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ECOSYSTEM SERVICES IN THE WUPPER CATCHMENT (NORTHRHINE WESTPHALIA, GERMANY)

Assessment and Comparison

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Ecosystem Services in the Wupper Catchment (Northrhine Westphalia, Germany) –Assessment and Comparsion

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Abstract

Ecosystem services are defined as the provided and potential functions of an ecosystem which are effectively realized regarding human benefits (Maes et al., 2012). According to Target 2, Action 5 of the EU Biodiversity Strategy, member states are requested to map and assess ecosystem services (CBD 2010). In contrast to water quality monitoring, an ecosystem service assessment is not only referring to the state but the actual functions and processes within an ecosystem. The objective of this thesis is to perform an initial assessment of water-related ecosystem services in the Wupper catchment, (North Rhine-Westphalia, Germany) which is highly modified by numerous dams. Therefore, the ecosystem service drinking water provision, habitat provision, water purification and tourism & recreation were assessed. The general level of drinking water provision and habitat provision is relatively low, whereas water purification shows slightly higher scores. The high scores of tourism & recreation are more concentrated on the Wupper than on the 21 tributaries. Also, the ecosystem services were investigated within a use profile. There, no direct correlations were found among the 52 management sections of the Wupper catchment. Furthermore, the water quality as assessed under the Water Framework Directive does not correlate with the ecosystem services. Lastly, ecosystem services are compared by stream characteristics, such as heavily modified and natural water bodies, river type as well as management sections with or without dams. While the modified of water bodies did not show significant correlations with ecosystem services, a correlation of drinking water provision and tourism & recreation in management sections with dams was found. Additionally, land use was taken into account. It was shown that, in management sections without dams, water purification correlates negatively with urban areas ($R^2 = 0.36$). When considering dams, several positive (synergies) and negative (trade-offs) correlations of ecosystem services and land use categories were found. Hence, this study provides the first explicit analysis of several ecosystem services for a multi-use river catchment in Germany.

Danish Summary of the thesis

Økosystemtjenester er defineret som de funktioner af et økosystem som menneskeheden kan drage til fordel (Maes et al., 2012) Ifølge Target 2, action 5 i EU biodiversity strategy, anmodes medlemsstaterne om at kortlægge og vurdere økosystemtjenester (CBD 2005). Formålet med denne afhandling er at udføre en indledende vandrelateret vurdering af økosystemtjenester i Wupper oplandet, (Nordrhein-Westfalen, Tyskland), der er stærkt påvirket af en lang række dæmninger. Derfor er tilgængeligt drikkevand, habitater, vandrensning og turisme & rekreation først vurderet. Den generelle mængde af tilgængeligt drikkevand og habitater er relativt lav, mens vandrensning viser lidt højere score. De høje scores for turisme og rekreation er mere koncentreret i Wupper end i de 21 bifloder. For det andet blev økosystemtjenester undersøgt indenfor en anvendelsesprofil. Her blev ingen direkte korrelationer fundet blandt de 52 sektioner af Wupper oplandet. Desuden korrelerer vandkvaliteten i henhold til vandrammedirektivet ikke med økosystemtjenester. For det tredje er økosystemtjenester sammenlignet med karakteristikker, såsom stærkt modificerede og naturlige vandområder, vandløbstypen samt sektioner med eller uden dæmninger. Mens stærkt modificerede og naturlige vandområder ikke viste signifikante korrelationer blev en korrelation af drikkevand og turisme & fritid i områder ved dæmninger fundet. Endvidere blev arealanvendelsen taget i betragtning. Det blev vist, at i sektioner uden dæmninger, korrelerer vandrensning negativt med byområder (R^2 = 0.36). Når man tager dæmninger i betragtning, er flere positive (synergier) og negative (trade-offs) korrelationer af økosystemfunktioner og arealanvendelseskategorier fundet.

Preface and Acknowledgements

This document represents the master thesis performed at the Aalborg University in Denmark (AAU) in cooperation with the Leibniz-Institute of Freshwater Ecology and Inland Fisheries in Germany (IGB). It is written during the summer term 2016 within the master's study programme "Water and Environment" of the Department of Civil Engineering at AAU. The content of the master thesis is composed after the actual study and examinations regulation of the corresponding programme (Aalborg University, 2015) and written individually as proof of academic achievement of 30 ECTS.

All chapters throughout the thesis are enumerated consistently, whereby references are shown in brackets by author (one or more persons, organizations) and the year of publication corresponding to the Harvard-method. If the reference is implemented in the sentence, it is directly referred to the information of the sentence. When referring to tables, pictures and appendices, the location can be identified by the continuous numbering corresponding to their chapters. Appendices are marked alphabetically according to their order of appearance.

I would like to thank both of my supervisors, Dr. Morten Lauge Pedersen (AAU) and PD Dr. Martin Pusch (IGB) for a lot of advice, proofreading and inspiration for working tasks and structures of the thesis. Special thanks go to my co-supervisor M.Sc. Simone Beichler (Co-supervisor, IGB), who spend a lot of time with me to figure out and heal my stoppages throughout the whole working procedure. I would have stocked in several ways if I did not achieve such good advice and motivation. I'm grateful for the given opportunity to work on that project in a close collaboration with the IGB. It has been an honour for me to be part of their teams and to have the chance to get an inside view on the working atmosphere in a research institute. I would like to express my special gratitude to all members of the working group at the IGB who supported me during complicated periods of writing and criticized honestly the intermediate results of my work. Additionally, I would like to thank to the Wupperverband for providing data within the frame of the RESI project. For proofreading and especially the emotional support, I give thanks to Olaf Seidenfaden who had to ride this semester out with me and I know that it was not always the easiest task. And last but not least, I wish to thank to my parents for their financial support and for making it possible for me to attend an education in Aalborg University.

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List of Abbreviations

AAU	Aalborg University
ACP	General chemical and physical parameters
AS	aquatic structure classes
BKG	Federal Agency for Cartography and Geodesy of Germany
C	Cropfields
CBD	Convention on Biological Diversity
CICES	Common international Classification of Ecosystem Services
CORINE	Coordination of Information on the Environment
EEA	European Environment Agency
ESS	Ecosystem Services
F	Forests
FFH	Flora-Fauna-Habitat-Directive
G	Grasslands
HMWB	Heavily modified water bodies
IGB	Leibniz-Institute of Freshwater Ecology and Inland Fisheries
JRC	Joint Research Centre
LANUV	State Agency for Nature, Environment and Consumer Protection of the State of North Rhine-Westphalia
MA	Millennium Ecosystem Assessment
MKNLUV	The Ministry for Climate Protection, Environment, Agriculture, Conservation and Consumer Protection of the State of North Rhine-Westphalia
MP	Macrophytes
MS	Management sections
MZB	Macrozoobenthos
NPZ	Nature protection zone
NWB	Natural water bodies
PBSM	plant protection products
POI	Points of interest
QGIS	Geographic Information System
RESI	River Ecosystem Service Index
TEEB	The Economics of Ecosystems and Biodiversity
U	Urban areas
W	Water bodies
WFD	Water Framework Directive
WPZ	Water protection zone
WV	Wupperverband
WWTP	Wastewater treatment plants

1. Introduction and Research Hypotheses

Rivers and their floodplains represent a highly diverse landscape, which includes terrestrial, semiaquatic and aquatic ecosystems. River corridors are subject to multiple uses, such as agriculture, navigation and hydropower generation. At the same time, river corridors have the potential to provide various ecosystem services and therewith contribute to the human wellbeing. Often, rivers and floodplains are technically modified, for example by the construction of dams and reservoirs in order to suit particular uses (Rouquette et al., 2011). The intensive use of these limited resources leads to increasing pressures on the environment decreasing biodiversity and increasing problems related with climate change. This often leads to conflicts in the use of dams and their environment as well as in the rivers further downstream (Morris et al., 2009). Since the Wupper catchment in North Rhine-Westphalia belongs to a region with the highest densities of dams and reservoirs in Germany, this study area was chosen to be investigated in this thesis.

Even though this concept was already part of a landscape research in the end of the 20th century (e.g. Daily, 1997; Costanza et al., 1997) ecosystem services became increasingly popular after the publication of the international Millennium Ecosystem Assessment (MA, 2005). The European breakthrough was mainly driven by the direct inclusion in the new 10-year Strategic Plan of the Convention on Biological Diversity (CBD, 2010), wherein the ecosystem services are considered to support the preservation of biodiversity. According to the plan the EU-member states are now obliged to map and assess the ecosystem services on a national basis.

Ecosystems and their services provide the basis for human wellbeing and existence. The ecosystem service concept provides a framework to describe the benefits people obtain from ecosystems (MA, 2005). As such, the ecosystem service approach focusses on the relation between ecosystems and human wellbeing. Therewith the ecosystem services concept can enhance the understanding of interactions within social-ecological systems, in order to understand how changes in land use could affect the services obtained by society (MA, 2005; Sukhdev et al., 2010). A well-known concept in the research of ecosystem services is the cascade after de Groot et al. (2010). There, the biophysical structure and processes have to be considered as the status of the current ecosystem. The ecosystem function then describes the capacity of ecosystems providing services directly and indirectly for human usage. The actual usage of ecosystem services creates benefits which are transferable into economic, monetary or non-monetary values (de Groot et al., 2010). Hence, ecosystem services are the linkage of the natural system and the socio-economic system (de Groot et al., 2010; Sukhdev et al., 2010). In this context, the benefit for society can be described by the diverse use of ecosystems, such as rivers and their floodplains (Grizzetti et al., 2015). Accordingly, this thesis analyses different use-profiles of the management sections in the Wupper catchment.

There are multiple ecosystem service frameworks, classifications and assessment approaches (for review see Hermann et al.(2011)). In general, ecosystem services should be assessed comprehensively in order to ensure that not only the obvious services but also the more indirect and less obvious ones, such as habitat provision, water purification or greenhouse gas storage, are considered (Scholz et al., 2012).

In recent times, the first attempts were made to standardize the methods of ecosystem assessments. The European Joint Research Centre (JRC) provided a Common International Classification of Ecosystem Services (CICES), in which the following three main ecosystem service groups provision, regulation and maintenance as well as cultural services cover a comprehensive list of ecosystem services (Haines-Young and Potschin, 2013). Provisioning ecosystem services refer mainly to products that can be gathered from the ecosystem, for instance cereals, timber, animal products as well as water extracted for different purposes. Regulation and maintenance services refer to benefits obtained through the regulation of environmental conditions, such as flood regulation, local climate regulation or even the lifecycle regulation related to provision of habitats. The group of cultural ecosystem services includes the nonmaterial benefits people obtain through experiences, recreation and tourism. (MA, 2005; Haines-Young and Potschin, 2013)

Figure 1: Reservoir in the Wupper catchment and surrounding landscape (online source: Wupperverband 2016a).

For the purpose of ecosystem service assessments, there are multiple lists of proposed indicators (e.g. Egoh et al., 2012; Grizzetti et al., 2015; Burkhard et al., 2014). Therefore, an exploration of appropriate and available indicators is required. Thereby, the scale has to be considered since a national assessment focusses on different indicators than a regional assessment, such as this thesis in the Wupper catchment.

The overexploitation or mismanagement of ecosystem services, can lead to habitat loss, urbanization and pollution, placing a great pressure on rivers and their floodplains (Long et al., 2015). It was shown that ecosystem services, such as habitat provision and flood regulation, are in danger and their decrease could lead to serious economical disadvantages (Sukhdev et al., 2010). In the Wupper catchment, a high number of technical constructions, a high level of urbanization and corresponding high population density can be found. These characterize the serious pressures that are put on river corridors in the study region, which could lead to a decrease in ecosystem services and therewith human wellbeing.

This thesis aims to assess water-related ecosystem services for the first time in this study area. Hereby, on the one hand the influence of the structural characteristics of the water bodies and floodplains on the provision of ecosystem services is analysed. On the other hand, use-profiles are developed in order to show potential relations between ecosystem services. For the spatial assessment of ecosystem services, a non-economic valuation approach was chosen using five classes in order to focus on quality aspects and not on the monetarization. The assessment is based on indicators proposed in different studies, which are adjusted to the scale and characteristics of the study area. Hence, during method development, the indicators and classes for valuation were modified.

The study focusses on four ecosystem services, which represent the three main ecosystem service groups according to CICES, namely drinking water provision, habitat provision, water purification and tourism & recreation. These ecosystem services were chosen as they play a major role in the Wupper catchment and are of special interest concerning conflicts in use-profiles. In the context of this thesis the following key hypotheses covering the four selected ecosystem services were elaborated:

1. Ecosystem services in the Wupper catchment are distributed unequally among the management sections.
2. The use-profiles of management sections with dams are only dominated by the ecosystem service tourism & recreation.
3. The assessments of the four selected ecosystem services show trade-offs with characteristics of the management sections.

