2%	100%	655
RvM		3%		3%	60%			17%						17%	100%	71
RvO		11%				23%	5%		11%					50%	100%	9
RwD				3%			91%	4%						2%	100%	179
RwM						3%	4%	81%						9%	100%	414
RwO	2%	3%		2%			3%	21%	44%				2%	23%	100%	51
RzD										95%	2%				100%	2913
RzM		29%	2%							13%	41%	7%		7%	100%	322
RzO		41%								11%	18%	15%	2%	13%	100%	81
VI.2-3		5%											21%	73%	100%	122
other														98%	100%	7752
Total		2%		5%			2%	3%		22%	2%			62%	100%	12770

Graphs

As a third option the data can be presented in graphs. Figure 34 is a graph showing the total area of each aquatic ecotope, and Figure 35 shows the contribution of each ecotope to the total EQR score of the area.
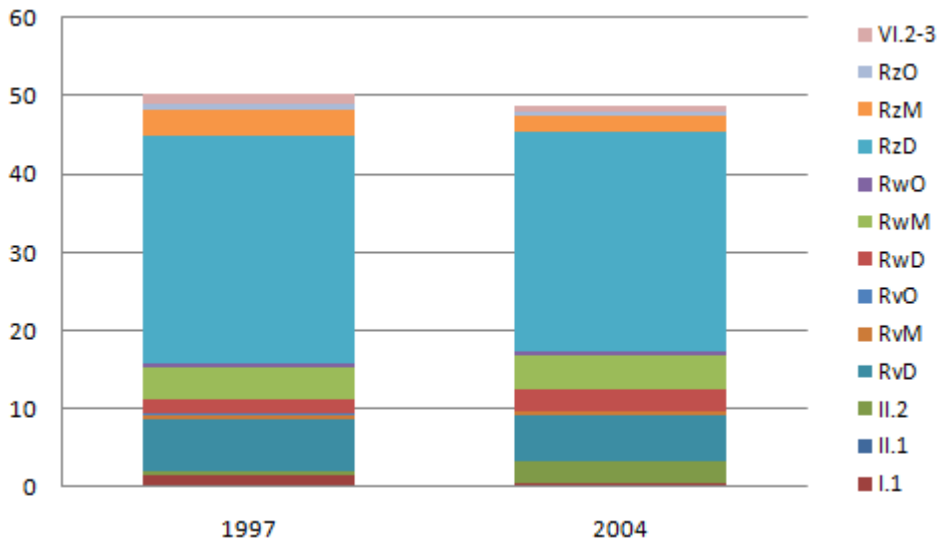
Figure 34 The surface area of the ecotopes (10^{6}m^2) for the years 1997 and 2004. The total surface of aquatic ecotopes in 2004 is less then 1997 for a lower water level during the aerial photo survey.
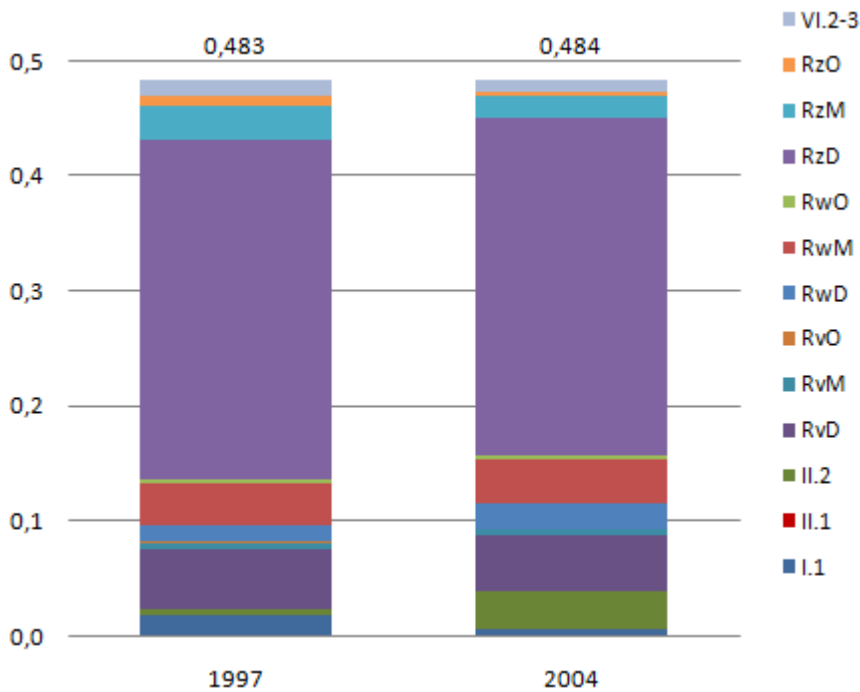

Figure 35 The EQR contribution of each ecotope in the total EQR value for the years 1997 and 2004

4.2 Comparison of ecotope maps 1830-1997

Maps

The same way as the ecotope maps of 1997 and 2004 were compared, the map of 1830, before the normalisation, has been compared with the 1997 ecotope map. Examples of the results can be found below.
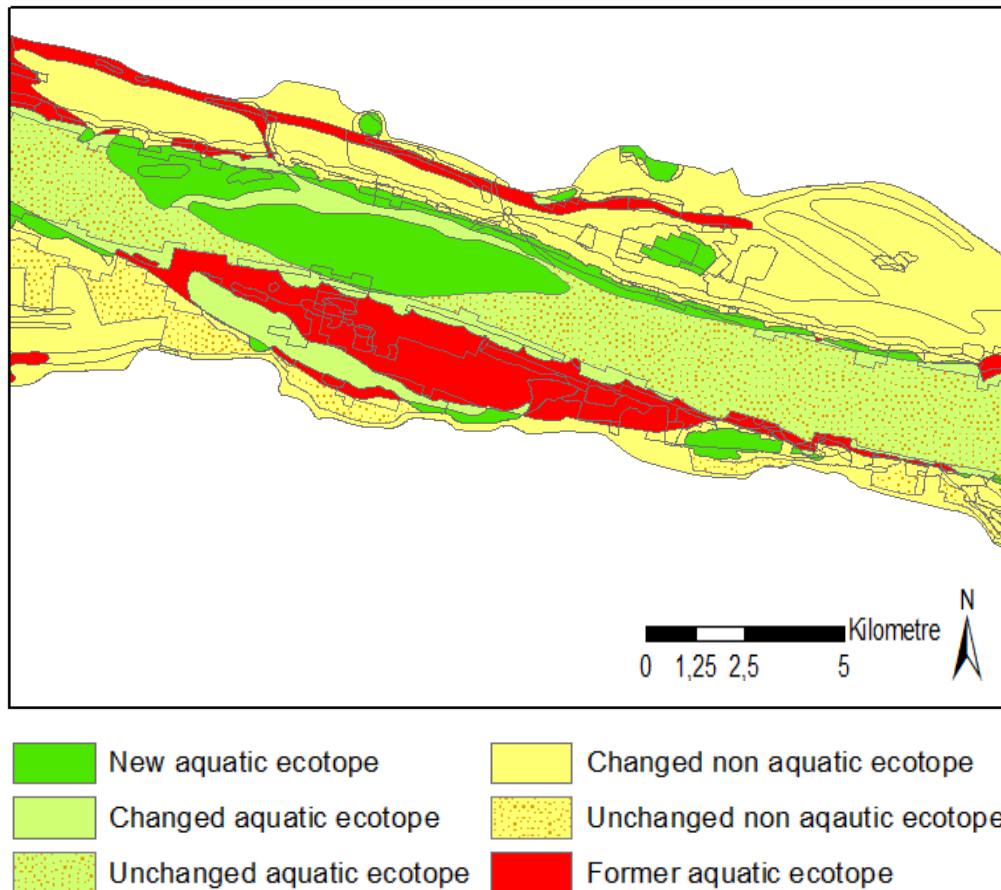
Figure 36 Change of ecotope suitability for Fish between 1830 and 1997. (Lower left corner at 178.5, 431.3 *km*, projection RD_new)
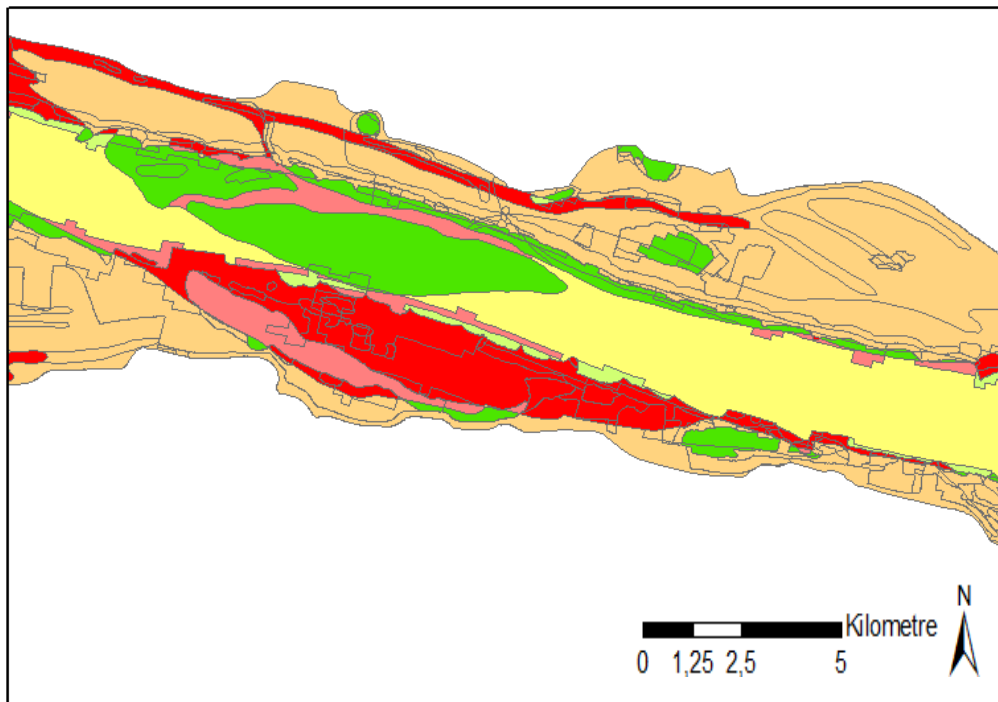
Figure 37 Relative change in EQR values between 1830 and 1997. (Lower left corner at 178.5, 431.3 *km*, projection RD_new)

Tables

In Table 14 the numeric values of the maps in Figure 36 and Figure 37 are presented. Table 15 is calculated out of Table 14. The EQR for the total area is better in 1997 then before 1830. The total EQR value for the entire river is better for the 1997 map compared to 1830. It is also clear that a lot more ecotope patches were mapped in 1997. The EQR value in 1997 is lower for the aquatic ecotopes. The 1997 EQR value differs from the EQR value when the comparison with the 2004 map was made. This is caused by the different areas of the used maps. The 1830 map is only available for 32 kilometres instead of 80 kilometres.