2. Area Description of the Wupper Catchment

The present study area focuses on the catchment of the Wupper river in North Rhine Westphalia (Germany). The Wupper is a right-side tributary to the Rhine with a length of 115°km, which itself receives 21 streams as tributaries, including 4 streams discharging to its only major tributary, the Dhünn river (Figure 2). Its source is located in a part of the German uplands called Oberbergisches Land at about 475 m above sea level (MKNULV and LANUV, 2015)

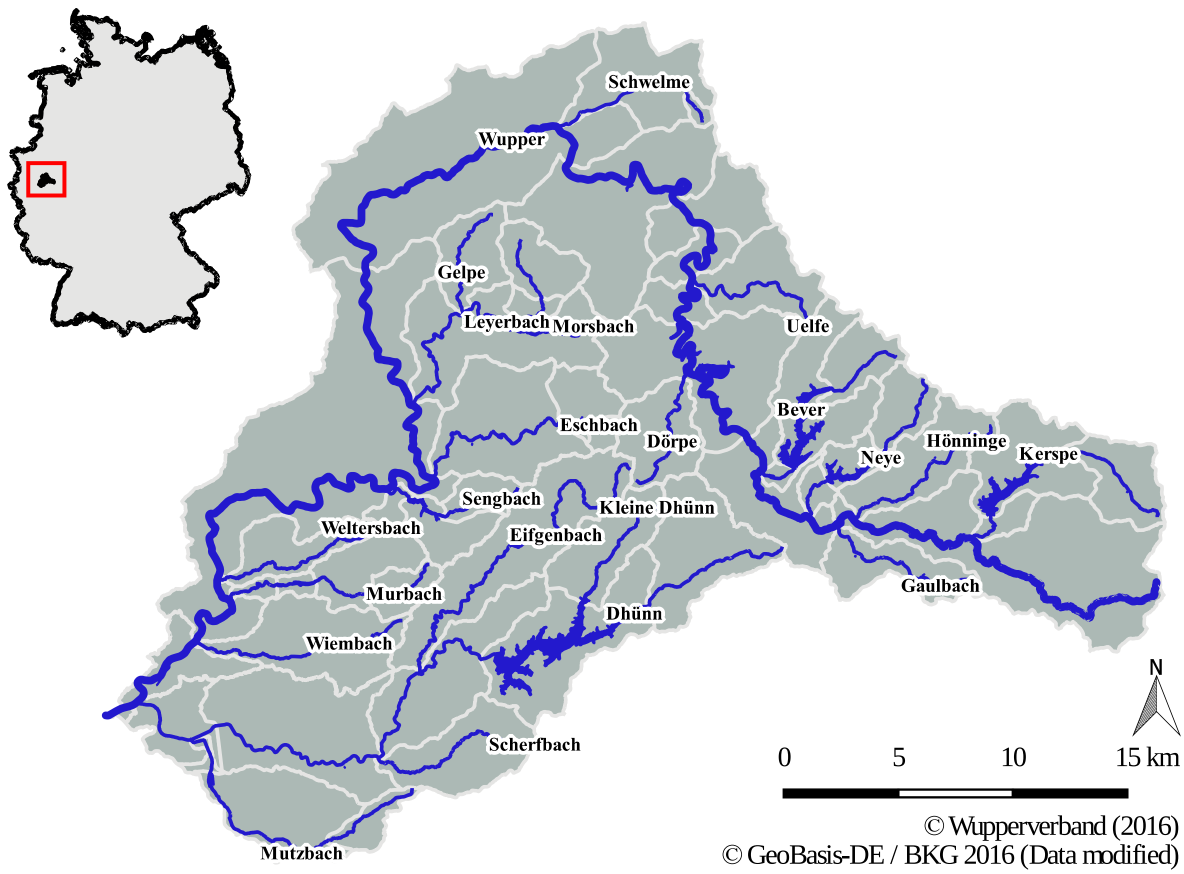

Figure 2: The Wupper catchment and its river system as considered under Water Framework Directive (catchment > 10 km²)

The catchment area of 814 km² includes a part of the German uplands that are known as one of the rainiest areas in Germany, where precipitation reaches up to 1388 mm/a. In contrast, the lower parts of the catchment near the Rhine only receive 754 mm/a of precipitation (MKNULV and LANUV, 2015). For several purposes, 17 dams and reservoirs have been constructed in that catchment with a volume of 165.9 Mio m³, as for flood regulation, low flow enrichment, hydropower or drinking water purposes. In the following chapters of this thesis, the term dam included both dams and reservoirs. The major tributary Dhünn is impounded by the Dhünn-Talsperre, which is the largest dam for drinking water extraction supplying half a million inhabitants with water. The high density of dams in the Wupper catchment, especially in the headwaters, is unique in Germany and strongly shapes the characteristics of the river system. (MKNULV and LANUV, 2015)

With a population density of 1040 people per km², the Wupper catchment represents a densely populated area in Germany. Thereby, urban area is mostly concentrated at the four larger cities located in the catchment area (Figure 3). with 100.000 to 345.000 inhabitants (IT.NRW 2016; Currency Dec.2014) which are surrounded by relatively natural landscape. The land cover map of the catchment clearly shows the unequal distribution of land use (Figure 3).

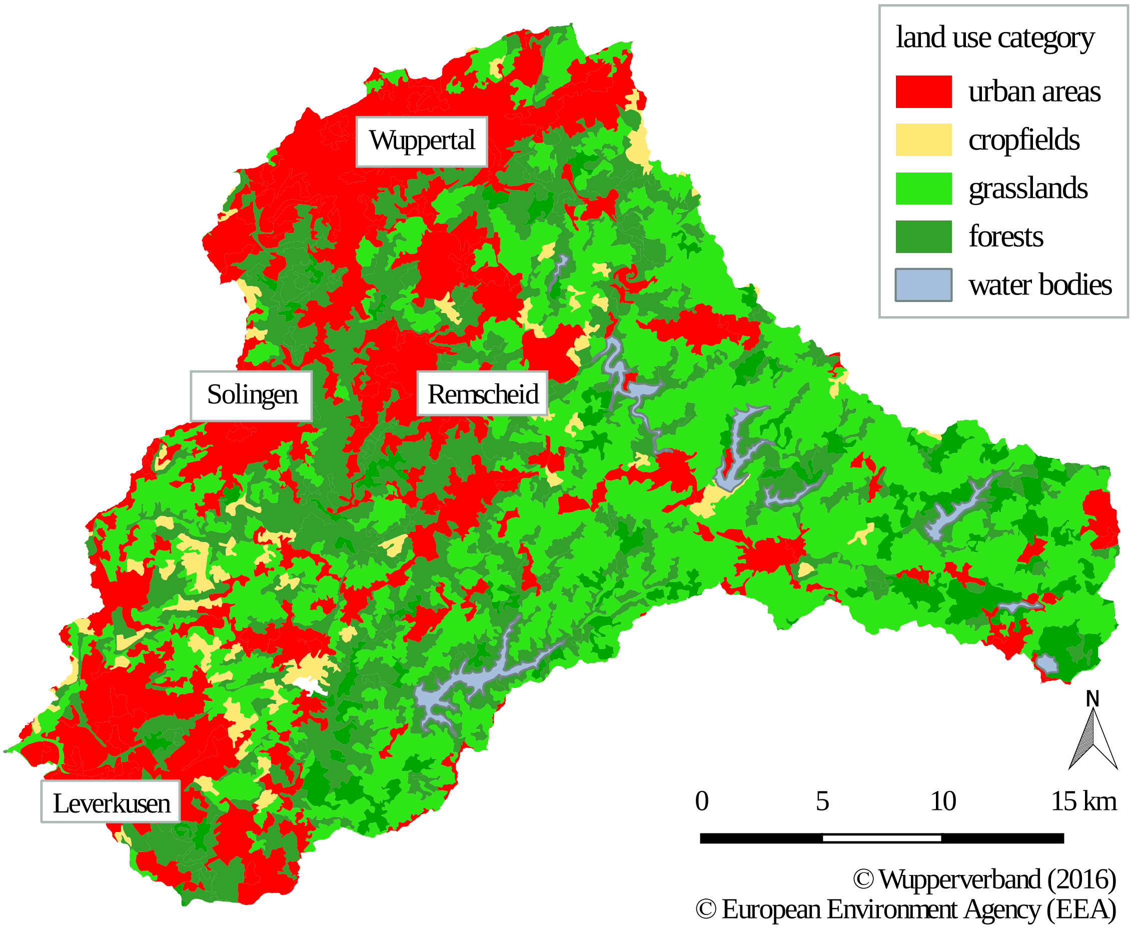

Figure 3: Land use categories, formed by the use of CORINE Land Cover Data 2012, in the Wupper catchment and cities with population > 100 000

In this thesis, land use was analysed using the categories water bodies, forests, cropfields, grasslands and urban areas. Urban areas are only dominating the west and north parts of the catchment, while the uplands and the southern areas show mostly forests and grasslands. The dams are represented in these land use maps by the related water bodies of the dams. Cropfields only cover a minor fraction of the catchment. In terms of the CORINE land cover code, the categories used in this thesis mostly correspond to level 1 (Table 1). Artificial surfaces represent urban areas. Agricultural areas have been subdivided in this thesis into cropfields and grasslands in order to increase their applicability as an indicator. Forests and semi natural areas have been summarized as forests since semi natural areas are not relevant in the Wupper catchment. Wetlands were not considered because they did not occur.

Table 1: CORINE land cover code and included classes assigned to applied land use categories, where only occurring classes in the Wupper catchment are represented

CORINE CODE LEVEL 1	INCLUDED CLASSES AFTER CORINE LAND COVER	LAND USE CATEGORY APPLIED
Artificial surfaces	111/112/121/122/132/141/142	Urban areas
Agricultural areas	211/222/242/243	Cropfields
	231	Grasslands
Forest and semi natural areas	311/312/313/324	Forests
Water bodies	511/512	Water bodies

3. Methodology

3.1 Approach

In order to subdivide the Wupper catchment into comparable units, the management sections were chosen as an output for the spatial analysis. Based on that, the assessment of ecosystem services enables to identify differences between the management sections regarding drinking water provision, habitat provision, water purification and tourism & recreation. The subsequent visualization of use-profiles enables a statement specified on dams and reservoirs. In this case, based on the review of literature on the Wupper Catchment it was expected that tourism & recreation is dominating compared to the other ecosystem services assessed. Here, the use-profiles including all four ecosystem services are compared. The evaluation needs to be compared to existing political instruments, especially water quality monitoring according to the Water Framework Directive (WFD). The third hypothesis is focussed on the comparison of ecosystem services and characteristics found in the Wupper catchment. The relation between ecosystem services and factors of water quality monitoring according to the WFD (WFD, 2000) is evaluated. The main focus of the analysis is laid on land use which is a driving factor for the quality value of ecosystem services. There, the differentiation of management sections with and without dams and reservoirs are considered.

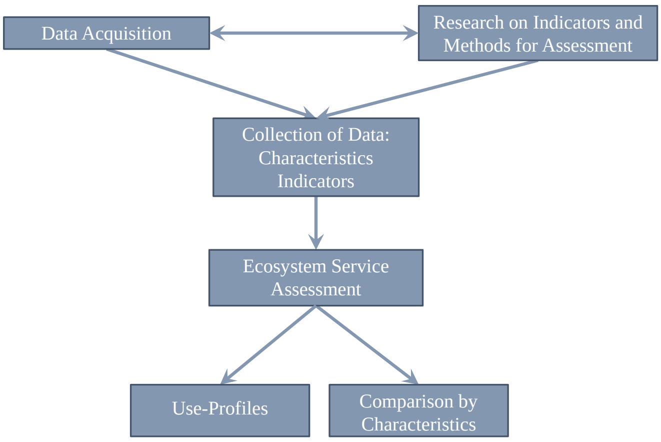

Figure 4:Schematic flow diagram of working procedure within this thesis

The working procedure of this thesis is illustrated in the flow-diagram in Figure 4. Firstly, the case study area was characterized and described (Chapter 0). A search on available datasets was conducted. In parallel, the indicators for the spatial assessment of drinking water provision, habitat provision, water purification and tourism & recreation were identified based on a review of literature. For each of the four ecosystem services the method for the spatial assessment was developed based on the indicator and data availability. For the subsequent analysis, the relevant data was collected in tables assorted to the corresponding management sections. These methods considering data acquisition and the assessments of drinking water provision, habitat provision, water purification and tourism & recreation are described in detail in Chapter 3.2 and 3.3 respectively.

Based on that the ecosystem services were assessed for the case study area and visualized in spatially explicit maps for each of the service. In addition, an integrated visualisation including all ecosystem services as use-profiles is presented (Chapter 3.4). The results of the ecosystem service assessment were compared to characteristics of the management sections in the Wupper catchments. In detail, river types (Chapter 4.4.1), heavily modified and natural water bodies (Chapter 4.4.2), and management sections with and without dams/ reservoirs are investigated (Chapter 4.4.3). Finally, the results are discussed (Chapter 5) and a summary with final conclusions completes the thesis (Chapter 6).

The ecosystem service assessment and further analyse require a search for data and the selection of transparent methods to be applied. The following chapter on data acquisition gives an overview about available data on the characteristics of the Wupper catchment. In the next chapter, the methods for assessing four selected ecosystem services are presented. Then, the formation of the use-profiles and the performance of comparisons by characteristics are presented. Furthermore, the inclusion of data on land cover and water quality state of the water bodies according to the European Water Framework Directive (WFD) is described.

3.2 Data Acquisition and Management Sections

This thesis is based on geographical data sets. For data acquisition and measurements, the Wupper catchment is subdivided into a number of management sections, as the tributaries with a catchment >10 km² are managed under the regulations of the WFD (WFD, 2000). Additionally, the Wupperverband has divided the area further into structural different sections, so that finally 52 management sections have been formed. Due to the thresholds of relevance for the WFD, only nine of 17 dams are considered in this analysis.

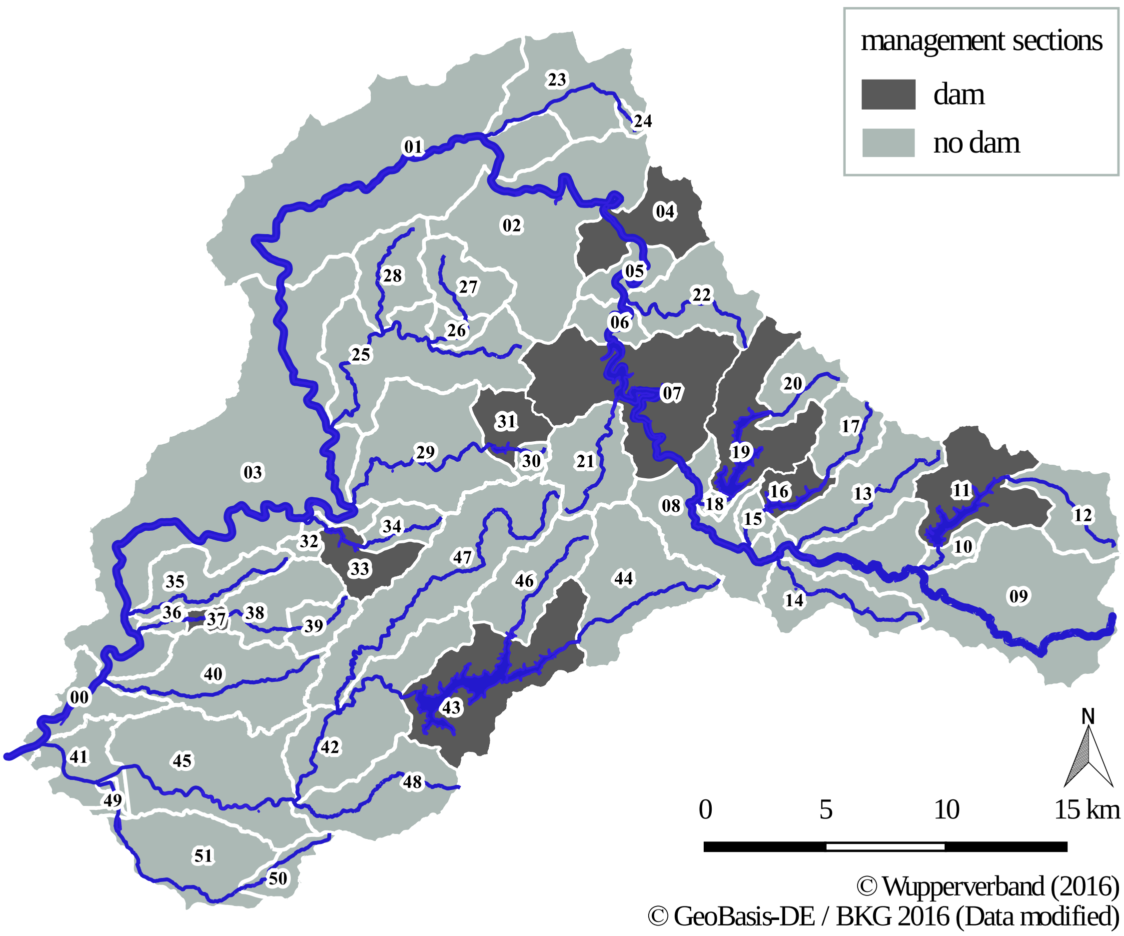

Figure 5: Management sections of the Wupper catchment and corresponding IDs, management sections with dams are indicated by dark colour.

Within the framework of an assessment of ecosystem services provided by rivers, the structural characteristics of the respective management sections are required. Besides the data provided by the Wupperverband, the European Land Cover data were found at the website of the European

Environmental Agency (EEA). The project 'Coordination of Information on the Environment' (CORINE) has transformed satellite images into 44 land cover classes. The pan-European data set is accessible at the earth observation programme Copernicus directed by the European Commission and European Space Agency.

The Wupperverband (WV) provides shape files of the Wupper catchment and the river system. On their website, the results of the water quality monitoring performed according to WFD are collected, too. Moreover, the State Agency for Nature, Environment and Consumer Protection of the State of North Rhine-Westphalia (German abbreviation: LANUV) provides extensive geological and hydrological data of the federal state North Rhine-Westphalia. Additionally, the required administrative data are freely available at the Federal Agency for Cartography and Geodesy of Germany (BKG). The data sources obtained for this thesis are shown in Table 2.

Table 2: Accessed data sources for acquisition of Wupper catchment

SOURCE	NAME OF DATA SET	CONTENT DESCRIPTION	EXTENT	SCALE	YEAR OF COLLECTION	DATE OF HIT
EEA	CLC12	CORINE Land Cover 2012	European	1:100 000	2011-2012	06.04.2016
BKG	VG250	Administrative areas	National	1:250 000	2014	24.04.2016
LANUV	FFH	Natura-2000 areas	Regional (Federal State)	1:5 000	2008-2014	31.03.2016
	Biotopkataster	Biotope zones		1:5 000	2008-2014	
	NSG	nature protection zones		1:5 000	2013	
	WSG	Water protection zones		1:5 000	2013	
WV	Wasserkörper	Water bodies and catchments	Regional (Federal State, Wupper catchment)	1:25 000	2006 / 2010	31.03.2016
	Strukturgüte	Aquatic structure of water bodies		1:50 000	2013-2015	
	Kläranlage	WWTP		(Points)	2014	
	Querbauwerke	Barriers		(Points)	2012	
	Freizeit & Tourismus	Data on trails and POI for tourism and recreation		(Points/Lines)	Until 2016	

In order to make use of the various data sources on the Wupper catchment, the data need to be prepared regarding the coordinate reference system, spatial extent and partly simplifying the contents of GIS-layers to the extent necessary. All maps are shown in the European Terrestrial Reference System 1989 (ETRS89, code EPSG:3044).

3.3 Ecosystem Services Assessment

The assessment of water-related ecosystem services is highly dependent on the provided amount and quality of the geographic and hydrological data. Furthermore, it is obvious that an assessment of the complete set of ecosystem services would represent a very complex task. In order to present an informative analysis within this frame, this thesis has focused on the following four selected ecosystem services:

- Drinking Water provision
- Water purification
- Habitat provision
- Tourism & Recreation

The resulting assessment of the services will be dependent on the input data. In order to compare the extent of the provision of the various services, classes from 1 – the highest class for the corresponding service – to 5 – the worst class for services - were defined. Thereby, the assignment to classes can be based both on single indicators and on multiple indicators. Indicator data may be available as punctual, linear and spatial data. The analysis of ecosystem services was thereby restricted to the river system and its floodplains, or alternatively to buffer zones of 200 m alongside the water bodies, which were considered as significantly influenced by the stream. The buffer zones of 200 m were applied to the water bodies of the Wupper catchment and their area per management section was then calculated by QGIS. Only the analysis of drinking water provision was performed by the use of the complete catchment areas.

3.3.1 Drinking Water Provision

In general, the provision of drinking water is assessed by application of water abstraction rates, water exploitation index or by the actual consumption of drinking water (e.g. Egoh et al., 2012; Burkhard et al., 2014; Grizzetti et al., 2015). In this analysis, the provision of clean drinking water was considered to be spatially distributed since the processes of cleaning and transportation of water are taking place within the whole catchment. Hence, the responsible catchments for providing and producing drinkable water define the potential ecosystem service(Maes et al., 2014). The water protection zones were designated in accordance to drinking water catchments. The data are subdivided into different protection levels. In this thesis, these levels are not considered. Thereby, the catchment area is only divided into protected and non-protected zones. In consequence, the spatial fraction of water protection zones per management section is used as indicator of drinking water. Finally, the ratios were then assigned to the corresponding class (Figure 6). The delimitation of classes follows a quantiles approach which is usually applied, but was somewhat modified. due to the relatively large amount of data and to optimize visualisation.

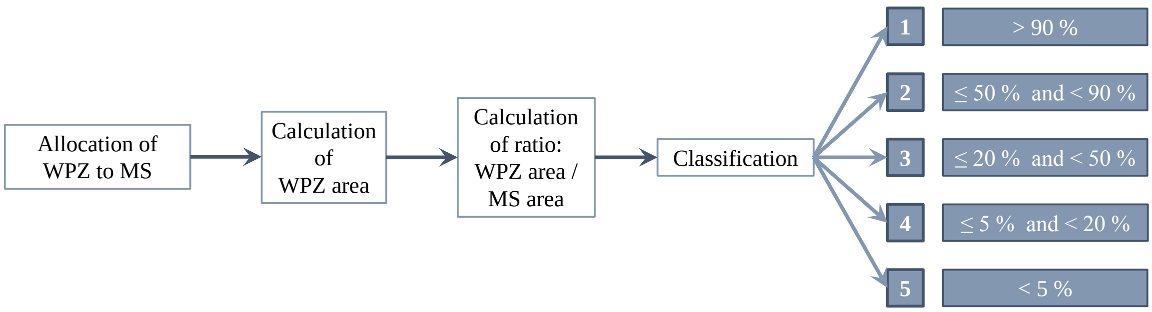

Figure 6: Scheme of classification by water protection zones as indicator of the ecosystem service drinking water provision (WPZ = water protection zones; MS = management sections)

3.3.2 Habitat Provision

Habitat provision is seen as the most complex and also most important ecosystem service potential. Based on the interaction of geomorphology, hydrology, soils and vegetation, habitat quality is dependent on several circumstances in the environment. A national assessment of water-related habitat provision in floodplains was conducted by integrative indicators (Scholz et al., 2012). Considering the required data and the comprehensive inclusion of numerous factors, the mentioned method was applied in this thesis, too. The assessment was based on four components which are significant when evaluating habitat provision.

Firstly, it is assumed that nature protection zones, such as those according to Natura 2000, are providing comparatively better habitats than non-protected zones. Therefore, the data on national nature protection zones (designated until 2008) and on zones of the Flora-Fauna-Habitat-Directive (FFH) were considered. These representative areas are then classified corresponding to Scholz et al. (2012) (Figure 7).

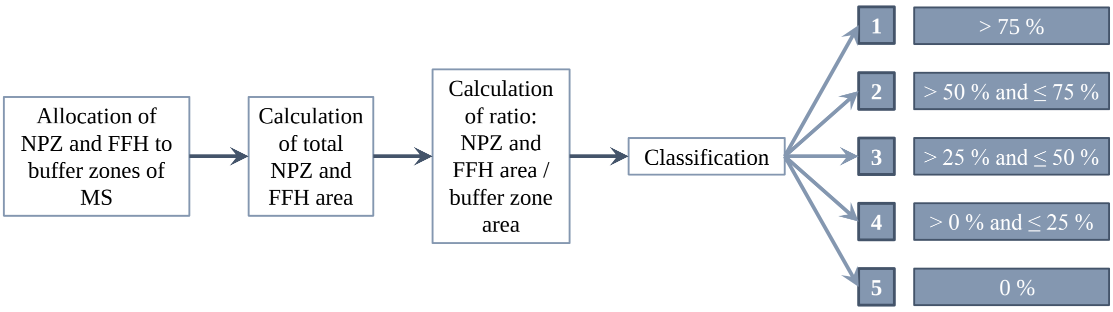

Figure 7: Scheme of classification for nature protection zones and Flora-Fauna-Habitat-zones as indicators of the ecosystem service habitat provision (NPZ = nature protection zones; FFH = Flora-Fauna-Habitat-zones; MS = management sections)

Secondly, land use intensity was extracted as indicator from the European CORINE Land Cover data. Compared with Scholz et al. (2012), the category of "Other Areas" was not formed. The ratios of land use categories were assessed and classified following the flow diagram (Figure 8).

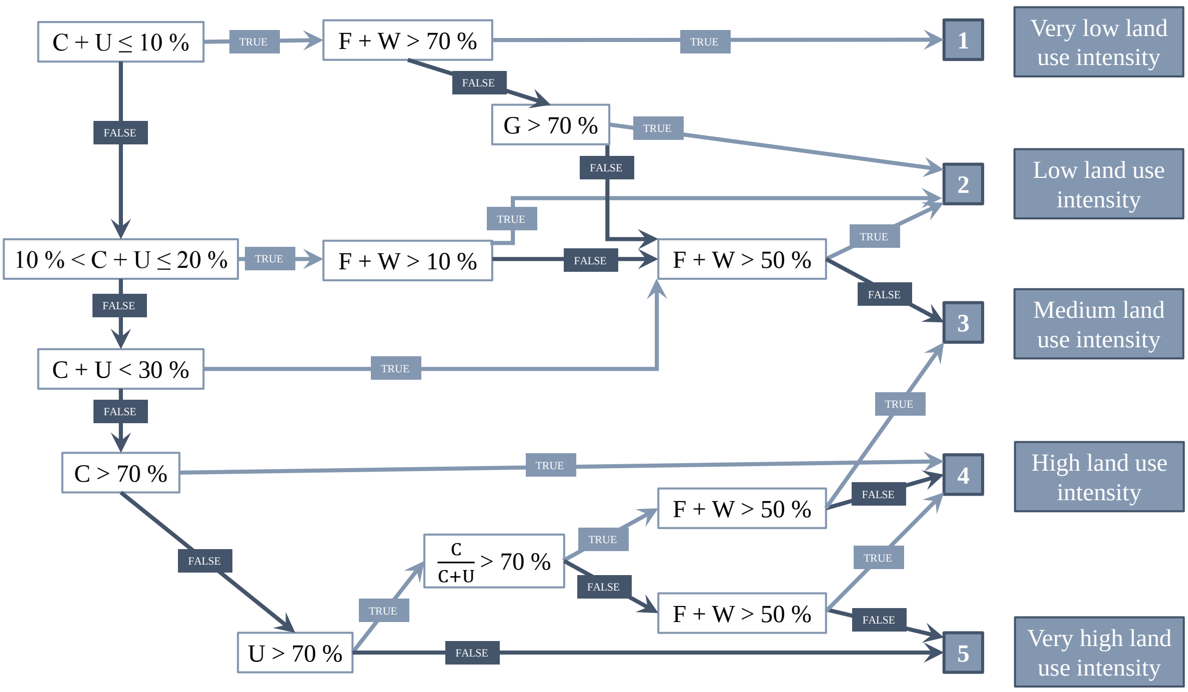

Figure 8: Scheme of classification by CORINE categories as indicator of the ecosystem service habitat provision (C = cropfields, U = urban areas, F = forests, W = water bodies, G = grasslands), modified after Scholz et al. (2012) and Koenzen (2005)

In general, it may be said that a lower land use intensity, such as forests, water bodies and wetlands, are resulting in a higher class for habitat provision. On the contrary, high land use intensity by, for instance, urbanization and cropfields are resulting in a lower class of habitat provision. Contrary to the original method, no further distinction of forest types was performed. It has also to be considered that the major part of the water bodies, such as rivers and streams, are not represented. This occurs due to the rough grid of the CORINE data, so that large dams were included only.