Table 14 Values belonging to map Figure 37 and Figure 36

fish EQR ecotoop change (values from Arcmap Table => eqr*area / polygon area)							
1830-1997 fish EQR	# polygons	Tot. Area (Ha)	mean area	mean EQR 1830	mean EQR 1997	change mean EQR	mean EQR*area
New aquatic ecotope	396	824	2.1	0.000	0.462	0.462	381
Changed aquatic ecotope	158	272	1.7	0.488	0.474	-0.013	-13
Changed non aquatic ecotope	2178	2016	0.9	0.000	0.000	0.000	0
Former aquatic ecotope	797	570	0.7	0.473	0.000	-0.473	-278
Unchanged aquatic ectope	106	170	1.6	0.000	0.000	0.000	0
Unchanged non aquatic ecotope	8	716	89.5	0.414	0.414	0.000	0
Total	3643	4567	1.3		mean EQR change / m2		0.020

fish EQR relative ecotope change (values from Arcmap Table => eqr*area / polygon area)							
1830-1997 fish EQR	# polygons	Tot. Area (Ha)	mean area	mean EQR 1830	mean EQR 1997	change mean EQR	mean EQR*area
++	396	824	2.1	0.000	0.462	0.462	381
+	66	56	0.9	0.454	0.509	0.055	3
+-	13	718	55.2	0.422	0.422	0.000	0
-	87	214	2.5	0.516	0.449	-0.067	-16
--	797	570	0.7	0.473	0.000	-0.473	-278
0	2284	2186	1.0	0.000	0.000	0.000	0
Total	3643	4567	1.3		mean EQR change / m2		0.020

Table 15 Fish EQR values for the river Waal per year

fish EQR value / area / year	1830	1997	1997 min 1830
sum eqr*area	776	865	89
sum area	4567	4567	0
gem eqr	**0.170**	**0.189**	**0.020**
sum eqr*area	776	865	89
sum area_EQ	1557	1811	254
mean EQR	**0.499**	**0.478**	**-0.021**
number of po	324	1795	1471
mean area of	**14.1**	**2.5**	**-11.6**
number of EQ	51	204	153
mean area of	**30.5**	**8.9**	**-21.7**

4.3 Higher resolution through depth information

The depth chart made for 1780 was used to recalculate the total EQR of that year by using a higher resolution (Figure 38). In Figure 39 this higher resolution EQR outcome is compared with the results of 1997 and 2004. Clear differences in ecotope distribution can be observed as the deep main channel is now split into deep, moderate and shallow main channel.
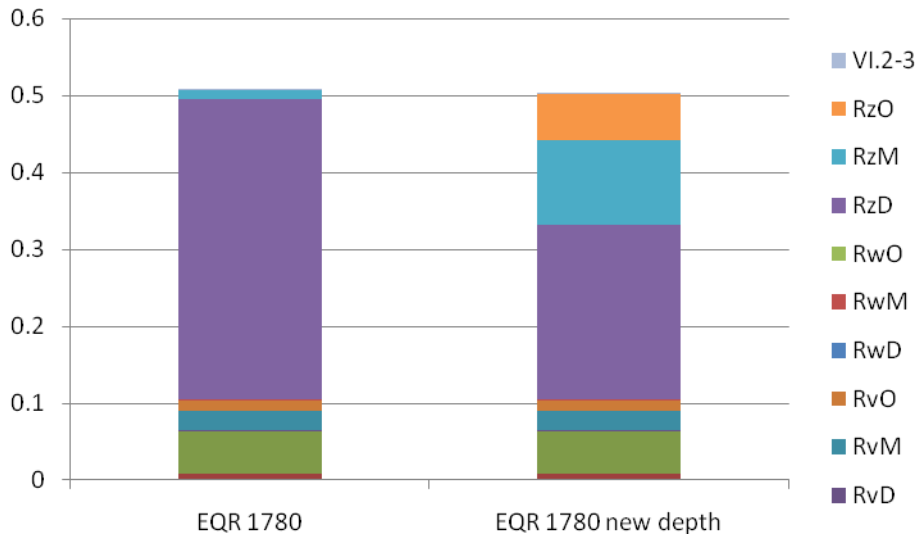
Figure 38 The fish EQR values for 1780 with and without depth resolution. On the Y-axis the EQR ratio (0 to 1).

The depth profiles clearly add extra information on the depth distribution. It has little influence on the EQR value
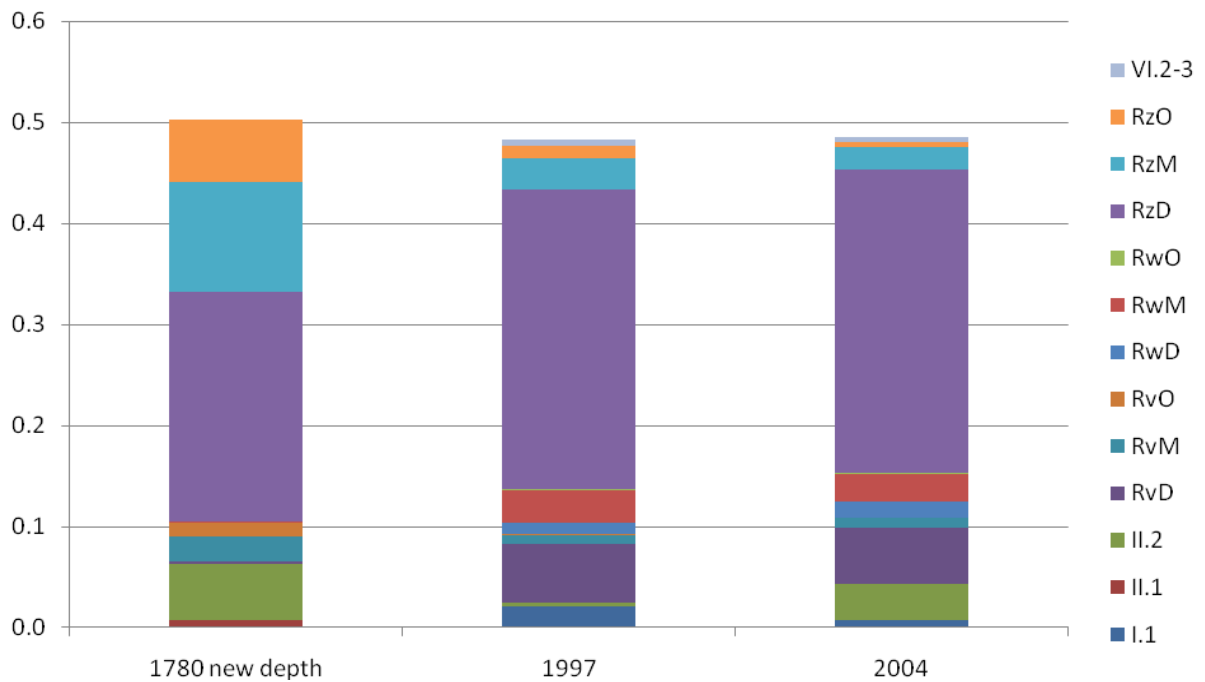

Figure 39 Difference in EQR and ecotope contribution between 1780, 1997 and 2004. On the Y-axis the EQR ratio (0 to 1).

After normalisation the aquatic ecotopes have become deeper.

4.4 Shoreline index

In Figure 40 is shown that all diferent river parts have a different pattern of shoreline types. Figure 41 shows the contribution of each river part in the total shoreline index of the river Waal.
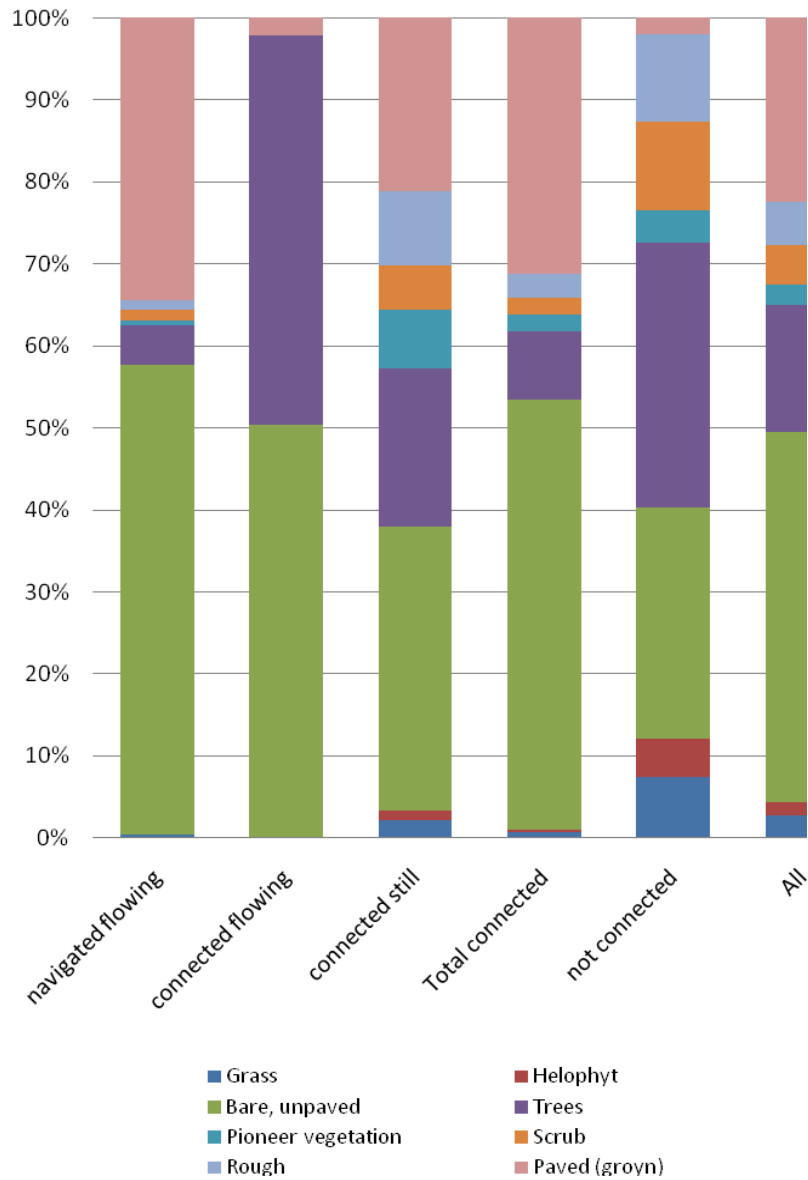
Figure 40 Type of shoreline per river part (see for the river parts Figure 29). This can be used to see the differences in land cover type of the shore lines in each different part of the river. The shoreline cover is given as percentage of the total border length where the total border length of a class is 100%.
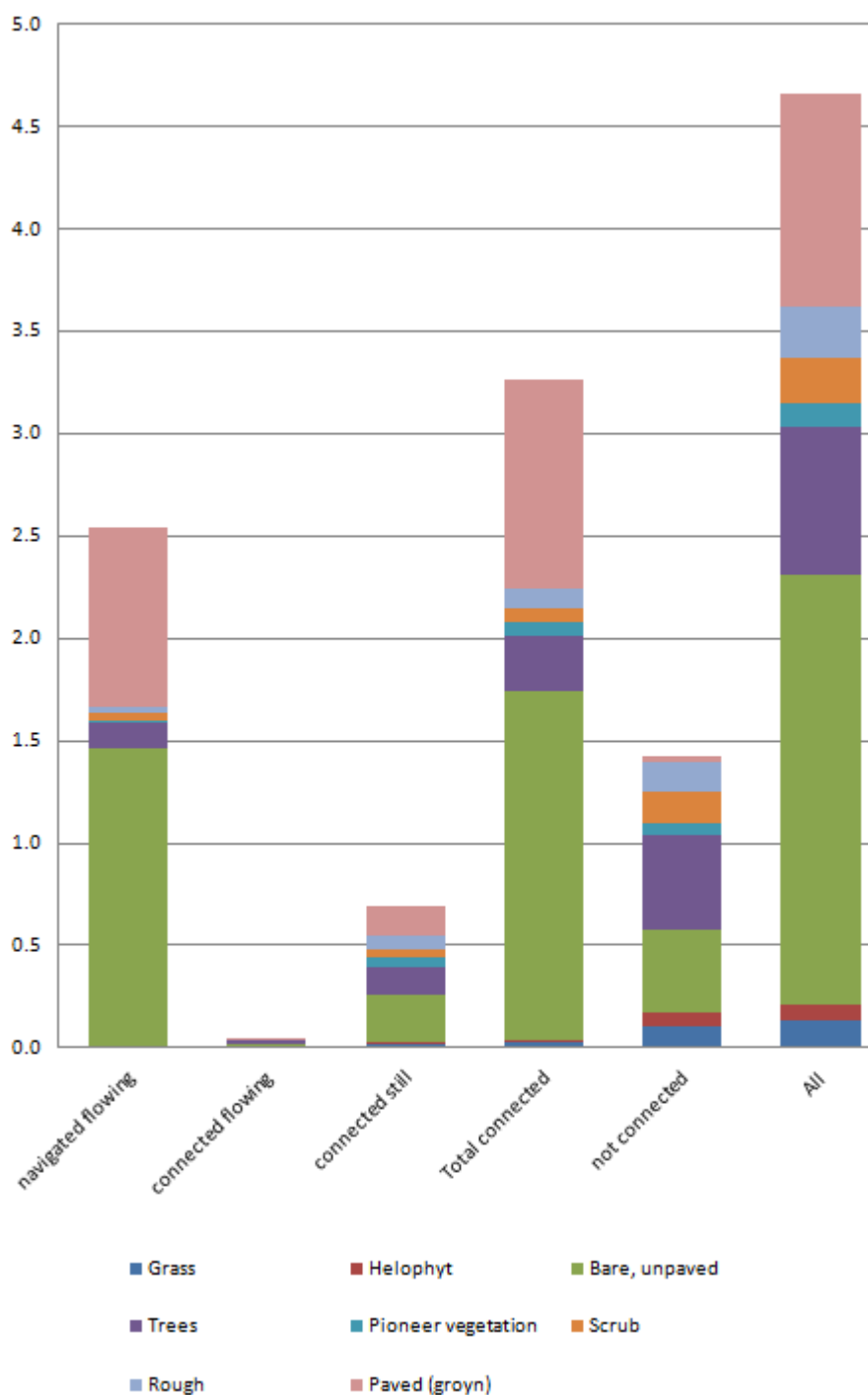
Figure 41 Shoreline value per shoreline type. The index has been calculated over 80 km of the river Waal. Some short river parts score therefore below 2.