Thirdly, the ecosystem service habitat provision considers the national biotope protection zones. Similar to Natura 2000 zones, the habitats in biotopes provide a higher quality than non-protected zones. These representative areas are then assessed and classified (Figure 9) (Scholz et al., 2012).

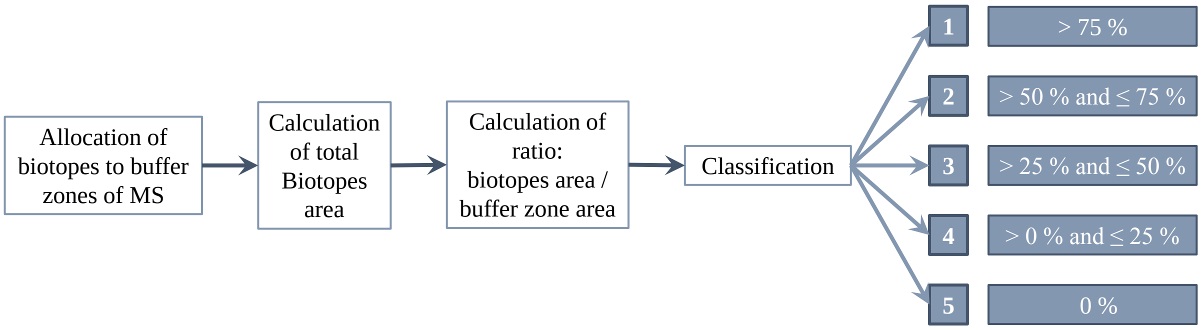

Figure 9: Scheme of classification by biotopes as indicator of the ecosystem service habitat (MS = management sections)

Finally, the connectivity of the streams was investigated by consideration of barriers. Constructions within the streams inhibit a constant exchange and transport of materials as well as change the permanently flowing environment to a static and lake-like habitat. This has a high influence on species which are dependent on running water conditions. Additionally, barriers prevent fish migration. The data set of barriers provides information on the falling heights in combination with constructed barriers in the Wupper catchment, which are used to weight the influence of the total amount of barriers in each management section.

In this method, the backwater indicator is replaced by technical barriers and their falling heights. If the falling height in the river exceeded a limit of 100 cm, this lowered the habitat provision score by either one or two classes (Figure 10). If more than one technical barrier is present in a management section (up to $n_{barriers}$ = 24), the heights are summed up. The level of 100 cm was chosen due to fact that no information on the shape of the barrier was given. While a sloping barrier would be conquerable also for small species, a vertical barrier with this height would only be passed by larger species, such as fishes. In sloping barriers, the installation of a fish passage is feasible but at this point, there are no data on already existing fish passages.

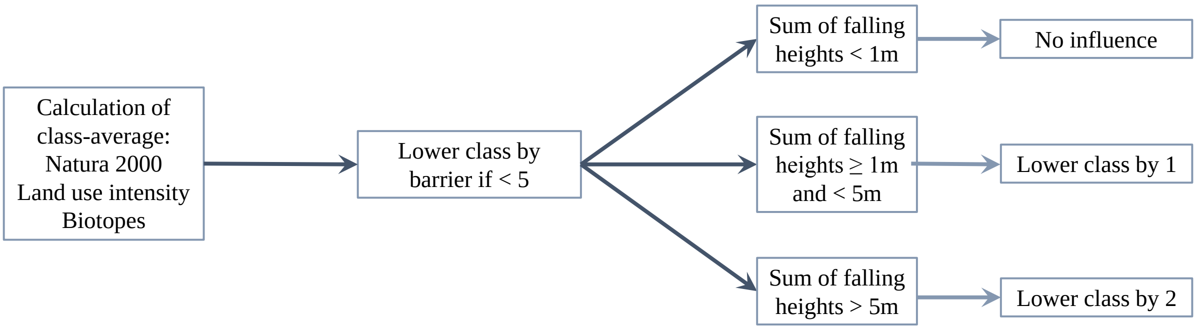

Figure 10: Scheme of classification by inclusion of barriers and falling heights as indicator of the ecosystem service habitat provision

The four investigated indicators of the ecosystem service habitat provision are then combined to a total class (Figure 12). For that, the average was calculated from the scores for Natura 2000, land use intensity and biotopes and subsequently, the potentially negative influence by barriers in the water bodies was added. It has to be noted that the spatial data were assessed for the buffer zone of 200 m alongside the water bodies of the Wupper catchment only.

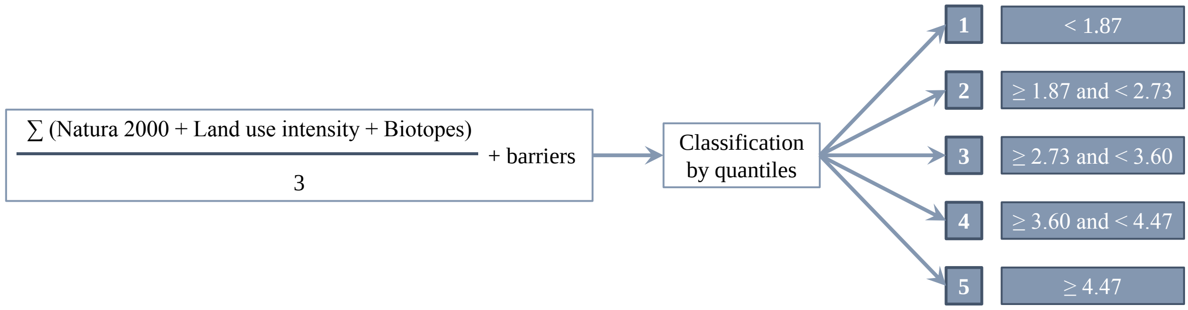

Figure 11: Scheme of total classification of the ecosystem service habitat provision, modified after Scholz et al.(2012)

3.3.3 Water Purification

The water purification ecosystem service represents the capability of a stream to clean itself from pollutants and therefore achieve good water quality. The assessment of the potential purification in a regional scale involved a large search and analysis of complex and dynamic processes to determine for example the elements removed from water in kg/m³/year in each management sections. Discrepancies between actual measurements and standards of water quality are also frequently used as indicators of purification. Recently, there has been a development of a method for the assessment of purification (Albert et al., 2015). This method allows a rough but informative overview on the ecosystem service of purification by calculating the ratio of good aquatic structure after the WFD per total length of the water bodies. In order to adapt this assessment on national scale towards a regional scale of the Wupper catchment, the method was modified (after Albert et al., 2015). Instead of the ratio, the average class of aquatic structure is taken into account. Additionally, wastewater treatment plants (WWTP) were considered. In order to underline the effect of additional wastewater discharged to the water body, a specific method needs to be applied. In general, it can be stated that a water body with a better water purification score is less influenced by the presence of WWTP discharges than a water body with low purification. This correlation is included in the assessment by the following equation:

$$\bar{\mathbf{x}}_{\mathbf{aquatic\ structure}} - \mathbf{n}_{\mathbf{WWTP}} \cdot \frac{\mathbf{2}}{\bar{\mathbf{x}}_{\mathbf{aquatic\ structure}}} \qquad \mathbf{(1)}$$

While

$\bar{x}_{aquatic\ structure}$ = average of aquatic structure class

n_{WWTP} = number of WWTP

This equation is only used for illustrative purposes to show the significant effect of WWTP effluents on the purification. Then, a classification of water purification into quantiles was performed, as shown in Figure 12.

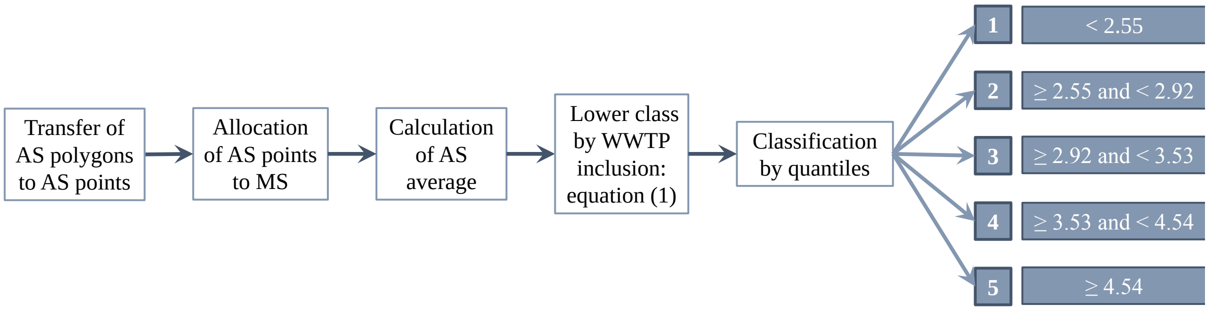

Figure 12: Scheme of classification by aquatic structure and wastewater treatment plants as indicator of the ecosystem service water purification (AS = aquatic structure classes; MS = management sections; WWTP = wastewater treatment plants)

3.3.4 Tourism & Recreation

Most of the assessments considering cultural ecosystem service are often reduced to the class of tourism & recreation (Burkhard et al., 2014). Other cultural services are mainly investigated by questionnaires, hedonic price models or interviews in comprehensive case studies, when assessing the ecosystem service flow (e.g. Maes et al., 2014; de Groot et al., 2010; Burkhard et al., 2014). In the context of this thesis, a more practical and easy available data set is required. Hence, it is focussed on present infrastructure for the purpose of potential tourism or recreation. More explicitly, labelled hiking and cycling trails and paths as well as water-related points of interests (POI) were used as indicators (comp. Grizzetti et al., 2015). The trails and, for instance, baths indicate the access to interesting sites and the ability to swim which are seen as indicators (Bark et al., 2015). The assessment of recreational structures (points and lines) included, e.g. trails for walking, cycling or kayaking, baths and other POI, such as observation points and camping sites. The flow diagram shows the steps of assessment and further classification into quantiles (Figure 13).

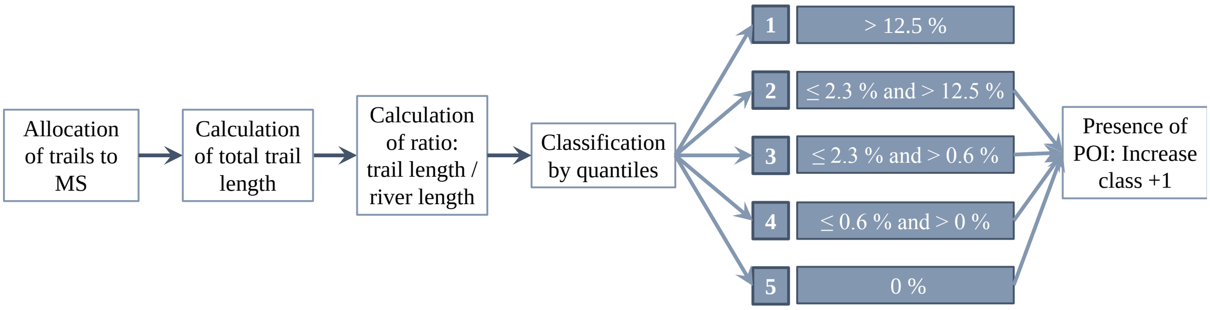

Figure 13: Scheme of classification by trails and points of interest as indicator of the ecosystem service tourism & recreation (MS = management sections; POI = point of interest)

In order to determine only the water-related touristic infrastructures, the spatial extent of the assessment was restricted to a buffer zone of 200 m alongside the water bodies of the Wupper catchment.

3.4 Use-Profiles

The use-profile of the management sections was assessed by the help of QGIS. The classes of drinking water provision, habitat provision, water purification and tourism & recreation were visualized for each management section. For the management sections with no data, the lowest class of ecosystem service (5) is assumed and shown due to restrictions of the visualization in QGIS. The correlation among the services is analysed by regression. Furthermore, the ecosystem services were investigated regarding correlations with characteristics determined according to the WFD. In detail, Macrozoobenthos (MZB), macrophytes (MP), Metals, plant protection products (PBSM) as well as general chemical and physical parameters (ACP) are chosen to be representative indicators for the state of quality of the water bodies (MKNULV and LANUV, 2015).

3.5 Comparison of Ecosystem Services by characteristics

The ecosystem services were compared by the help of three different characteristics, as natural and heavily modified water bodies (NWB, HMWB), river types as well as the presence or absence of dams in the management sections. The comparisons were either visualized as bar diagrams, box plots or regressions. When finding significant differences, the correlation of ecosystem services according to the characteristic is investigated. Additionally, the comparison of dam presence is extended by a regression with land use categories. Finally, the use-profiles of the dams are then compared to information given by literature (Wupperverband 2016a; Quaißer 2016).

4. Results

4.1 Characteristics of Management Sections of the Wupper Catchment

In this chapter, the characteristics of the 52 management sections are described by means of spatial statistics regarding the area, length of the river section, river type, and percentages of land use categories. The area of the 52 management sections varied from 1.0 km² (ID:24) to 85.0 km² (ID:03) (Figure 5). The longest river section was located in the management section 03 of the Wupper with a length of 34.3 km and a resulting buffer area of 14.4 km². The shortest stream section was found in the management section 32 of the Sengbach with a length of 1.40 km and a buffer area of 0.49 km². In these 52 management sections, five different river types were found as defined in Germany for the implementation of the WFD. Among the management sections, 59.6 % represented the river type 5 with coarse-rich and siliceous material, 19.2 % type 9 with siliceous, fine to coarse material. The remaining management sections were assigned to river types that are rich in either fine material and carbonatic (type 6), coarse material and carbonatic (type 7) or lowland streams characterized by sand (type 14).