4.5 Other methods

4.5.1 Area ratio

In appendix 9.4 (Table 22) the complete set of tables is given out of which the following table is made. The depth classes of the 1780 and 1830 maps are obtained by incorporating the depth profiles (see section 3.2.5).

Table 16 Ecotope distribution between the three main aquatic ecotope types and within these classes. Given for the averaged area of before the normalisation(1780/1830) and after (1997/2004).

		1780/1830		1997/2004	
		% of total aquatic ecotopes	Distribution in depth classes within ecotope class (%)	% of total aquatic ecotopes	Distribution in depth classes within ecotope class (%)
Downstream connected backwater	RvD	7	10	15	90
	RvM		62		10
	RvO		28		1
Not connected to main channel	RwD	2	25	15	32
	RwM		75		62
	RwO		0		6
Main Channel/Floodplain waterbody	RzD	90	13	70	90
	RzM		54		8
	RzO		33		2

Because of the normalisation not only more water has been partially disconnected from the main stream or became downstream connected backwater out of a floodplain water body but also the depth distribution within the classes has changed. In the new maps most ecotopes are deep where they where moderate or shallow before.

5 DISCUSSION

In this chapter the result will be discussed. The results will not only be interpreted from an ecological viewpoint, by discussing the results of the assessments, but above all from a technical GIS viewpoint. I will discuss why certain methods were chosen (section 5.1). And I discuss how good the results are in terms of the data quality, and of factors like temporal scale and resolution. I will look into the question if and how the results can be improved with additional data or methods. Section 5.8 discusses the usability of the tool for two types of users: the GIS users and the users of the results.

5.1 Chosen method

The question was whether it was possible to see EQR changes by using ecotope maps and quality indicators. To do this an approach was chosen of using a GIS in combination with a spreadsheet program. The actions performed in the spreadsheet program can also be performed in a GIS environment when it is used in combination with databases. This would probably result in a system that can be applied and adjusted more easily. But to avoid spending too much time on making the method work in such an environment, I spent more thoughts on the method itself and the types of outcome that can be created. Apart from this choice concerning the architecture of the system, a more fundamental choice was made when I decided to work with polygons instead of raster files.

5.1.1 Polygon vs. raster

When working with a GIS one of the choices to be made is the choice between vector and raster based data. The choice will have influence on the possible tools that can be used, and possibly also on the results (Lausch and Herzog 2002). Rasters represent an area by using a regular cell structure of rows and columns whereas a vector based map uses lines to represent an area (Figure 42).
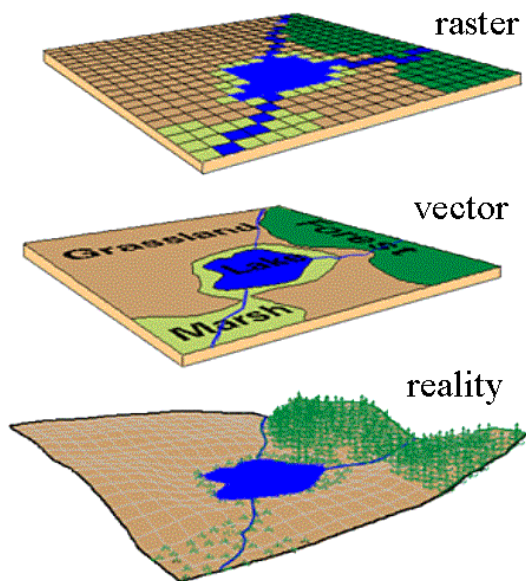
Figure 42 Difference between vector (polygon) and a raster map (www.lincoln.ac.nz)

The most important factor for choosing vector polygons for this research is that it is possible to store multiple attribute data for each feature in the file. This method provides the opportunity to do several analyses while using just one file. It creates the possibility not only to store the EQR value for each polygon, but also to store all fish and vegetation data. This makes it possible to switch in the representation of the data between the various attributes. It also provides the possibility to query a location on occurring fish and vegetation. In addition, all this information stays available after intersecting two ecotope maps. This makes it possible to see the difference in the fish and aquatic vegetation population at a location between any two periods.

Another advantage of vector data is that the graphical representation of an area in vector shape usually gives a 'nicer' view than the more "cubic" raster visualisation.

For the calculation of the shoreline index, vector data is the most logical choice because the vector lines represent the shorelines best. Using raster for this calculation would lead to longer line lengths and thus to different results.

Raster would have been an interesting choice if the EQR values of only one year would have been under consideration. The reason for this is that there are a lot, and probably more, statistical possibilities with raster files than with the vector alternative.

5.2 Results and their interpretation

Maps (Figure 32 and Figure 33) show where changes took place and whether these changes are an improvement for the ecological quality or not. The results are also represented in pivot tables (Table 12). This option will make it possible to see if measures cause the desired change. The tables show that the ecotope 'deep summer bed' (RzD) of 1997 stays 98% the same in the 2004 ecotope map. And from the 'shallow summer bed' (RzO) only 15% of the total area in 1997 stayed the same in 2004. Most of the former RzO changed into bare banks (II.2). This is probably caused by the lower water level in 2004 that causes shallow parts to fall dry. Another example is that in 2004 a 'side channel' (RnM) was formed out of a 'medium deep summer bed' ecotope (RzM). This new RnM was formed out of 2% of the total RzM.

Another representation of the results is given in Table 10 and Table 11. In these tables the values, represented graphically in the maps, are given and used for computation of the final EQR. Additional information is used out of the attribute tables in the GIS showing the number of polygons in each map and their total area. It appears that the 1997 map had less patches then the 2004 version. The 2004 edition can therefore be considered more detailed. This is probably due to the different WEC used while producing the map for the actual situation did not change very much between 1997 and 2004. The original 1997 classification has been converted to the current WEC. In the former classification fewer ecotopes had been identified, and therefore less patches have been mapped. Consequently, despite the use of the new WEC, the number of patches remained lower in the 1997 edition. The overall EQR for the complete map becomes lower (Table 11). And the EQR for all aquatic ecotopes is almost stable. This means that the total area of aquatic ecotopes within the area reduced. This can be explained by the lower water level in 2004 resulting in a smaller area of aquatic ecotopes but also in shallower ecotopes that have a higher EQR value.

The map comparison between 1850 and 1997 (Figure 16) shows clearly that the formerly meandering river is now flowing in a more straight line. The EQR changes between the two years in Table 14 and Table 15 show that the value for the total area has risen, but that the EQR value for the joined aquatic ecotopes has become lower. This lower value can be explained by the fact that the river has become deeper. A deeper river has less nature value resulting in a lower EQR. The rise of the EQR for the complete area is caused by a relatively higher amount of aquatic ecotopes in 1997. As with the changes seen between 1997 and 2004, this can be explained by a difference in water level when making the maps. When the old maps were made, it was important for the land surveyors to map as much dry land as

possible. Their clients, land owners and the tax authorities, were only interested in dry land. Therefore they had to measure when the water level was low.

5.2.1 Mapping exact EQR values vs. relative changes

The maps show the relative changes, not the absolute EQR value change. This has been done for the only slight differences occur when the EQR value changes. These small differences are caused by the rather small difference in possible EQR values. And because the largest ecotope, deep summer bed (RzD, EQR 0.507), is a dominant factor (Table 17). Aquatic ecotope rates can vary in EQR between 0.401 and 0.577, giving a bandwidth of 0.176. This is rather small to show in map classes. Table 17 shows how large the influence of the deep summer bed is in 1997. With its large influence the total EQR for the aquatic ecotopes cannot vary more than between 0.467 and 0.534 (Table 18). Because of this big influence the actual bandwidth is not 0.176, but actually less than half: 0.067. On account of this small difference, I have decided to use the relative change for mapping purposes.

Table 17 Area percentage of the deep summer bed ecotope (RzD) in relation to the total river plain and in relation to the total area of aquatic ecotopes map (1997)

Ecotope	Area (Ha)	all ecotopes	aquatic ecotopes
RzD	2913	23%	62%
Aquatic ecotopes	4699	37%	100%
All ecotopes	12812	100%	

Table 18 Influence of the deep summer bed (RzD) on the maximum and minimal possible EQR outcome for fish in 1997

| | EQR value | All other ecotopes | | | |
| | | lowest EQR | | highest EQR | |
		Area (Ha)	Area*EQR	Area (Ha)	Area*EQR
EQR lowest	0.401	1785	716		0
EQR highest	0.577		0	1785	1030
EQR RzD	0.507	2913	1477	2913	1477
Total EQR		4699	0.467		0.534

5.2.2 How good is the model?

The EQR values computed are based on the suitability of ecotopes for species. This suitability is based on expert knowledge. The EQR values calculated with this knowledge are now shown with three digits behind the decimal point. This suggests a very high precision of the results. This has been done to show that the method works, but for interpretation of the results it is better to use only one or two digits as three will give a false idea on precision.

5.3 Map accuracy and other error sources

The used method makes an intersection between two ecotope maps. Each map has its own data quality. The errors made in each map will have its effect on the resulting map. Also slivers will be created (see section 5.3.1) along the borders of patches mapped in different years (Wang and Ellis 2005).

The quality of a map is represented in a users and a producers accuracy. These accuracies give an indication of the identification errors made during the map production. When combining two maps these accuracy errors will propagate into the new map. This results in patches where the change between ecotopes is almost certain for ecotopes with a high accuracy. But also places where the change is less certain if it is a change between less reliably mapped ecotopes (Ellis and Wang 2006).

Another source of error is that the maps have been mapped using a different WEC and a different type of aerial photo. The difference in WEC is not large for the aquatic ecotopes and is therefore regarded not to influence this research. But if also shoreline ecotopes and terrestrial ecotopes are going to be assessed, there will be an influence. Between the 1997 and 2004 ecotope map the number of polygons has risen about 20%, largely caused by more resolution in the new WEC. The difference in photos used making the maps will also be of influence. The first edition was mapped using real color (RGB) photos and the second edition used false colour photos. This difference will not have much influence on the aquatic ecotopes, but can have an impact on the other ecotopes. This is because the difference between types of grass vegetation can be better recognised in false colour then in RGB photos. For future ecotope map productions it would be best to use a combination. The modern photo scanners are capable of making pictures in more than three wavelengths, making it possible to make combined false colour / RGB surveys.

5.3.1 Slivers

For the comparison between two ecotope maps an intersection was performed. When making intersections of maps it is very likely that slivers will occur. The occurrence of slivers when comparing ecotope maps has been minimized by the production method of the map by Rijkswaterstaat using the old border method (see section 3.2.1.2). Visually, the slivers do not show. The still occurring slivers do not have a large influence on the outcome (Table 19). The small polygons that occur after making the intersection are only a small percentage of the total area. Therefore the slivers that occur will not have much influence on the total EQR value calculated. As can be seen in the table, this will have its influence on the total number of polygons. Depending on possible other uses of the results this can be a significant number, but for the EQR values it does not matter.

Table 19 Small polygons after intersection of the 1997 and 2004 ecotope maps. The small polygons are given as percentage of the total area and as percentage of the total number of polygons in the map.

	Area (m^2)	Percentage	Number of polygons	Percentage
Total area	127695241	100.0%	20597	100%
Area < 400	650262	0.5%	8548	42%
Area < 250	311114	0.2%	7500	36%
Area < 100	82472	0.1%	6164	30%
Area < 10	5212	0.0%	4502	22%
Area < 1	818	0.0%	3260	16%

It is arbitrary when to call a polygon a sliver polygon and when a normal change. Therefore the results in the table are given for different area sizes. The ecotope publication of Rijkswaterstaat is mapped on a 1:10.000 scale. And the smallest mapped patch size is 400 m^2. At a 1:10.000 scale one millimetre on the map is equal to 10 meters in the field. The areal percentage of small patches is so low that they do not influence the calculated EQR outcomes.

If the current comparison of maps is extended to investigate also which ecotope changes into what, it would be wise to first remove slivers before drawing conclusions about the amount of changes. But for the comparison of the total areas it will not matter.

5.3.2 Difference in water level between two ecotope maps

When comparing two maps for their aquatic features, it is important to know if the aquatic conditions in both maps are the same. The base source for the production of ecotope maps are aerial photos. Conditions for making aerial photos have to be right. Rijkswaterstaat demands the photos to be taken within certain months. The water level during these months is not every year the same, and can therefore differ between two editions.
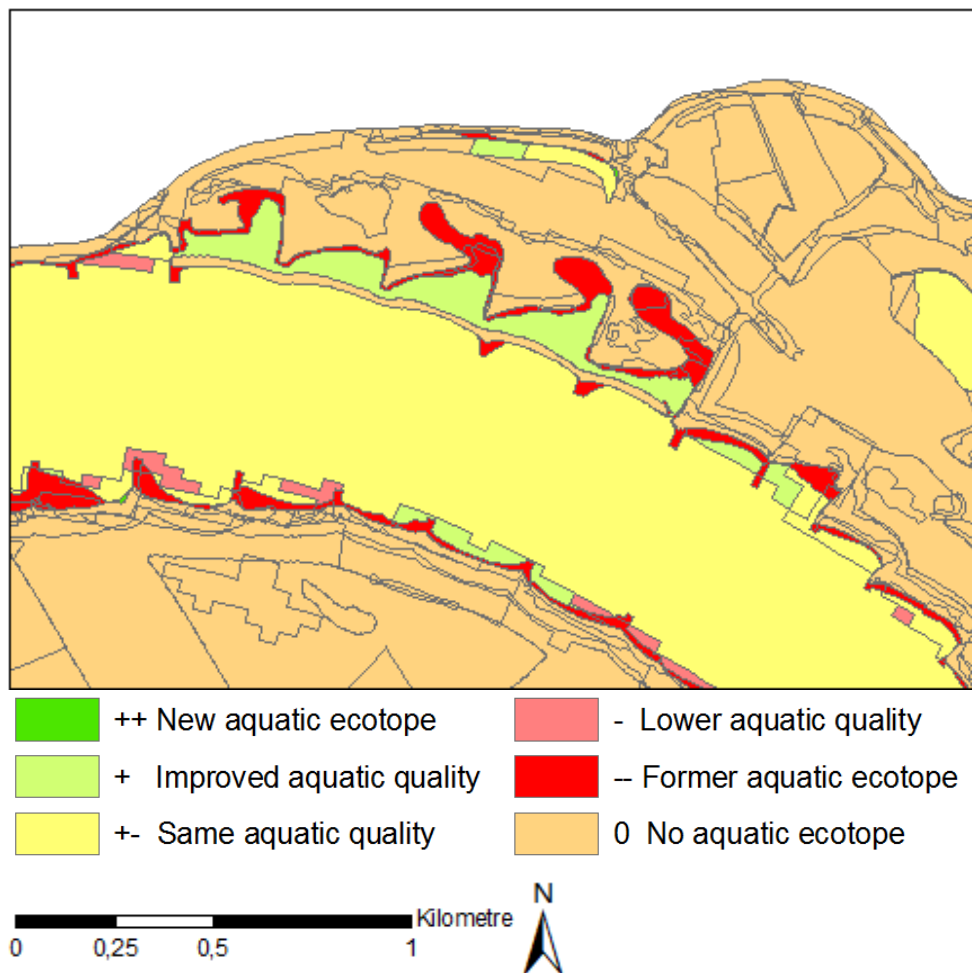
(Lower left corner 149.0, 425.5 *km*, projection RD_New)

Figure 43 Map of the relative change in EQR values for 1997-2004 at Opijnen

The difference in water level has an impact on the ecotopes mapped. When the water level is lower, the total area of aquatic ecotopes will decrease and the amount of shoreline ecotopes will increase.

The ecotope map of 1997 is based on pictures taken on the 11th of July 1997, with a water level of 10.61 meter NAP at the measure point Lobith. The 2004 photos were taken on the 18th of August 2004. The water level was then 8.75 meter NAP at Lobith. Between these

two editions this results in a difference of 1.86 meter. The river bank has mostly an inclination of 1:3, resulting in a reduction of the width of the river by 11 meters. This results in more than one hectare difference in aquatic shoreline ecotope per kilometre river length. For the complete river Waal this means about 80 *ha* of differently interpreted ecotope areas along the main channel. The total amount of aquatic ecotopes that changed into a non-aquatic ecotope between 1997 and 2004 is 300 *ha* (Table 10). Of these 300, 80 are caused by a change in water level. This results in interpretation errors of the resulting EQR value. The difference shows as red parts in the resulting maps comparing 1997 with 2004. One third of this change is temporal change caused by differences in water levels.

To avoid this type of interpretation error it is better to take the aerial photos at a pre-defined water level or, as this can compromise the possibility of making the photo survey, by the use of a fixed water level that is modelled into the ecotope map. To be able to do so, it is necessary to introduce the height component. This can be done by making the complete map 3D or by adding a height information layer to the model that is used for the classification into ecotopes. Both options are possible by combining the available height model of the Netherlands made by Rijkswaterstaat and the Dutch Water Boards (www.ahn.nl) with bathymetric data surveyed by Rijkswaterstaat, and by adding this to the map or model.

A difference in water level will not only have its influence on the mapped ecotopes and the derived EQR values but also on the shoreline index (Figure 44) as Nat et al. (2002) have shown for the Tagliamento River. When the water level is lower, more sandbanks in-between groins are mapped. This will result in a high soft bank index. Whereas with a height level the water will have its border at the hard banks of the groins; resulting in a high index for hard surface.
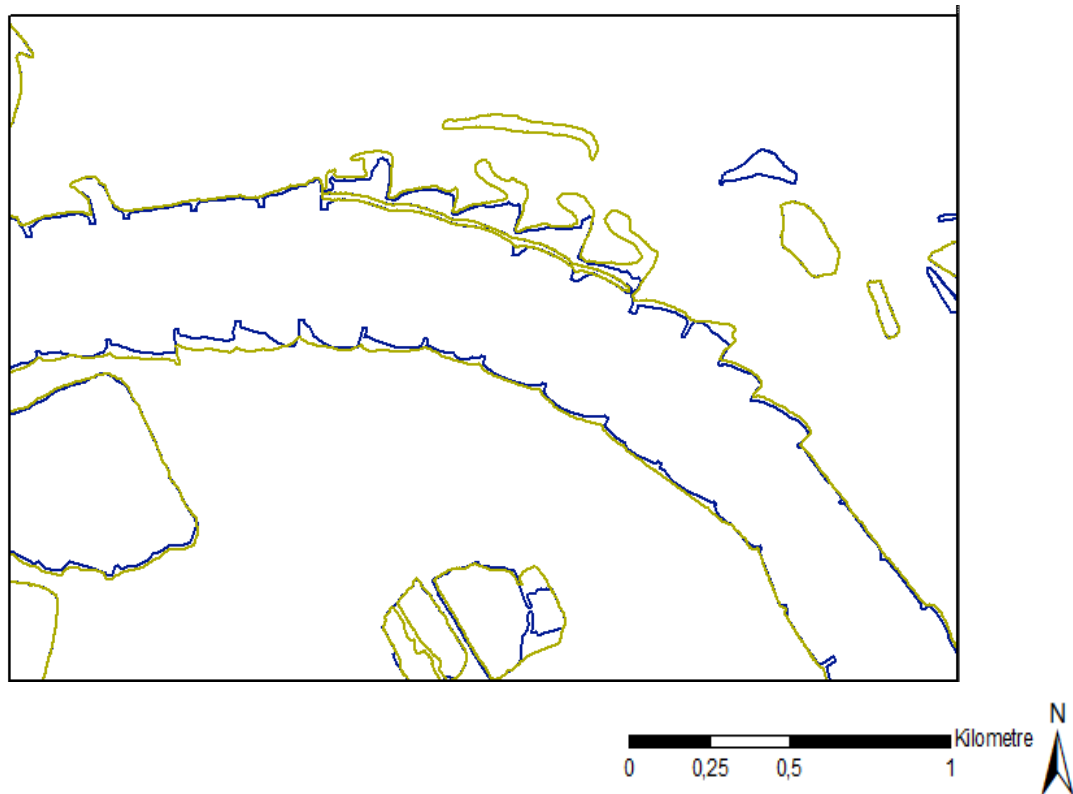
Figure 44 Difference in Shoreline between 1997 (green) and 2004 (blue). (Lower left corner 148.3, 424.9 *km*, projection RD_New)

5.4 Extra resolution

The described method only uses the standard ecotope maps. These maps only describe the ecotopes up to a certain level. More exact information on local occurring parameters like Flow velocity, water depth, temperature, water level fluctuation, sediment, river bank shape and wave intensity will make the results more accurate for both fish and vegetation. These factors are already available in the used tables, but not in the ecotope maps. Adding information on these topics would make the outcomes more precise.