Corresponding to the assessment under the WFD, 59.6 % of the management sections were natural water bodies (NWB) and 40.4 % were heavily modified water bodies (HMWB). The objective of the WFD is to reach a good ecological status and does not allow a worsening of the current state. However, if the use of resources is sustainable and comes with social advantages over other opportunities, modifications could be accepted in line with Art. 2, Sec. 8 and 9 of WFD. The Federal State North Rhine-Westphalia has identified 47 % of the water bodies to be HMWB in 2015 (MKNULV and LANUV, 2015). Hence, the amount of HMWB in the Wupper catchment exceeds the regional average. In the HMWB, the goal to be achieved is a good ecological potential.

An extreme modification of a water body is the construction of dams for the use of drinking water (e.g. Dhünn-Talsperre, Kerspe-Talsperre) and other purposes (Table 3).

*Table 3: Overview on nine dams which are located in one of the management sections (ID) within the Wupper catchment, associated with their volume, impoundment height and use (obtained from the websites Wupperverband (2016), additionally Quaißer (2016) marked by *)*

DAM/RESERVOIR	ID	VOLUME [MIO M³]	IMPOUNDMENT HEIGHT [M]	USE
KERSPE-TALSPERRE	11	14,9	27,8	Drinking water
NEYE-TALSPERRE	16	6,0	23,2	Flood protection, water table regulation, reserve drinking water
BEVER-TALSPERRE	19	23,7	31,5	Non-drinking water, flood protection, water table regulation, hydropower
WUPPER-TALSPERRE	07	25,6	32,0	Non-drinking water, flood protection, water table regulation, hydropower, tourism & recreation
STAUSEE BEYENBURG	04	0,465	6,0	Hydropower (water table regulation)
ESCHBACH - TALSPERRE	31	1,052	25*	Drinking water, hydropower, tourism & recreation*
SENGBACH-TALSPERRE	33	2,8*	43*	Drinking water
DIEPENTALER TALSPERRE	37	0,4*	10*	Tourism & recreation*
DHUENN-TALSPERRE	43	81	53	Drinking water (tourism & recreation)

The resulting map shows that the land use varied considerably among the 52 management sections (Figure 14). The results indicated that the northern and south-western area of the Wupper catchment was dominated by urban areas, while the central area and the tributaries further upstream are more dominated by grasslands and forests. Nine management sections included even less than 1 % of urban areas. In contrary, the management sections of the Wupper, Schwelme and Mutzbach were characterized by a share from 89 to 100 % urban areas (ID:01/23/49). Further five management sections were used to more than 50 % as urban areas (ID:08/27/48/51). Therefore, it can be concluded that the urban areas are distributed quite heterogeneously within the Wupper catchment.

In contrast, cropfields play only a minor role in the study area, as their share in land use is rather low for most of the management sections. Only one management section of the Bever was dominated by cropfields by c. 65 % (ID:18). Further 13 management sections included cropfields at percentages between 0.1 and 15.6 %. The remaining 38 management sections did not include any cropfields, which obviously represents an atypical situation for Germany. Another agricultural land use under consideration was grasslands, which is present in the whole catchment area. In a management section of the Bever (ID:20), over three quarters of the area was covered by grasslands. Six management sections (ID:00/10/13/14/21/48) showed above 50 % grasslands in the buffer zones. Especially upstream of the Wupper and alongside the first tributaries, such as Kerspe, Hönninge, Neye and Dölpe, as well as the Scherfbach, an even higher percentage of grasslands was present. Also the lowermost management section of the Wupper where it discharges into the Rhine (ID:00) had more than 50 % grasslands. Apart from this, the northern area of the Wupper catchment was characterized by comparatively small ratios below 20 % of grasslands.

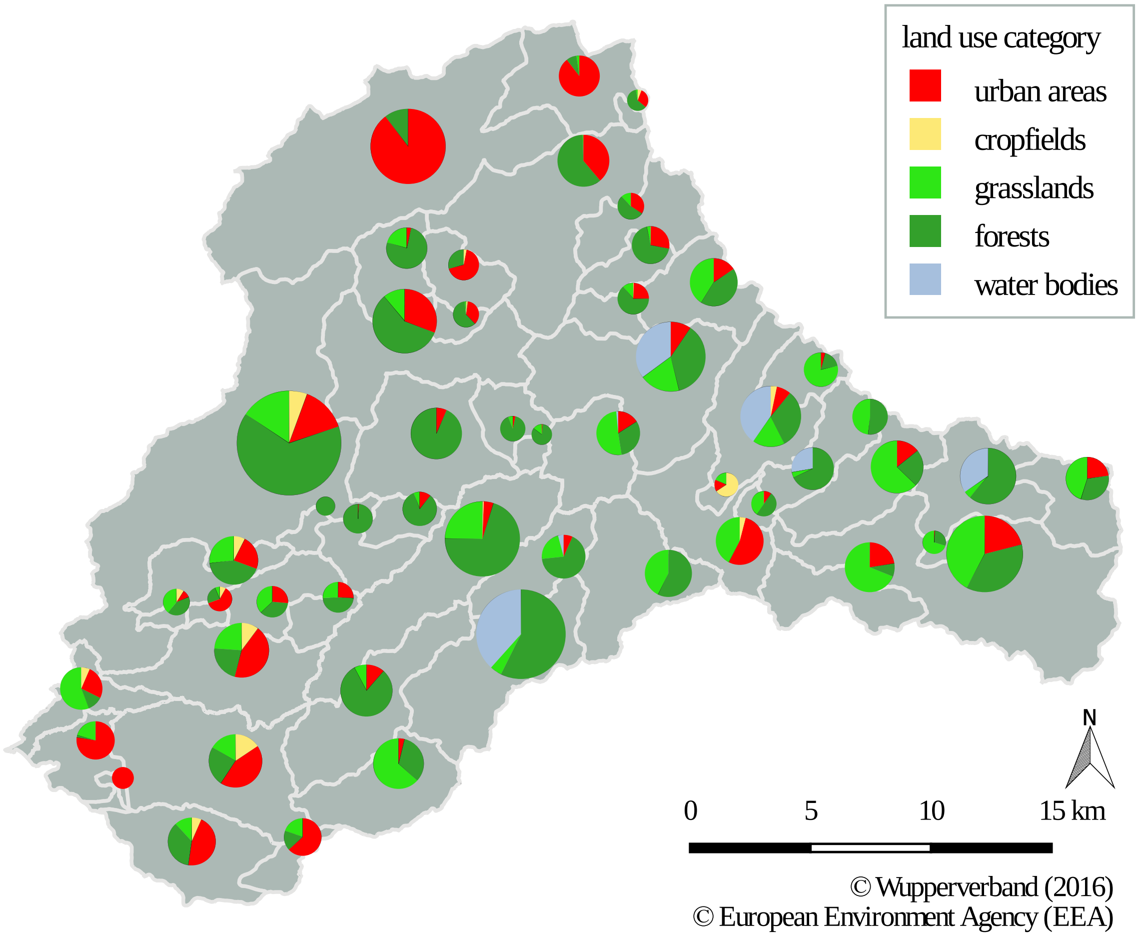

Figure 14: Land use distribution based on CLC dataset. The results are displayed per management section, whereby the size of the diagram represents the relative area of the 200 m buffer zone within each management section

The highest ratios of the land use category forests were found in the management sections of the two tributaries Eschbach and Sengbach (ID:29/30/31/32/33/34), where one of them was even covered by forests by 100 % and the others above 83 %. Otherwise, forests ratios were between 0 and 80 %. Considering the overall spatial distribution of forests, downstream areas and in the city area of Wuppertal displayed the lowes values.

For the land use category of water bodies, only five management sections showed considerable values of 27 % to 40 % which was related to the presence of the five largest dams in the Wupper catchment (ID:07/11/16/19/43). In three management sections, up to 5 % of the area is covered by water bodies (ID:00/21/46). In the remaining management sections, water bodies were not represented, which was a result of the resolution of the CORINE land cover data (25 ha), which does not represent streams or small rivers. Comparing the different land use categories in this context, high percentage of water bodies was associated with a low share of urban areas cropfields and low grasslands. Hence, the buffer zones in the management sections with dams were mainly covered by forests.

In summary, forests occur in most of the management sections, whereas the percentage of cropfields is rather low. Urban areas are mostly present in the northern and south-western parts of the catchment. These statistics underlined the various land use categories in the 52 management sections used for subsequent analysis.

4.2 Ecosystem Services Assessment

4.2.1 Drinking Water Provision

An assessment of the potential for the ecosystem service drinking water provision revealed hotspots in specific areas (Figure 15 A). The water protection zones, which were used as indicator for drinking water provision, were strongly related to the management sections with dams. The dams in these management sections are used for drinking water extraction (Table 3). Hence, management sections containing one of the drinking water relevant dams, as well as upstream management sections which were assigned to the highest degree of provisioning of this ecosystem service (ID:11/12/30/33/34/43/44/46). The catchment of the Eschbach-Talsperre is only partly designated as a water protection zone and therefore, it was only assigned a medium ecosystem service class.

The extraction of groundwater for drinking water purposes is rare due to the geologic conditions which are mostly not associated with good aquifers. Only the management sections 50 and 51 include an aquifer suitable for drinking water provision. Furthermore, management sections 02 and 06 show a relevance of the ecosystem service drinking water provision due to the presence of the Herbringhauser-Talsperre.

The remaining 38 management sections can be seen as not relevant for drinking water provision. Their small percentage of below 1.6 % water protection zone area per management section area was neglected due to uncertainties and inaccuracy of the borders from different data sets especially as the water protection zones were located alongside the borders of management sections.

4.2.2 Habitat Provision

The ecosystem service habitat provision, which was defined here primarily as providing classified terrestrial habitats along the streams, revealed that this ecosystem service was mostly provided by the tributaries and to less extent by the Wupper (Figure 15 B). In detail, only one third of the tributaries show the lowest class of habitat provision, whereas 70 % of the Wupper management sections were assigned to the lowest class of habitat provision. Among the management sections with dams, three were classified as the lowest service of habitat provision, too (ID:04/31/37). The remaining six management sections with dams in the Wupper catchment were assessed as providing habitats at medium to very high extent. The only management section that was assigned to the highest class of habitat provision is the management section of the Neye-Talsperre (ID:16). Furthermore, the three highest classes are mostly related to management sections either with a dam or its discharging/supplying management sections. The coincidence of provisioning terrestrial habitats with the presence of dams is probably produced indirectly, as those areas benefit from multiple measures securing good water quality there.

The effect of technical barriers within the water bodies on habitat provision, which was considered by assigning a malus on the respective habitat provision class, was relevant in 30 management sections, where the class of habitat provision was finally lowered down by at least one class due to the occurrence of technical barriers in the stream channel. This resulted in a generally low level of the service of habitat provision in the Wupper catchment, as more than 45 % of the management sections were designated to the lowest habitat provision class.

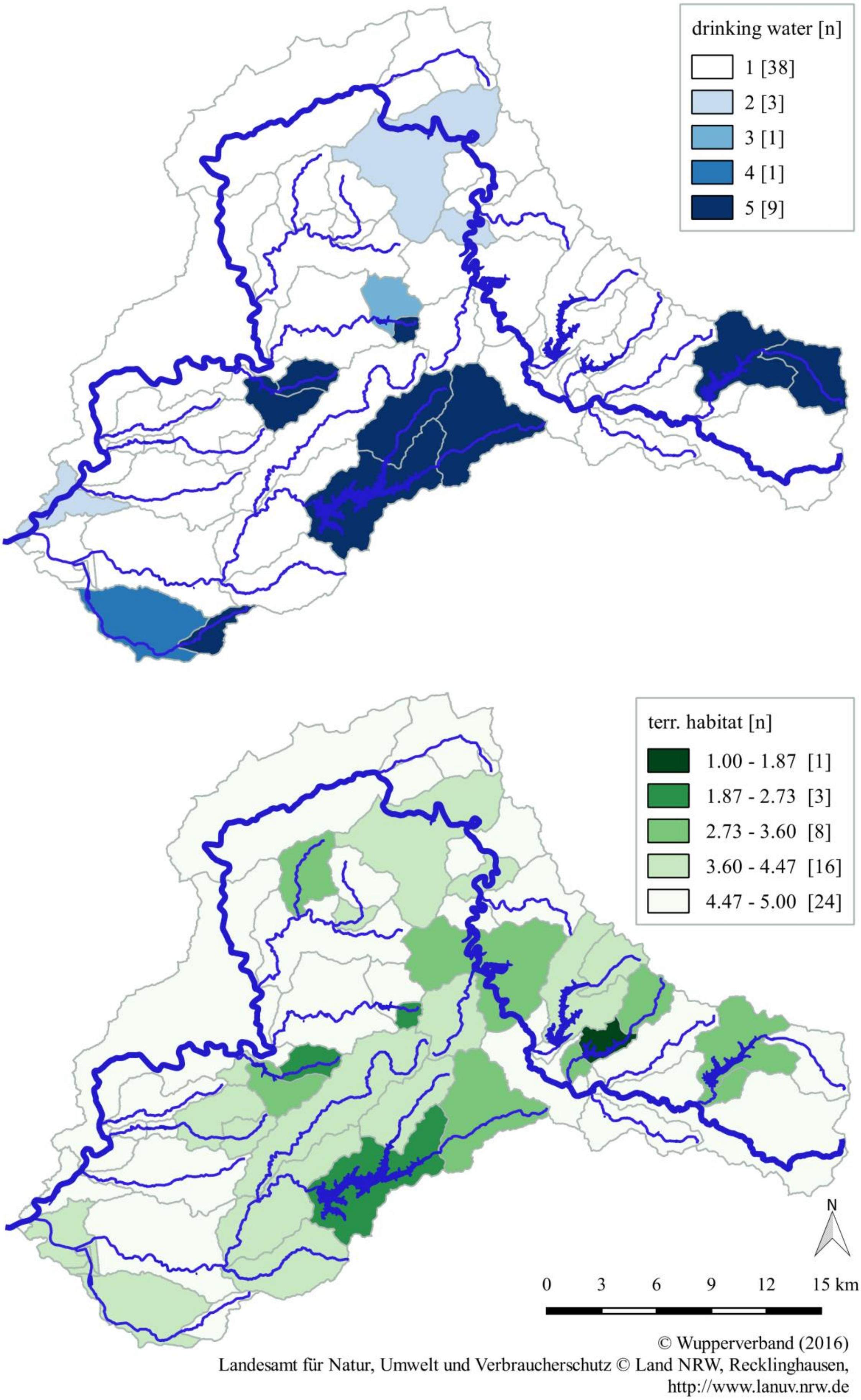

Figure 15: Ecosystem services drinking water provision (top) and terrestrial habitat provision (down) per management section. The darker the colour the higher the service indicates a higher service class (1 = very high – 5 = very low)

4.2.3 Water Purification

Water purification was assessed based on the assessment of physical habitat structures at stream banks, as it is known that self-purification capacity of rivers is mainly governed by their morphological heterogeneity, which is supporting the exchange of stream water with the hyporheic zone in the sediments, where most of microbial metabolism in rivers takes place. The assessment of water purification revealed an unevenly distribution of this ecosystem service (Figure 16 A). Four management sections in the present data set did not receive values of classification, as the Eschbach and another management section of the Wupper upstream (ID:03/29/30/31), due to an incomplete dataset.