In the course of this research I have introduced the factor Depth for the 1780 map. It shows that the influence is significant for the ecotope distribution (Figure 38). Therefore additional components are advised when making future ecotope maps. Together with the water level problem, this is in favour of a more exact height component when making the map.

5.5 Presentation of the data

The combination of two ecotope maps results in a wealth of information. This information can be presented to the end users in several ways. In this report three options have been used. The first is to represent the data as a map, the second is to represent the data in

tables, and the last is to present the data in graphs. The type of presentation used will depend on the user. For communication purposes maps and graphs which show the information visually will be preferable. But to researchers the tables will provide better insight.

As tables are not easy to interpret, I have also used graphs. In a graph the absolute results can be shown graphically, resulting in a representation that shows the most important conclusions of an outcome in an easy way. For example, a table with the differences in the summer bed area before and after adding depth information to the ecotope map of 1780 has to be read for the difference to become apparent. This in contrast to looking at the resulting Figure 38: looking makes everything clear in a flash.
Bar graphs show the difference in EQR between years. This presentation method makes it possible to see changes more easily than in tables. This can be best seen in the bar graph of the 1780 map before and after adding additional depth information (Figure 38). Changes between years can be seen in Figure 39. Although the absolute EQR value does not change much, the change in the ecotope area distribution and therefore in bio diversity is evident.

The results of the shoreline index are also given in a bar graph representation. The bars provide a better understanding of differences in shoreline type between the different parts of the river. The bar graphs represent the results relatively and absolutely. The first (Figure 40) makes it possible to see the difference in shoreline types covering each river part, and the latter (Figure 41) shows the index value for each part of the river.

For representation of landscape changes, a Belgian study on landscape change out of aerial images suggests the use of only three colours: for new elements, removed elements and unchanged elements (Lacroix et al. 2004). As this study focuses on road systems, this classification is more line driven and not directly applicable to changes in areas. Classes should depict the degree of change, and this is possible in different ways (de By et al. 2004). Various map examples of showing change can be found in a publication of Law (2008). I have used only five classes for the representation of the results in a map. This makes it easy to see where changes took place. The classes are represented with commonly used colours. Red for bad EQR values, yellow for stable values and green for good and increasing values. Thus, users will be able to understand the maps almost without a legend. It was chosen to use classes rather than a gradual colouring because the EQR differences can be very small; hence, gradual colouring would result in a map that would be more difficult to interpret.

5.6 Not modelled important factors

Some factors that not have been modelled have been mentioned in section 5.4. The factors mentioned there are known for their effect on fish and aquatic vegetation, and can therefore be incorporated in the model if data layers with this information become available.

In this study only the aquatic ecotopes have been investigated. In the zone between aquatic ecotopes and dry terrestrial ecotopes the shoreline ecotopes are located. These ecotopes will inundate for some time during the year. When looking at the results, one sees clearly that some measures will be falsely marked as not working. A good example of this is the adjacent river part near the municipality Opijnen (Figure 43). Due to the reconstruction of this adjacent river the water level is now lower, resulting in dryer ecotopes that are not permanently under water any more. Here aquatic ecotopes have been transformed into shoreline ecotopes. In the model this is shown as going from a suitable ecotope for fish to an unsuitable ecotope (a red colour). The result is a lower overall EQR rating. But in reality this is not a negative change. The new ecotopes are also important for fish. During the period that the water level is high enough some types of fish reproduce themselves in this kind of areas. The reintroduction by the measure of these type of ecotopes is therefore on the whole an improvement for the fish population (Nagel 1998). To see these changes as positive ones when using the proposed method, also the shoreline ecotopes have to be included. Unfortunately there is no data available at the moment about the suitability of these ecotopes for fish. In order to see its influence, some shoreline ecotopes have been given the EQR values of comparable aquatic ecotopes (expert judgment Buijse, 2009). This shows that it has influence on the ecotope changes (Figure 45) and the EQR. The total mean EQR change is not -0.009 but –0.005 with a mean EQR for the aquatic ecotopes changing from –0.001 to 0.001. The total mean EQR value is then 0.483 in 1997, whereas it was 0.477. In 2004 this change is from 0.476 to 0.484 (Table 11 and Table 20)
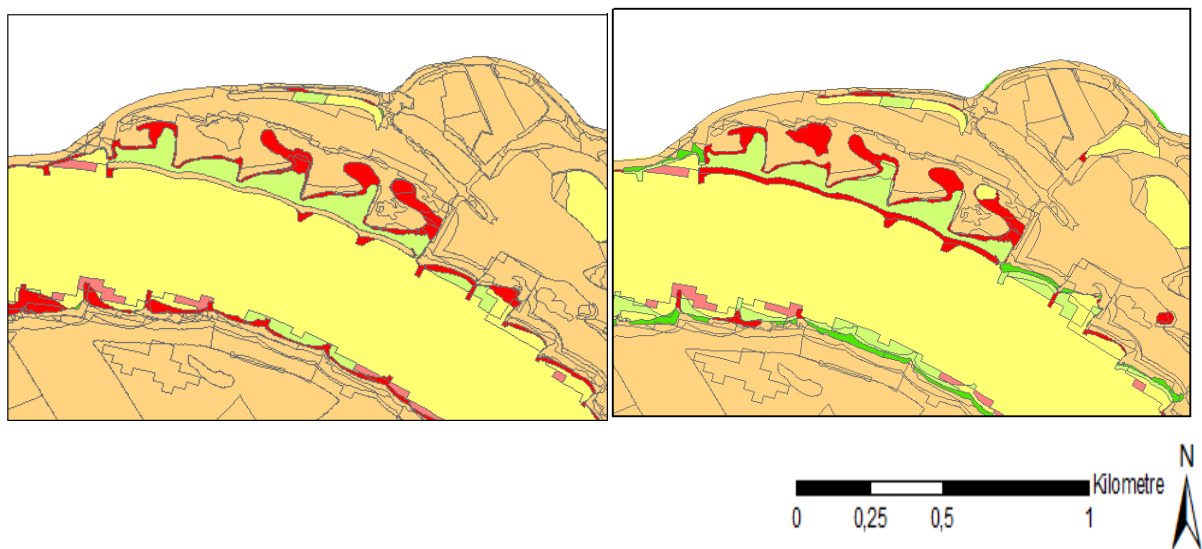
Figure 45 Opijnen before and after adding shoreline ecotopes to the comparison 1997-2004. After incorporating shoreline ecotopes there are less unsuitable areas. (Lower left corner 149.0, 425.5 *km*, projection RD_New)

Table 20 EQR values for 1997 and 2004 with additional shoreline ecotopes added

fish EQR value / area / year			Waal
with shoreline ecotopes	1997	2004	difference
sum ekr*area	24257082	23600038	-657044
sum area	127695241	127695241	0
gem ekr	0.190	0.185	-0.005
sum ekr*area	24257082	23600038	-657044
sum area_EQR	50174072	48739610	-1434462
mean EQR	0.483	0.484	0.001
number of polygons	4972	5966	994
mean area of a polygon	25683	21404	-4279
number of EQR polygons	1121	1098	-23
mean area of EQR polygons	44758	44389	-369

5.7 Implementation of the tool

The method shows that it is possible to derive EQR values out of the ecotope maps and to represent the data. This works but is not optimal for frequent and easy use. If a parameter of, for example, fish changes, it is obligatory to repeat the complete procedure. It would be better to automate all steps. The easiest way would be to use a macro like the ArcGIS model builder, but it would be even better to build a complete geo-database including all data on ecotopes, fish and aquatic vegetation. This way a change in a parameter can be directly shown in the resulting EQR and map.

To use the tool in rivers other than the river Rhine, certain parameters in the spreadsheet will have to be adjusted in order to suit local differences.

5.7.1 Improve the EQR outcome with other models

When this method is going to be used, it may be necessary to add not only extra resolution by adding information, but also by adding extra model parameters for calculating the overall EQR. Extra information can improve the precision of the results, but additional models can improve the overall results. In section 5.2.1 I have shown that the calculated EQR values cannot be higher than 0.467 or lower then 0.577. In section 2.1.1 I explained that the current EQR is estimated to be around 0.3, and in the reference situation 0.8. These values do not match the calculated results. A reason for this can be found in the fact that with the used method the average alpha in calculated instead of the gamma diversity.

To improve this other factors than only the ecotope types have to be considered. In literature, two other important methods for assessing the same data have been found (Ward, Tockner, and Schiemer 1999; Dehairs et al. 2001). These methods are beta diversity and area ratio: they might be useful to improve the reviewed methods. The area ratio outcomes are shown in section 4.5; the results in section 4.5.1 show that ecotope classes have become a lot deeper (Table 16). By adjusting the weight of deep and shallow ecotopes the EQR results can be adjusted to better match the 0.3 and 0.8 results. The other method for further improvement will be explained in section 5.7.2. The 'alpha beta gamma' theory can help to identify key ecotopes for creating extra diversity. The added value of this method is that it enables to look at another level of diversity: the gamma diversity where the used method only calculates the average alpha diversity on the ecotope level.

5.7.2 Alpha, beta and gamma biodiversity

An aspect of biodiversity is the level of spatial-temporal heterogeneity (Ward, Tockner, and Schiemer 1999). The interaction between all ecotopes is very important for the biodiversity as a whole. Therefore, in order to improve the ecological quality of a river, we must look how these ecotopes interact with each other. This can be done on different levels. Biodiversity as a whole is the outcome of all levels together. Once this relationship is known, choices can be made about which types of ecotopes should be created and on what scale.

The method has three diversity levels: alpha, beta and gamma. The alpha diversity is the number of species in each ecotope, the beta diversity is the turnover of species between habitats and the gamma diversity the total species pool. These three levels can be found in each hierarchical level of an eco system (Figure 46).
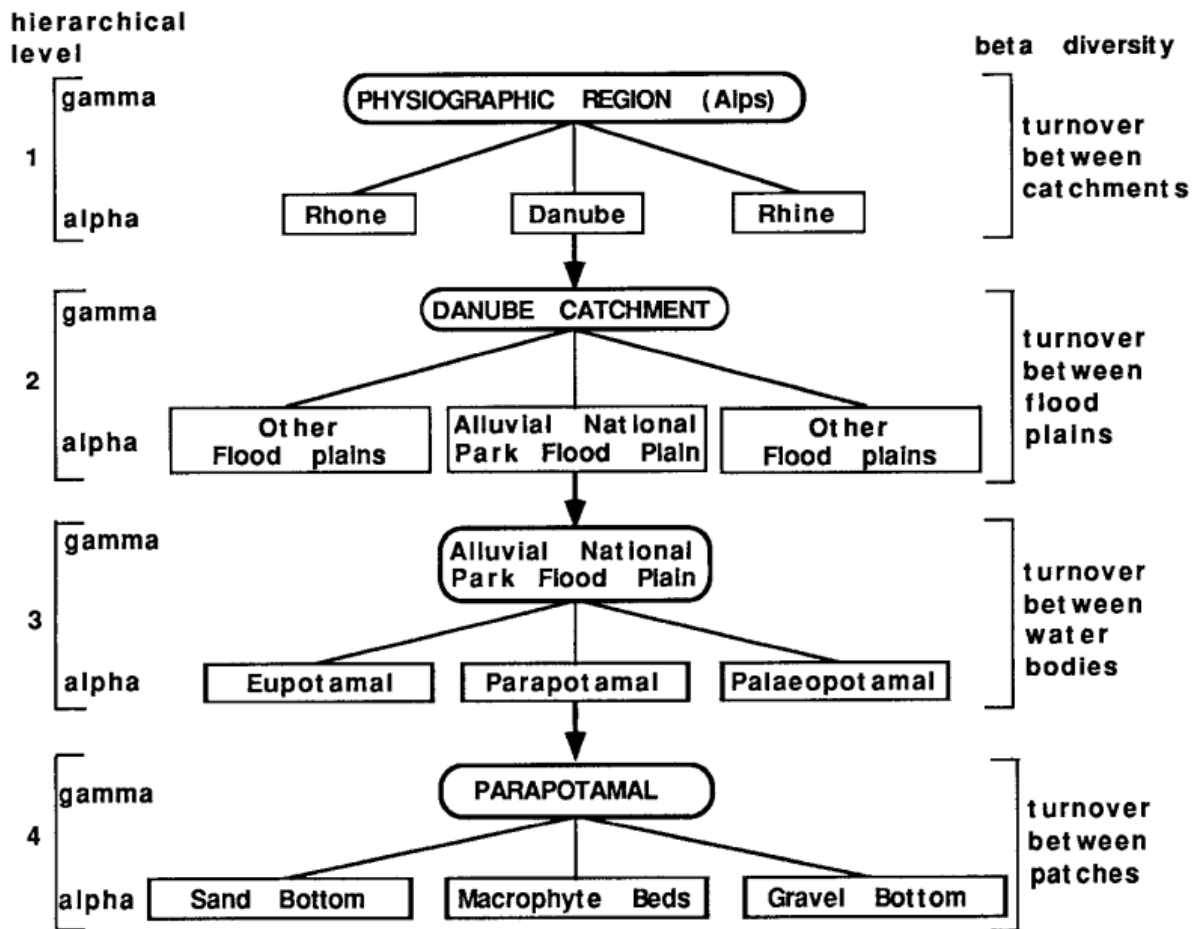
Figure 46 Example of an ecological hierarchy structure with alpha and gamma. (Ward, Tockner, and Schiemer 1999)