Among the management sections with the lowest degree of water purification, six of the ten management sections include a dam. This result was produced since the evaluation was performed on flowing water bodies only, as the self-purification capacity of standing water – including reservoirs – is quite low. In the highly urbanized northern part (see Chapter 4.1) of the Wupper catchment (ID:01/02/23/27), river and streams only provide a low water purification service. The tributaries showing low or very low water purification service are management sections of the Neye, Bever, Schwelme, Leyenbach, Sengbach, Wiembach and Mutzbach (ID:16/18/23/27/32/40/49/50/51). Among the Wupper, six of nine assessed management sections were classified as having either low or very low purification capacity. The influence of WWTP effluents on purification capacity was considerable, since by this way nine of ten affected management sections decreased their services by one or two classes in terms of water purification as ecosystem service.

4.2.4 Tourism & Recreation

The assessment of the ecosystem service tourism & recreation showed that this ecosystem service generally increased with the stream size (Figure 16 B). All ten management sections of the Wupper showed the highest class. Additionally, the tributaries Gaulbach (ID:14) and single management sections of the Dhünn (ID:45) as well as Bever (ID:19) showed very high tourism & recreation (ID:14/19/45). On the contrary, the remaining headwaters of the tributaries mostly showed very low classes, whereas management sections further downstream were assigned to medium to low classes. Representative tributaries for this case were Kerspe, Schwelme, Eschbach, Sengbach, Murbach, Kleine Dhünn and Mutzbach (ID:12/24/30/31/33/34/37/38/39/46/49/50/51). Three tributaries were assigned to the lowest class on their whole length, as the Leyerbach, Gelpe and Scherfbach (ID:26/27/28/48). Hence, management sections located closer to the Wupper showed a higher provision of the ecosystem service tourism & recreation.

The assessment of tourism & recreation displayed an unexpected variability among reservoirs. Even though management sections with dams have similar characteristics, the scoring of the nine management sections with dams varied from the lowest class to the highest class. Within this range, the very high and high tourism & recreation are found in the management sections located upstream, such as the Wupper (ID:04/07), as well as the tributaries Kerspe, Neye and Bever (ID:11/16/19). In contrast, the very low and low classes of tourism & recreation are found in management sections with dams located downstream in the following tributaries, as Eschbach, Sengbach and Murbach (ID:31/33/37). The largest reservoir Dhünn-Talsperre also show a low class of tourism & recreation (ID:43).

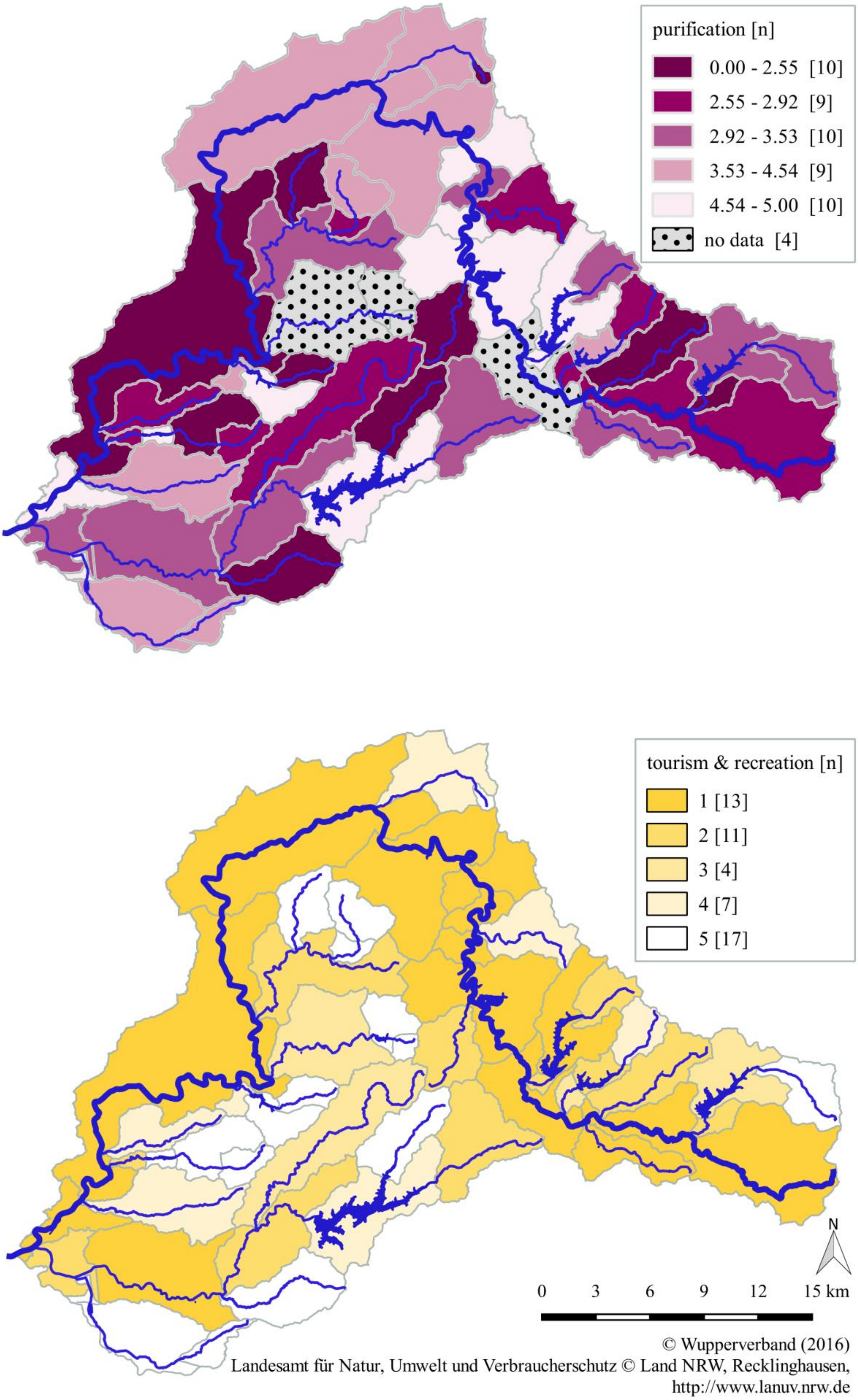

Figure 16: Ecosystem services water purification (top) and tourism & recreation (down). The darker the colour the higher the service class (1 = very high – 5 = very low)

In summary, the ecosystem services provided by rivers and streams in the Wupper catchment are distributed differently. Drinking water provision hotspots are found in and near management sections with dams. Habitat provision was assessed to be generally provided at low level only, whereby the high service classes were mostly found for tributaries. Additionally, the high amount of technical barriers in the water bodies have a strongly negative influence on the habitat provision. In comparison, water purification is evenly distributed in the Wupper catchment. Thereby, management sections with dams show consistently low classes. Tourism & recreation offers were concentrated on the Wupper. Also, a general trend for this ecosystem service were seen in management sections with dams, where a dam location upstream indicated a high service while downstream, tourism & recreation was found in relatively low classes.

4.3 Use-Profiles

An ecosystem service assessment does not only require the investigation of each ecosystem service itself, but also enables an analysis regarding relations among drinking water provision, habitat provision, water purification and tourism & recreation. A use-profile provides exactly this information comprehensively by presenting the specific combination of ecosystem services for each management section. Therefore, use-profiles were developed to enable a synoptic view on the use of ecosystem services in the Wupper catchment.

In order to perform an initial comparison of the total range and average classes of drinking water provision, water purification, habitat provision and tourism & recreation, boxplot diagrams were created (Figure 17).

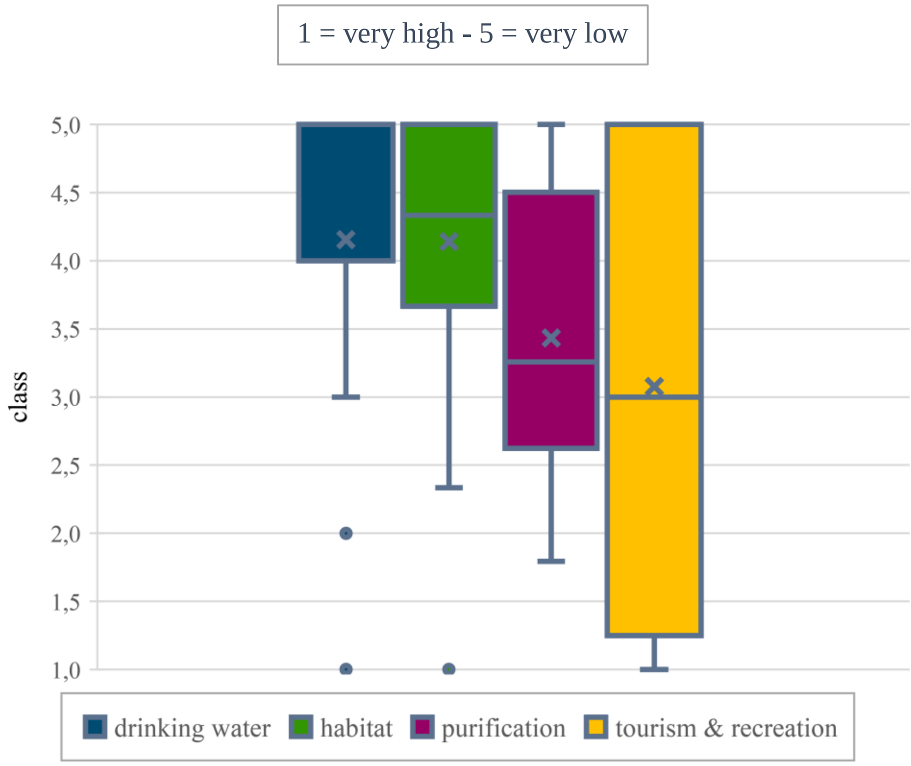

Figure 17: Boxplot diagram of the ecosystem service classes drinking water provision, habitat provision, water purification and tourism & recreation in the Wupper catchment

The four ecosystem services were distributed unequally among the 52 management sections, both in terms of the total range of classes of each ecosystem service and spatially, as shown in Chapter 4.2. The varying extents of the boxplots show the differences between the ranges and mean values of the ecosystem services. The ranges of drinking water provision (5.0 to 4.0) and habitat provision (5.0 to 3.67) were similarly situated in the lower classes. The range of water purification extended from 4.5 to 2.62, so that a higher average class of ecosystem service was found for this ecosystem service. The largest range of ecosystem service classes was revealed for tourism & recreation, as 5.0 to 1.25.

While the mean value of water purification represented a higher class (3.43) than the mean value of drinking water provision and habitat provision (4.15/4.14), the highest average class of ecosystem services was found for tourism & recreation (3.08). In consequence, it may be stated that drinking water provision and habitat provision were generally provided to less extent than water purification or tourism & recreation among the 52 management sections.

A more differentiated visualization of the ecosystem services is provided by application of use-profiles (Figure 18). These profiles represent the total ecosystem services per management section. In this way, hotspots of sustainable use-profiles were identified. Additionally, classes of drinking water provision, habitat provision, water purification and tourism & recreation were combined in a histogram.

Corresponding to the use-profile, a specific distribution is not visible at first sight. Even though, the sum of ecosystem services provided new information on the distribution. The highest sums were shown in management sections of the tributaries Kerspe, Eschbach, Sengbach and Dhünn (ID:11/30/34/43/44) and therefore indicating that these management sections were providing only low ecosystem services, which were characterized by the occurrence of at least twice the lowest class (5). In contrast, tributaries, as Uelfe, Eschbach, Murbach, Wiembach, Scherfbach and Mutzbach (ID:22/29/37/38/39/40/48/49/50/51) showed a rather small sum, and therefore, a high level of total ecosystem services. Apart from tributaries, the Wupper provided an intermediate level of total ecosystem services compared to tributaries.

In the histograms, drinking water provision was represented as either very high ecosystem service or as very low (zero line), which corresponds to Figure 17. Due to the fact that less high service provisioning was present than low service provisioning, the high drinking water provision classes were evaluated as exeptional values (Figure 17). This is also visualized by the use-profiles where drinking water provision is rarely represented. When focussing on the ecosystem services water purification and habitat provision, the use-profiles did not show anything conspicuous. The most present ecosystem service in the histograms is tourism & recreation, which occurred in most of the management sections. The histogram underlined the high range of tourism & recreation classes, similar to Figure 17.

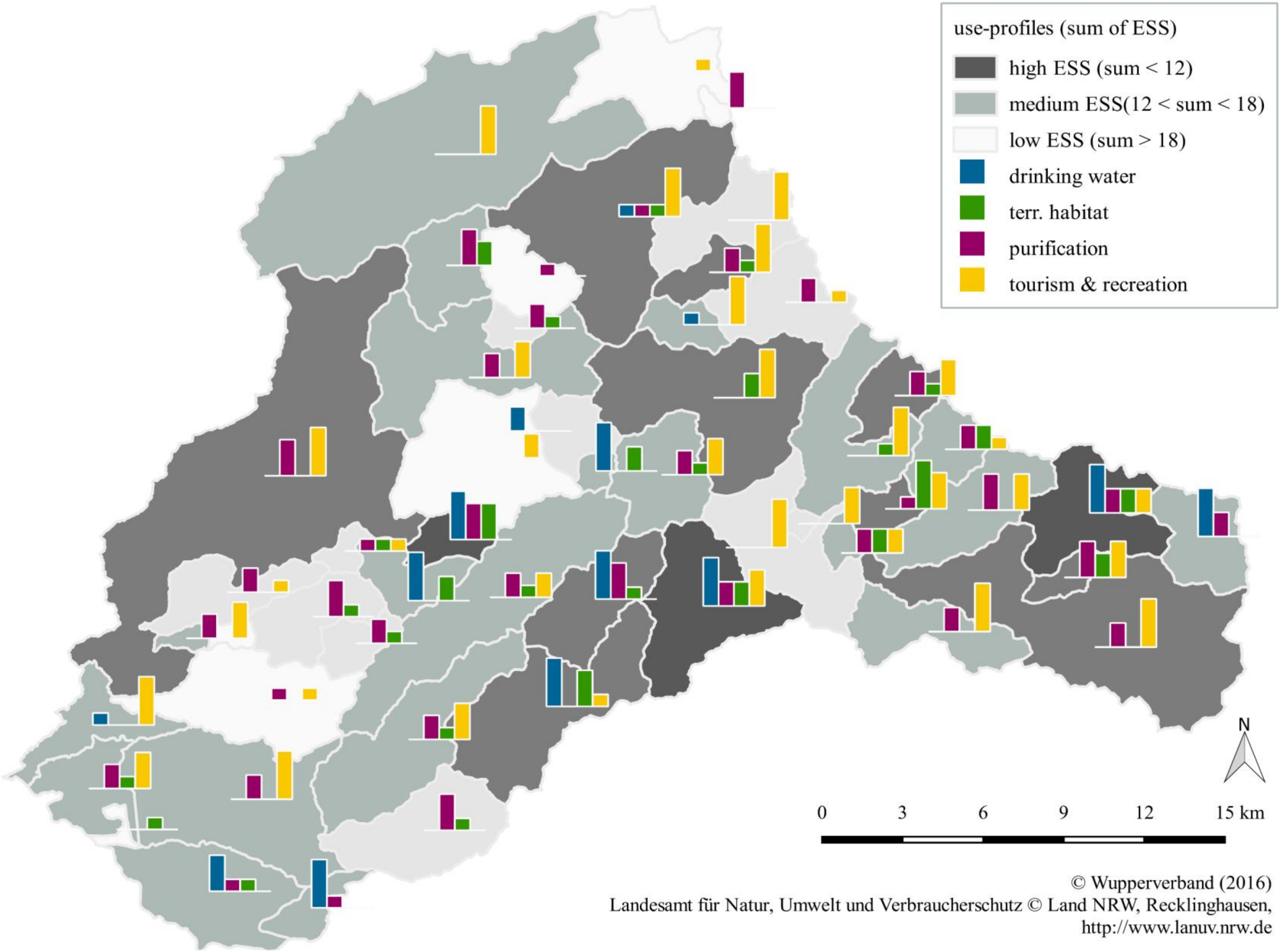

Figure 18: Use-profiles of the management sections in the Wupper catchment including four ecosystem services (ESS). The background colour indicates the sum of ecosystem services (dark = very high service; bright = very low) and the histograms display drinking water provision, terrestrial habitat provision, water purification and tourism & recreation

After the visual inspection by use-profiles, the relations of ecosystem services were investigated mathematically by regressions. The results of regression among the ecosystem services of the 52 management sections showed very low correlation coefficients of determination from 0.00 to 0.14 (Table 4). Therefore, no significant correlation among the ecosystem services was identified when considering the total of the management sections.

Table 4: Correlation coefficient (R^2) of ecosystem services classes (n =52)

R^2	DRINKING WATER PROVISION	WATER PURIFICATION	HABITAT PROVISION	TOURISM & RECREATION
DRINKING WATER PROVISION		0.01	0.12	0.14
WATER PURIFICATION	0.01		0.00	0.00
HABITAT PROVISION	0.12	0.00		0.01
TOURISM & RECREATION	0.14	0.02	0.01	

Besides searching for a correlation among the ecosystem services, also a correlation to water quality indicators according to the WFD were analysed. The regression resulted again in low coeffients of determination ranging from 0,00 to 0,21 (Table 5), whereby the highest correlation was assessed between macrozoobenthos and habitat provision. It was thereby shown that the four assessed ecosystem services were not correlating significantly with the five selected water quality indicators, too.

Table 5: Correlation coefficient (R^2) of ecosystem service classes with WFD features

R^2	DRINKING WATER PROVISION	PURIFICATION	HABITAT	TOURISM & RECREATION
MACROZOOBENTHOS	0.08	0.00	0.21	0.03
MACROPHYTES	0.02	0.02	0.06	0.04
METALS	0.03	0.00	0.03	0.08
PLANT PROTECTION PRODUCTS	0.05	0.02	0.01	0.00
GENERAL CHEMICAL AND PHYSICAL PARAMETERS	0.00	0.00	0.05	0.01

In summary, the use-profiles were highly variable in the 52 management sections. There were no direct correlations found among the assessed ecosystem services or between ecosystem services and water quality indicators according to WFD.

4.4 Comparison of Ecosystem Services by Characteristics

The availability of characteristics of the management sections offered the opportunity to search for factors influencing the ecosystem services drinking water provision, habitat provision, water purification and tourism & recreation considerably. In this chapter, structural differences were considered, such as river types and the designation to heavily modified or natural water body. Thereby, the management sections were divided in groups regarding the presence of dams in order to show potential correlations.

4.4.1 River Types

According to Chapter 4.1, the streams in the Wupper catchment have been categorized, which can be seen in Appendix Table A 1. River types differ in flow and sediment characteristics of the river bed. The comparison of ecosystem services in the five river types showed considerable differences in the corresponding ecosystem services (Figure 19).

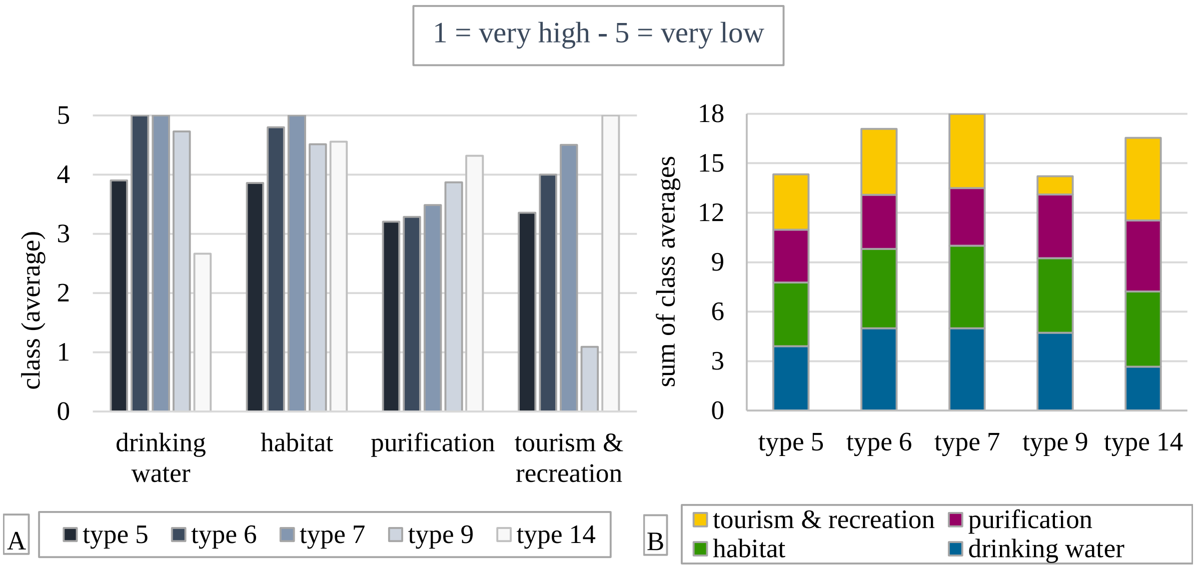

Figure 19: Comparison of the ecosystem services drinking water provision, terrestrial habitat provision, water purification and tourism & recreation A) per river type 5 (n = 31), 6 (n = 5),7 (n = 2), 9 (n = 11) and 14 (n = 3), each ecosystem service average class and B) use-profiles (sum of average ecosystem service per river type

It can be seen that the average drinking water provision in river type 14 was higher than in the other river types (Figure 19 A), and type 5 showed a comparatively high average of drinking water provision, too. This result may be explained by the presence of either dams or groundwater protections zones in river type 14 and 5 (see Chapter 3.3.1). When focussing on habitat provision and water purification, the averages were similar among the types, where the highest variations were found from 3.86 to 4.56 and 3.20 to 4.32 respectively. The most obvious differences among the river types were showed in tourism & recreation. Here, an average class of 1.09 was only found in type 9. In comparison, in types 5, 6, 7 and 14 tourism & recreation was from 3.20 to 5.00. By definition of type 9, only rivers but no tributaries were considered. This result correlated with the observation in Chapter 3.3.4 that tourism & recreation was higher related to main stream Wupper compared to its tributaries.

The sum of ecosystem services per river type provided insight about the specific use-profiles (Figure 19 B). According to this, the sum of ecosystem services per river type showed that type 5 and type 9 offered a lower sum and therefore higher classes in the use-profile of ecosystem services than type 6 and 7. This difference was obviously driven by tourism & recreation, especially regarding type 9. For completing the analysis, regressions of ecosystem services and river types were performed, whereby no significant relationships were found.

4.4.2 Heavily Modified and Natural Water Bodies

The designations ‘heavily modified water body’ and ‘natural water body’, according to WFD, showed an important characteristic of the management sections regarding the structure and human influences. Therefore, the management sections were divided into these two groups and its relation with ecosystem services was analysed.

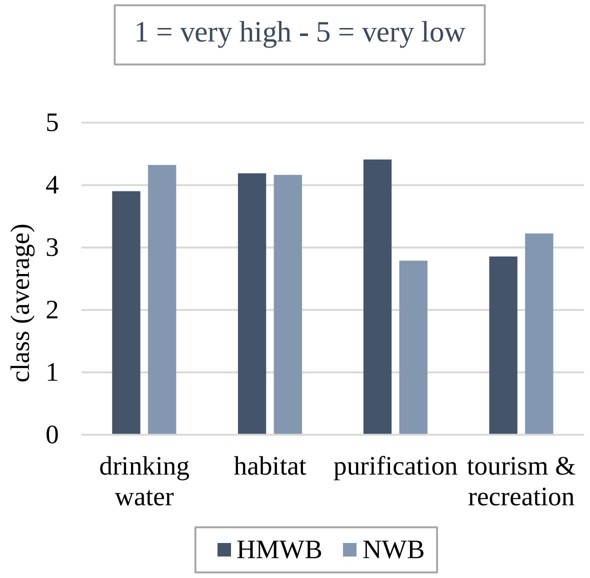

Figure 20: Comparison of mean ecosystem services per water body type NWB (n=31) and HMWB (n=21) (NWB = natural water body; HMWB = heavily modified water body)

The comparison of average classes resulted in a considerable difference regarding water purification (Figure 20) with a difference of the average classes from 4.41 in HMWB to 2.79 in NWB. In consequence, natural water bodies provided a considerably higher water purification than heavily modified water bodies. Concentrating on drinking water provision and habitat provision, the average classes of HMWB were similar to the average classes of NWB (3.90 – 4.32 and 4.19 – 4.16 respectively). Also, tourism & recreation showed very similar averages, but at a general higher level of classes (2.86 – 3.23 respectively). Even though a difference was identified for water purification, no correlations for ecosystem services were found even after separating management sections into heavily modified and natural water bodies.

4.4.3 Presence of Dams

In the Wupper catchment, the high density of dams is unique for German river catchments. Hence, it was analysed if the presence of a dam in management sections has a considerable influence on the ecosystem services and their use-profiles. Therefore, a comparison of ecosystem services in management sections either with or without dams was performed. This analysis revealed obvious differences, mainly for drinking water provision and habitat provision (Figure 21 A).