Out of the table on Fish the contribution of each lower level (alpha) to the higher level (gamma) for diversity has been extracted. This is shown in Figure 47. It shows that there is not very much difference in fish population between the depth classes of an ecotope. Also between ecotope classes there is not a lot of difference. The highest difference can be found on the ecotope group level. This means that for a high diversity both channels and river accompanying waters are needed. A good balance between these two is important for the total ecological quality of the river. The total area, or ratio between , of these two groups should be investigated to see what measures can help in improving the river ecological quality.
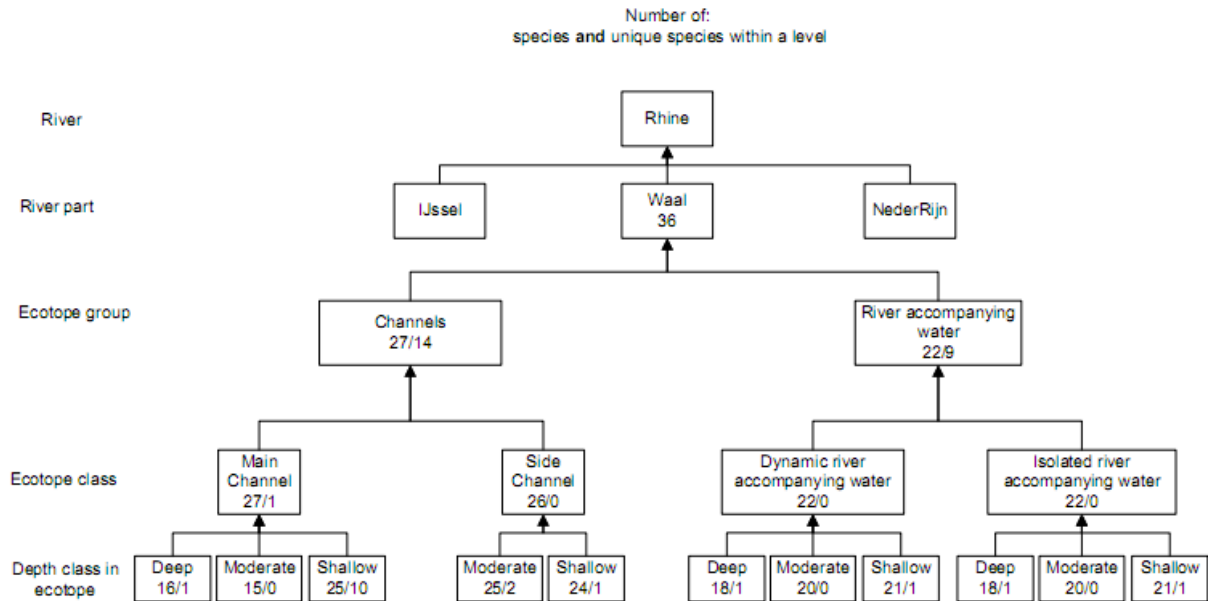
Figure 47 Alpha Beta Gamma tree for the river Waal. In each class two numbers are given. One for the total occurring species within that class and the other with the number of species in that class that is not found in the other classes (beta) on the same level (within the tree branch).

5.8 Usefulness of Geographical information

The results of the maps, tables and graphs show that it is possible to extract EQR metric values out of a standard ecotope map. GIS has an added value for the interpretation of the influence of measures on biota. This is because it enables to see where changes have occurred. This possibility to see *what* is changing *where* also enables us to identify problems in calculating EQR values with the method that has been used up to now. Without the graphical representations, errors caused by changes in water level possibly would not have been detected.

Another possibility introduced by the use of geographical data is that it is now possible to see, in pivot tables, not only the total area of ecotopes that have changed, but also which ecotopes changed into what ecotope and at what magnitude.

6 CONCLUSIONS

Reflecting on the main objective of this thesis and its research questions, we can conclude:

Main objective: *Develop a tool, using existing data, for the use of landscape elements within an ArcGIS environment to evaluate the ecological status of fish and aquatic vegetation in the river Rhine in the Netherlands.*

The main objective was met because the method as applied, using existing data, produces the same EQR values as calculated without geographical information.

Research question 1: *How can ecotopes be linked to biological quality element (fish, aquatic vegetation) metrics to evaluate landscape changes?*

It is possible to add quality indicators to ecotopes. This can be done by joining tabular data to the geographical patches. For future use, this can best be done by using a database.

Research question 2: *Is the current detail level of ecotope mapping suitable to support the assessment of fish and / or aquatic vegetation? Or should other data like height models and flooding frequency be incorporated in the model?*

The data sheets on fish aquatic vegetation already contain information on settlement factors that have not been used yet when making the ecotope maps. When this extra information layers will be added to the existing ecotope maps, thus creating more detailed ecotopes, the assessment can be made more precise. The method itself will not change.

Research question 3: *What is the best way of presenting results of the model?*

The answer to this question depends on the user. End users will prefer simple maps and graphs while researches will need the exact data values best reflected in tables.

The following additional conclusions can be drawn from the discussion:

GIS has an added value for the interpretation of the influence of measures on biota. Local changes can be seen in the produced maps.

To make a good comparison between two maps the water level should be normalised, eliminating area differences due to the water level. This has not been done yet in the current model without height information, which is likely to result in interpretation errors.

For fish not only the aquatic ecotopes are relevant but also the adjacent ecotopes which are being flooded occasionally. These ecotopes are relevant for the reproduction of certain types. The first results reached with the proposed method made it clear that only aquatic ecotopes are not enough for a good calculation of EQR values. Not only aquatic ecotopes should be used but also shore line ecotopes. They have a large influence on the results of the figures. To be able to do this additional research, it is necessary to develop metrics for calculating EQR values for this types of ecotope.

The shoreline index is a good tool for seeing how naturally the river is flowing. Water level is also important for this index when comparing different maps. This gives a good insight into the amount of natural shoreline in each different part of a river. This information can be used to see if measures are needed.

Extra model parameters like area ratio might be needed to improve the overall resolution. At this moment, the model does not allow EQR values below the ecotope with the lowest EQR value, or higher than the ecotope with the highest value. With the current knowledge, the spreading of these values is lower than the expected resolution in the EQR scale when comparing current data with reference data of before 1850.

7 LITERATURE

Buijse, A. D., F. Klijn, R.S.E.W. Leuven, H. Middelkoop, F. Schiemer, J.H. Thorp, and H.P. Wolfert. 2005. Rehabilitating large regulated rivers : Lowland River Rehabilitation Conference, September 29-October 3, 2003, Wageningen, the Netherlands. In , 738. Archiv for Hydrobiologie, v. 155, suppl. Stuttgart: Schweizerbart'sche Verlagsbuchhandlung.

Buijse, A. D., F.H. Wagemaker, J.S. Bouwhuis, and M. Ohm. 2008. *Verantwoordingsrapportage Afleiding Ecologische Doelen Rijkswateren*. Utrecht: Deltares.

Burrough, P., and R. Mcdonnell. 1998. *Principles of Geographical Information Systems*. Oxford University Press, USA, March 12.

de By, R. A.editor, R. A de By, P. Y Georgiadou, R. A Knippers, M. J Kraak, Y. Sun, M. J.C Weir, and C. J van Westen. 2004. *Principles of geographic information systems : an introductory textbook*. Third edition. Enschede: ITC.

Cabezas, A., F.A. Comin, S. Begueria, and M. Trabucchi. 2008. Hydrologic and land-use change influence landscape diversity in the Ebro River (NE Spain). *Hydrology and Earth System Schienced Discussions*, no. 5: 2759-2789.

Climate Change Science Program, and Subcommittee on Global Change Research. 2003. *The U.S. Climate Change Sciense Program: Vision for the Program and Highlights of the Scientific Strategic Plan*. Washington: Climate Change Science Program.

Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment* 37: 35-46. doi:10.1016/0034-4257(91)90048-B.

Coops, H., and R. Pot. 2008. Rekenregels voor macrofyten in grote rivieren. Voorspelling van verbetering van de ecologische toestand door herstelmaatregelen. Scirpus Ecologisch Advies, Weesp.

Coops, H., and R. Pot. 2009. Begroeibaar areaal van waterlichamen. Verhouding tot de referentie en berekening van de macrofyten-deelmaatlat Abundantie groeivormen. Scirpus Ecologisch Advies, Weesp.

van Dam, O. 2007. *Handboek hydromorfologie : monitoring en afleiding hydromorfologische parameters Kaderrichtlijn Water*. [Delft]: [Ministerie van Verkeer en Waterstaat], Directoraat-Generaal Rijkswaterstaat. http://www.helpdeskwater.nl/publish/pages/4595/eindversiehandboekhydromorfologi emeterratum.pdf.

Dehairs, F., A. Lausch, E. Müller, H. Thulke, U. Steinhardt, and S. Lehmann. 2001. Landscape Metrics for Assessment of Landscape Destruction and Rehabilitation. *Environmental Management* 27, no. 1: 91-107.

Duel, H., and M.J. Baptist. 2001. *Cyclic floodplain rejuvenation: a new strategy based on floodplain measures for both flood risk management and enhancement of the biodiversity of the river Rhine*. CFR project report;1. Delft: NCR. http://www.ncr-web.org/downloads/NCR14-2001.pdf.

Ellis, E.C., and H. Wang. 2006. Estimating area errors for fine-scale feature-base ecological mapping. *International Journal of Remote Sensing* 27, no. 21: 4731-4749.

European Parliament. 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0060:EN:HTML. (May 2009)

Geerling, G., A. Ragas, R. Leuven, J. Berg, M. Breedveld, D. Liefhebber, and A. Smits. 2006. Succession and Rejuvenation in Floodplains along the River Allier (France). *Hydrobiologia* 565 (July): 71-86. doi:doi:10.1007/s10750-005-1906-6.

Gergel, S.E., M.G. Turner, J.R. Miller, J.M. Melack, and E.H. Stanley. 2002. Landscape indicators of human impacts to riverine systems. *Aquatic Sciences* 64.

Grift, R.E. 2001. How fish benefit from floodplain restoration along the lower River Rhine. PhD Thesis, Wageningen University. http://library.wur.nl/wda/dissertations/dis3045.pdf.(January 2010)

van Halderen, L. 2005. Vergelijking tussen de interpolatiemethodes DIGIPOL, SURFIS en KRIGING. Rijkswaterstaat.

Hebinck, K.A. 2008. *Databank van de lithografische opbouw en morfologische ontwikkeling van de uiterwaarden van de Midden-Waal*. Alterra-rapport;1678. Wageningen: Alterra. http://library.wur.nl/way/bestanden/clc/1877526.pdf.

Janssen, J.A.M., and B. van Gennip. 2000. De oude grenzen methode : een manier om betrouwbaar veranderingen in landschap en vegetatie te monitoren op basis van luchtfoto-karteringen. *Landschap* 17, no. 3/4: 177-186.

Johnson, W.C. 1997. Equilibrium response of riparian vegetation to flow regulation in the Platte river, Nebraska. *Regulated rivers: Reserach & Management* 13: 403-415.

Jones, K.L., G.C. Poole, J.L. Meyer, W. Bumback, and E.A. Kramer. 2006. Quantifying Expected Ecological Response to Natural Resource Legislation: a Case Study of Riparian Buffers, Aquatic Habitat, and Trout Populations. *Ecology and Society* 11, no. 2. http://www.ecologyandsociety.org/vol11/iss2/art15/.

Kerle, N., L. L.F.editor Janssen, G. C. Huurneman, W. H Bakker, K. A Grabmaier, G. C Huurneman, F. D van der Meer, et al. 2004. *Principles of remote sensing : an introductory textbook*. Third edition. Enschede: ITC.

Kroes, M.J., F.T. Vriese, and W.A.M. Emmerik. 2007. Vis in stromende wateren. Rijkswaterstaat.

Lacroix, V., M. Idrissa, A. Hincq, H. Bruynseels, and O. Swartenbroekx. 2004. SPOT5 images for urbanization detection. PRL(27), No.4, March 2006, pp. 226-233.

Lausch, A., and F. Herzog. 2002. Applicability of landscape metrics for the monitoring of landscape change: issues of scale, resolution and interpretability. *Ecological Indicators*.

Law, M. 2008. *ESRI Map Book, Volume 23*. Redlands: ESRI Press, August 1.

Leuven, RSEW, Y Gerig, I Poudevigne, GW Geerling, L Kooistra, and BGW Aarts. 2002. Cumulative impact assessment of ecological rehabilitation and infrastructure facilities in floodplains along the middle reach of the River Waal. *Application of geographic information systems and remote sensing*: 201-216.

Middelkoop, H., E. Stouthamer, M.M. Schoor, H.P. Wolfert, and G.J. Maas. 2003. *Kansrijkdom voor rivierecotopen vanuit historisch-geomorfologisch perspectief : Rijntakken, Maas, Benedenrivieren*. NCR-publicatie;21. Delft: NCR.

van der Molen, D.T, and R. Pot. 2007. *Referenties en maatlatten voor natuurlijke watertypen voor de Kaderrichtlijn water*. RWS-WD;2007 018. Utrecht: STOWA. http://library.wur.nl/ebooks/STOWArapporten/1891766.pdf.

van der Molen, D.T., H.P.A. Aarts, J.J.G.M. Backx, E.F.M. Geilen, and M. Platteeuw. 2000. *Rijkswateren-ecotopen-stelsels: RWES aquatisch*. Rapport / RIZA;2000.038. Lelystad [etc.]: Ministerie van Verkeer en Waterstaat, Directoraat-Generaal Rijkswaterstaat, RIZA Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling.

van der Molen, D.T., N. Geilen, J.J.G.M. Backx, B.J.M. Jansen, and H.P. Wolfert. 2002. Water ecotope classification for integrated water management in the Netherlands. *European water management online*. http://www.ewaonline.de/journal/2003_03.pdf.

Mortel, J.H. van de. 2005. *Samen werken aan de Midden Waal. Alternatieven voor rivierverruiming tussen Nijmegen en Tiel*. Meerssen: Groen-planning Maastricht b.v.

Nagel, W. 1998. De beschikbaarheid van ondergelopen terrestrische vegetatie als habitat voor vissen langs nevengeulen in de Waal. In , 35. RIZA. werkdocument 98.157X. Lelystad [etc.]: RIZA, Inrichting & Herstel, taakveld ecologie, 6.

Nat, D. van der, A.P. Schmidt, K. Tockner, P.J. Edwards, and J.V. Ward. 2002. Inundation Dynamics in Braided Floodplains: Tagliamento River, Northeast Italy. *Ecosystems*, no. 5: 636-647. doi:10.1007/s10021-002-0170-0.

Rijkswaterstaat. 2008. Beheer- en Ontwikkelplan voor de Rijkswateren 2010-2015; Programma Rivieren en Kanalen; Waterbeheer 21ste eeuw, KRW en Natura 2000. Rijkswaterstaat.

Schiemer, F., H. Keckeis, W. Reckendorfer, and G. Winkler. 2001. The 'inshore retention concept' and its significance for large rivers. *Archive for Hydrobiology*, no. 135: 509-516.

Stalzer, W, and H Bloch. 2000. Preface: The Austrian Approach. *Springer Netherlands* 422-423, no. 0. Hydrobiologia: 19-22.

Stehman, S.V., and T.R. Loveland. 2005. An evaluation of sampling strategies to improve precision of estimates of gross change in land use and land cover. *International Journal of Remote Sensing* 26, no. 22: 4911-4957.

Waarden, J.A. van. 2009. *Writing to survive : a commentary on Sidonius Apollinaris, Letters Book 7, volume 1: The episcopal letters 1-11 Johannes Alexander van Waarden*. Krommenie: van Waarden.

Wang, H., and E.C. Ellis. 2005. Image misregistration error in change measurements. *Photogrammetric Engineering & Remote Sensing* 71: 1037-1044.

Ward, J.V., K. Tockner, and F. Schiemer. 1999. Biodiversity of floodplain river ecosystems: Ecotones and Connectivity. *Research & Management* 15. Regulated Rivers: 125-139.

Willems, D., J. Bergwerff, and N. Geilen. 2007. *RWES Terrestrisch : actualisatie ecotopenindeling van de periodiek tot zelden overstroomde en overstromingsvrije zones langs de rijkswateren*. RIZA;2007.030. [S.l.]: RIZA. http://www.watermarkt.nl/wm_user_files/File/watermarkt/publicaties/RWES%20Terrestrisch.pdf.

Yue, T.X., J.Y. Liu, Z.Q. Li, Y.Z. Tiana, and F. Gec. 2004. Diversity indices and spatial scales greatly effect the conclusions of relationships between biodiversity and ecosystem functions. http://www.millenniumassessment.org/documents/bridging/papers/yue.tianxiang.pdf. (August 2009)

8 TABLE OF FIGURES, EQUATIONS AND TABLES

Figures

Equations

Tables

9 APPENDICES

9.1 Types of measures and their influence on ecotopes

To obtain a better Ecological status measures can be implemented. For rivers these measures can be various but all strive to make the ecological status better. This can be for all topics monitored or only for one or some of them. A fish step for example will possibly improve the fish metric for some migrating fish but it will not change anything for the vegetation or chemical metrics.

In this research the EQR is measured by using ecotopes.
Therefore the influence of measures on the ecotopes is important. And not the possible direct improvements from measures on metrics without influencing the ecotopes. This for example is the case with a fish staircase. Below an overview of the main measure types and their impact on ecotopes (interview M. Verschoor).

Nature friendly banks.
By making hard cover banks or very steep banks soft and less steep they are more suitable for vegetation and also for fish. When this type of measure is implemented large enough for the mapping resolution it will indicate ecotopes with better potential EQR values.

Connecting pools and old disconnected river stretches.
The connection can be made at one side or at two sides. Depending on this the ecotope will change in a different type with other EQR values.

Lowering washlands.
Lowering the washland will result in a longer period of being submerse. This will have its influence on the fish and vegetation. For the ecotope map is mapped out of aerial maps in the summer it could be that this type of measure is not depicted well in the ecotope map. Adding height information will improve this.

Restore connection with regional streams.
This is good for some types of fish as they can reproduce in these streams. In the ecotope map and therefore in the derived EQR there will not be any difference.

Construct connected single or double attached adjacent streams.

The EQR value in these kind of adjacent streams is better than in the summer bed and will enlarge the total area of aquatic ecotopes.

Decontamination of the bottom.

A cleaner bottom will improve the situation for vegetation and fish. It will not show in the ecotopes and can only be deflected in the results if the data sheet with EQR values per ecotope gives higher values.

Seepage marsch and helophyt marsch lands.

This type of measure can be obtained by lowering wash lands. The ecotopes will change but the new ecotopes are not aquatic and will therefore not be included in the total EQR calculation.

Lock and sluice regime.

By controlling the water level with a lock and sluice regime it will be possible to change the vegetation types and land cover. Only when this has a large influence it will show up in difference of ecotopes.

Lowering washlands to create dynamic pools.

This measure will show up in the aquatic ecotopes and will therefore add to the ecological status EQR.

Making pools less deep.

By making deep pools less deep vegetation will have more possibilities tp grow. A possible side effect is the less steep banks that also result in better opportunities for vegetation. In the ecotope map there is at this moment no difference between deep end shallow pools. Therefore it will have no influence on the total EQR score. It can also turn out in a lower score for less water surface area will be mapped as the pools are smaller.

9.2 Interviews

Table 21 Interview list

| Name	Institute	Topic
Tom Buijse	Deltares	Overview topic and hints on literature and key persons.
Margriet Schoor	Rijkswaterstaat WD	Overview topic, measures, old map ecotopes and hints on literature.
Twan van der Beld	Deltares	Fish and their habitat
Gerben van Geest	Deltares	Vegetation and their habitat
Marjolein Haasnoot	Deltares	Habitat tool
Gertruud Houwkes	Rijkswaterstaat DID	Landscape element map production
Ellis Penning	Deltares	Hints on literature
Erwin Meijers	Deltares	KRW viewer tool
Gerjan Geerling	Deltares	GIS

9.3 ArcGIS flow diagrams
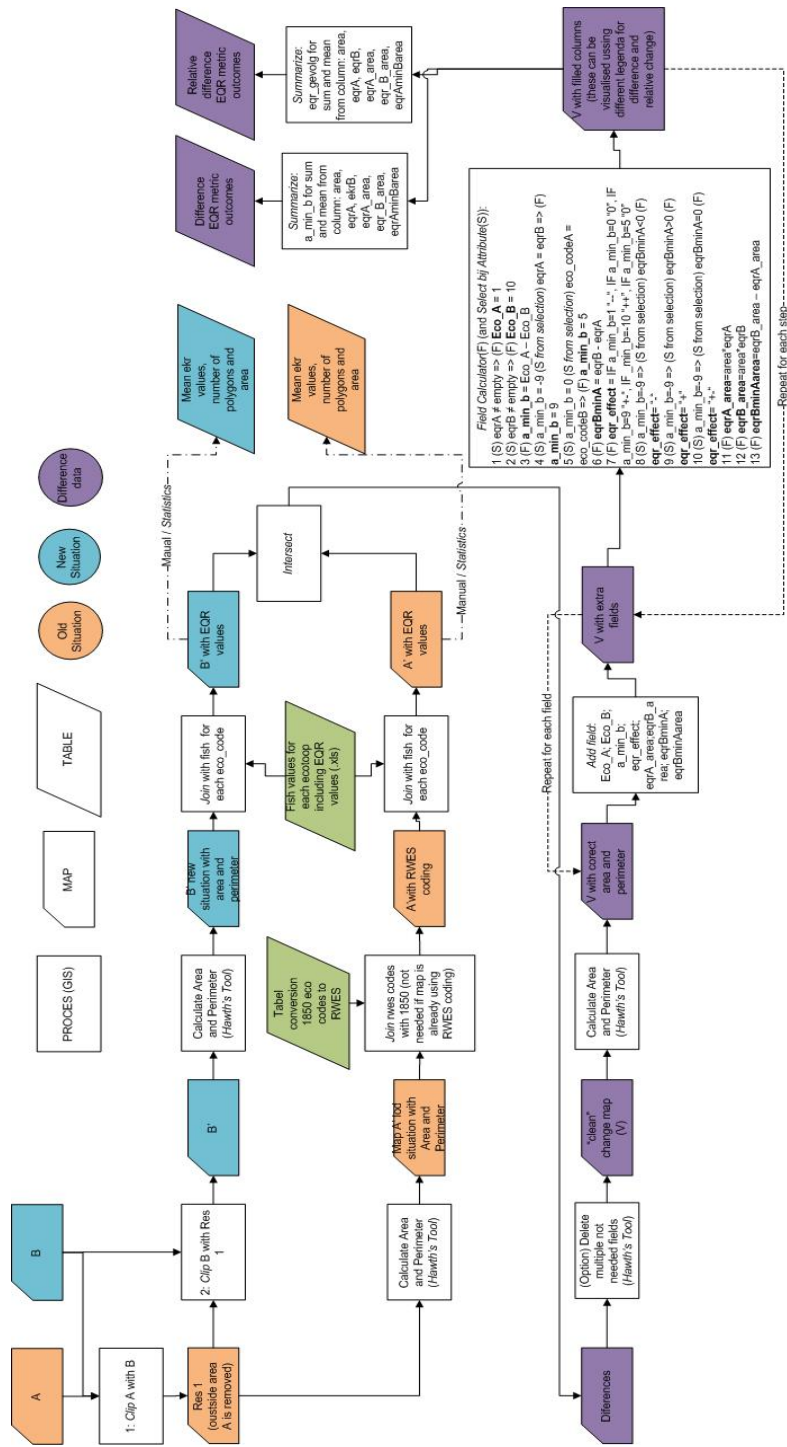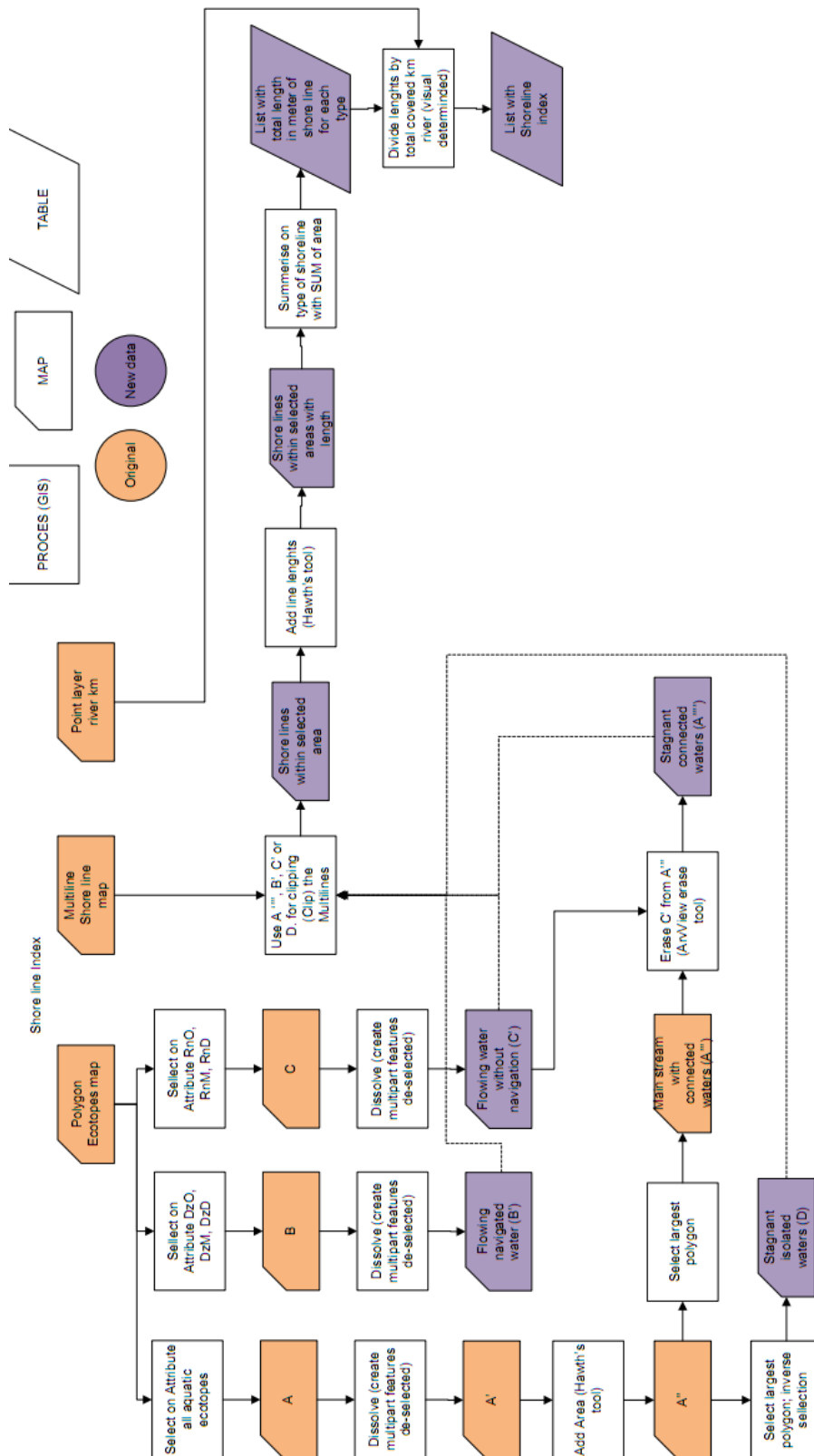
Figure 48 ArcGIS workflow ecotope map comparisation

Figure 49 ArcGIS workflow for calculating the shoreline index

9.4 Area ratios 1780-1830-1997-2004

Legend

Rv	Dynamische str river accompanying water >20d
Rw	Gesloerde str river accompanying water <20d
Rz	Hoofd stroom / main channel
Rn	Nevengeul / Side channel

Tabel1 — % from total aquatic area

32km	1780	1830	1997	2004
Rv	10%	4%	16%	15%
Rw	0%	5%	14%	17%
Rz	89%	91%	71%	69%
Rn	0%	0%	0%	0%

Tabel2 — Mean before and after

32km	1780/1830	1997/2004
Rv	7%	15%
Rw	2%	15%
Rz	90%	70%
Rn	0%	0%

Tabel3 — % from total aquatic area

32km	1780	1830	1997	2004
RvD	1%	1%	14%	13%
RvM	7%	2%	2%	1%
RvO	3%	1%	0%	0%
RwD	0%	2%	4%	6%
RwM	0%	3%	9%	10%
RwO	-	-	1%	1%
RzD	86%	82%	62%	63%
RzM	3%	9%	7%	5%
RzO	0%	0%	2%	1%
Rn	0%	0%	0%	0%

Tabel4 — % from total aquatic area adjusted RzD with profile %

32km	1780	1830	1997	2004
RvD	1%	1%	14%	13%
RvM	7%	2%	2%	1%
RvO	3%	1%	0%	0%
RwD	0%	2%	4%	6%
RwM	0%	3%	9%	10%
RwO	-	-	1%	1%
RzD	12%	11%	62%	63%
RzM	47%	51%	7%	5%
RzO	31%	29%	2%	1%
Rn	0%	0%	0%	0%

Tabel5 — Mean before and after (incl % profiles)

32km	1780/1830	1997/2004
RvD	1%	14%
RvM	5%	1%
RvO	2%	0%
RwD	1%	5%
RwM	2%	9%
RwO	-	1%
RzD	12%	63%
RzM	49%	6%
RzO	30%	1%
Rn	-	0%

Tabel6 — % within group

32km	1780	1830	1997	2004
Rv RvD	5%	15%	89%	90%
RvM	65%	60%	10%	9%
RvO	30%	25%	1%	1%
Rw RwD	12%	38%	28%	36%
RwM	88%	62%	64%	59%
RwO	-	-	8%	4%
Rz RzD	97%	90%	88%	92%
RzM	3%	10%	10%	7%
RzO	0%	0%	3%	1%
Rn	0%	-	-	100%

Tabel7 — % within group with adjusted RzD with profile %

32km	1780	1830	1997	2004
Rv RvD	5%	15%	89%	90%
RvM	65%	60%	10%	9%
RvO	30%	25%	1%	1%
Rw RwD	12%	38%	28%	36%
RwM	88%	62%	64%	59%
RwO	-	-	8%	4%
Rz RzD	13%	12%	88%	92%
RzM	52%	56%	10%	7%
RzO	35%	32%	3%	1%
Rn	-	-	-	100%

Tabel8 — Mean before and after (incl % profiles)

32km	1780/1830	1997/2004
Rv RvD	10%	90%
RvM	62%	10%
RvO	28%	1%
Rw RwD	25%	32%
RwM	75%	62%
RwO	-	6%
Rz RzD	13%	90%
RzM	54%	8%
RzO	33%	2%
Rn	-	x

Total aquatic area (1997 and 2004 ajusted from 80 to 32 km)

1780	15.694.102	unknown waterlevel
1830	18.624.332	unknown waterlevel
1997	18.794.065	known level
2004	17.870.022	known level 1.8m less then 1997
1780/1830	17.159.217	mean from two years
1997/2004	18.332.044	mean from two years

River length

	1780/1830	1997/2004
river	32	80
in a straight line	30	67

% Rz according to 1800 profiles 7.2 river km

RzD	14%
RzM	51%
RzO	36%

Table 22 Tables for the area ratios between 1780, 1830, 1997 and 2004

9.5 Used software

Microsoft Word 2007

Microsoft Excel 2007

Microsoft Visio 2007

ESRI ArcGIS, ArcMap 9.3 (Desktop ArcView licence)

ArcMap extensions:

 Hawths tool: Beyer, H. L. 2004. Hawth's Analysis Tools for ArcGIS.

http://www.spatialecology.com/htools.

ArcView Erase Tool: Jones, S.M. 2007.

http://arcscripts.esri.com/details.asp?dbid=14625

ET GeoWizards: Tchoukanski, I. 2009. ET Spatial Techniques. http://www.ian-ko.com

9.6 List of shoreline types

Table 23 Shoreline types

	Shoreline type
1	Grass
2	Helophyte
3	Bare unpaved
4	Bare unpaved caused by erosion
5	Trees
6	Pioneer vegetation
7	Scrubs
8	Roughness
9	Shells
10	Paved (groins)
11	Shoreline protection with scrubs
12	Shoreline protection without scrubs
13	Protection with scrubs
14	Protection without scrubs

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