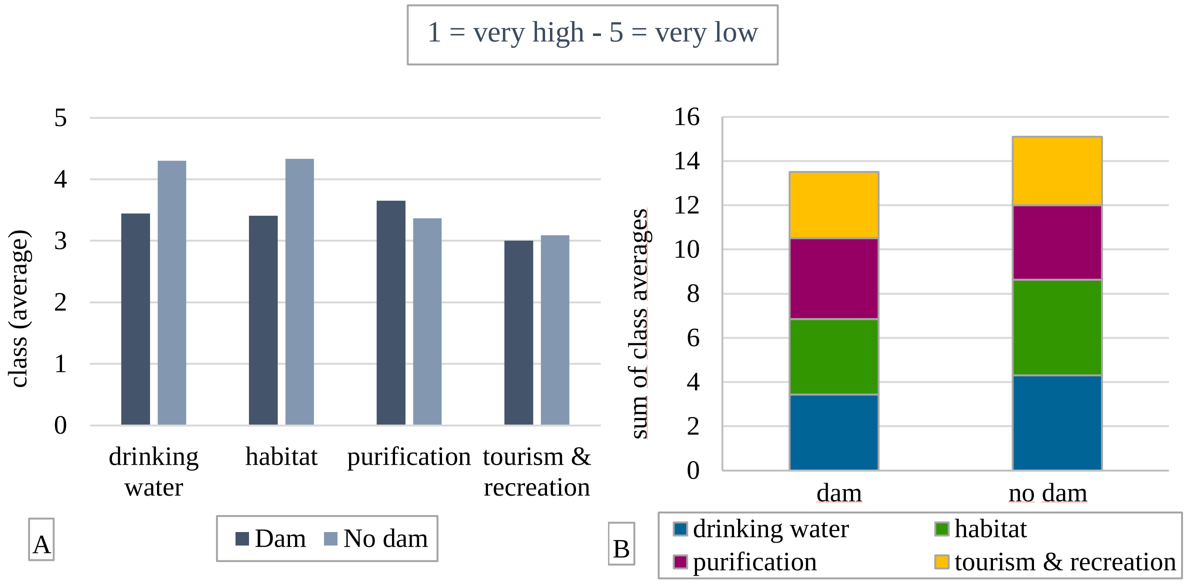

Figure 21: Comparison of mean ecosystem service classes of drinking water provision, terrestrial habitat provision, water purification and tourism & recreation in management sections A) with and without dams B) use-profiles (sum of ecosystem service) for dam and no dam

The average drinking water provision class was higher in management sections with dams than in river or stream management sections (3.44 and 4.30 respectively). Similarly, habitat provision exhibited higher services in management sections with dams (3.41 and 4.33 respectively). In comparison, both water purification and tourism & recreation hardly showed any differences in the average classes (3.65 to 3.37 and 3.00 to 3.09 respectively). The sum of ecosystem services indicated that, in general, management sections with dams provided higher services and therefore better use-profile than management sections without dams (Figure 21 B).

Since the average classes of management sections varied according to the presence of dams, the use-profiles were investigated again separately regarding potential correlations, too. In the management sections without dams, no correlations among drinking water provision, habitat provision, water purification and tourism & recreation were found. In contrast, drinking water provision correlated with tourism & recreation in use-profiles of management sections with dams (Figure 22).

The nine management sections with dams seemed to be grouped in two parts when excluding the Diepentaler-Talsperre (ID:37). On the one hand, low classes of drinking water provision (class 5) corresponded to high classes of tourism & recreation (class 1 or 2). On the other hand, high classes of drinking water provision matched with medium classes of tourism & recreation (class 3,4 or 5) (Figure 22 A). This inverse correlation is both shown in the bar diagram and also in the regression (Figure 22 B). The regression was performed twice. First, all nine management sections with dams were included, which resulted in a correlation coefficient of 0.33 only (n = 9). Second, the Diepentaler Talsperre (ID:37) was excluded, and the correlation coefficient increased up to 0.64 (Figure 22 B, n = 8). Considering the land use categories, the exclusion was reasonable due to the exceptional high urban areas of 61.6 % (ID:37) compared to the range of urban areas (0.0 to 34.2 %) in the remaining eight management sections.

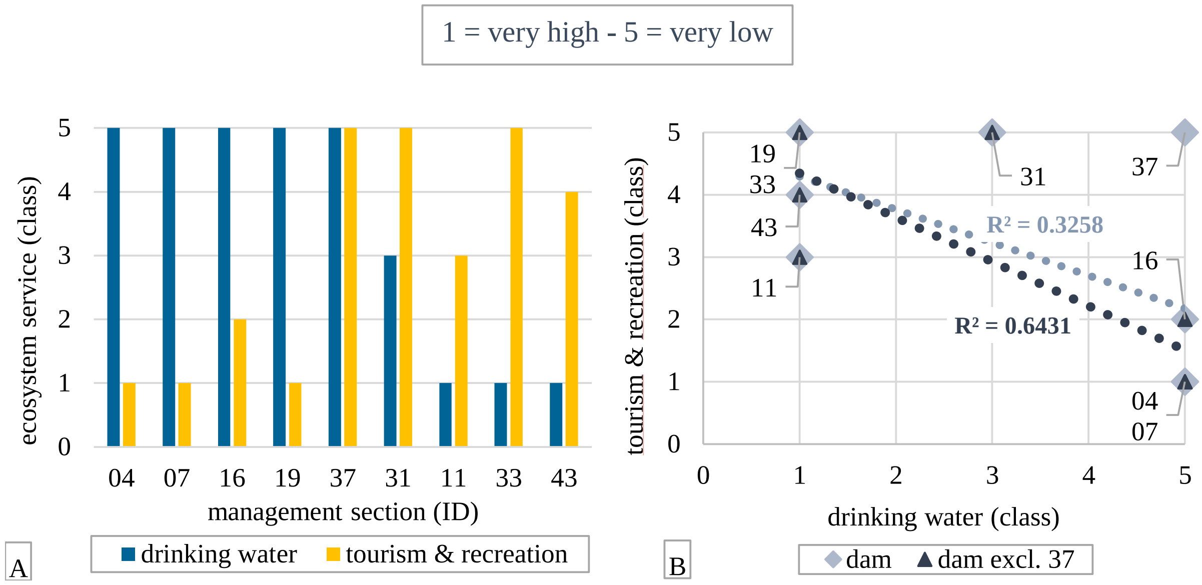

Figure 22: Comparison of drinking water provision and tourism & recreation classes in all management sections with dams (n = 9), A) individual values oer management sections and B) regression of the two ecosystem service classes classes in dams (n = 9) as well as exclusive ID:37 (n = 8)

The assumption of grouped use-profiles regarding drinking water provision and tourism & recreation were followed by the search for the driving factor of differentiation. The relevant management sections were completely represented in HMWB. Additionally, the dams were indeed found in two different river types (5 and 9), but these did not correlate with the groups formed (Figure 22). Since the land use category urban areas was the reason to exclude a single management section, an investigation of the linkage between ecosystem services and land use categories was performed. The six regressions exhibiting the best coefficients of determination occurred among all four assessed ecosystem services and the land use categories urban areas, grasslands, forests and water bodies, both as trade-offs and synergies (Figure 23). Cropfields did not correlate with any ecosystem service neither in management sections with dams nor in management sections without dams (Table 6 and Table 7).

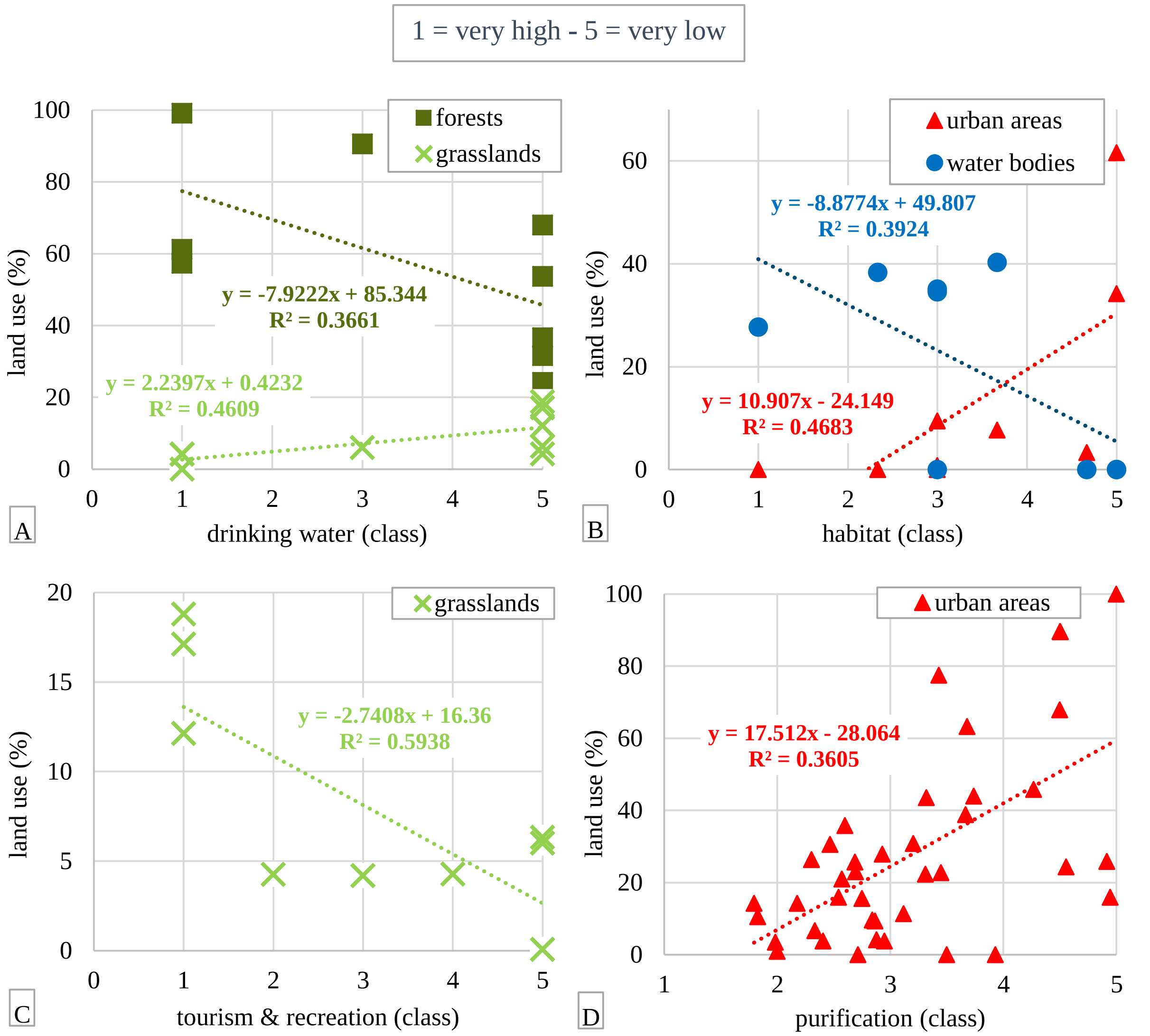

Figure 23: Significant regressions with land use categories in manangement sections with dams (A/B/C, n = 9) of A) drinking water provision, B) habitat provision and C) tourism & recreation as well as D) water purification with urban areas in management sections without dams (n = 43)

The coefficients of determination between ecosystem services and land use larger than 0.3 were highlighted in order to identify the most important interdependencies (Table 6 and Table 7). Considering only management sections without dams, water purification and urban areas were correlating negatively (Table 6, marked red = trade-off). This means that a higher ratio of urban area resulted in lower services of water purification and vice versa. The regression showed a correlation coefficient of 0.36 (n = 43) (Figure 23 D). Apart from that, no other correlations of ecosystem services and land use categories could be found in management sections without dams.

Table 6: Correlation coefficients (R^2) of ecosystem services and land use in management sections without dams. Above a level of significance = 0.3, the synergies (green) and trade-offs (red) were differentiated by highlighting colours

R^2	DRINKING WATER PROVISION	WATER PURIFICATION	HABITAT PROVISION	TOURISM & RECREATION
URBAN AREAS	0.01	**0.36**	0.16	0.00
CROPFIELDS	0.01	0.11	0.07	0.02
GRASSLANDS	0.00	0.11	0.00	0.05
FORESTS	0.04	0.21	0.20	0.04
WATER BODIES	0.10	0.03	0.00	0.02

Compared to the management sections without dams, a perceivable higher number of relevant regressions were found for management sections with dams (Table 7).

Table 7: Correlation coefficients (R^2) of ecosystem services and land use in management sections with dams. Above a level of significance = 0.3, the synergies (green) and trade-offs (red) were differentiated by highlighting colours

R^2	DRINKING WATER PROVISION	HABITAT PROVISION	WATER PURIFICATION	TOURISM & RECREATION
URBAN AREAS	0.27	**0.46**	0.08	0.01
CROPFIELDS	0.17	0.20	0.05	0.06
GRASSLANDS	**0.46**	0.06	0.04	**0.59**
FORESTS	**0.36**	0.05	0.01	0.22
WATER BODIES	0.00	**0.39**	0.11	0.27

Therefore, it can be seen that drinking water provision corresponded negatively with grasslands but positively with forests. Also habitat provision showed both a trade-off with urban areas and a synergy with water bodies. Water purification was not correlating with any land use category. Then again, tourism & recreation correlated positively with grasslands and thereby presented the highest correlation coefficient of the regressions.

In total, grasslands were the only land use category, which correlated significantly with two ecosystem services in management sections with dams, as drinking water provision and tourism & recreation. These correlations were inverse. Hence, a higher percentage of grasslands resulted in a lower class for drinking water provision but a higher class of tourism & recreation. Then, the percentages of grasslands were checked if they correlated with the formed groups (Figure 22). In doing so, it was observed that the average of grasslands in management sections 04, 07, 16 and 19 was approximately 3.6 times higher than the average of grasslands in management sections 11, 31, 33 and 43 (13.08 % and 3.64 % respectively). Thus, it can be shown that the land use category grasslands was the relevant factor for forming groups of the ecosystem services drinking water provision and tourism & recreation in management sections with dams.

In summary, the comparisons of ecosystem services separated by characteristics showed only correlations when management sections with or without dams are considered separately. In the comparison of heavily modified with natural water bodies, no significant differences were assessed. Similarly, by comparing the ecosystem services in the river types of the Wupper catchment no correlations were found. When focussing on dams, drinking water provision and tourism & recreation correlated significantly ($R^2 = 0.64$). Additionally, a direct significant correlation of ecosystem services with land use categories was shown. In management sections without dams, a trade-off between water purification and urban areas was identified. Finally, the land use category grasslands was found to represent the driving factor for both drinking water provision and tourism & recreation in management sections with dams.

5. Discussion

For the first ecosystem service assessment in the Wupper catchment interesting results were found (Chapter 4). In the discussion, the results are critically reflected with regard to the methods applied and indicators selected in order to verify and sort in the results. Furthermore, the identified correlations are interpreted which enables to describe the main outcome of this thesis.

Considering the methods, the acquisition of available **datasets** was the first step, which formed the basis for the ecosystem service assessment. Most of the specific data were collected by the Wupperverband, an association that maintains the data of this region. Therefore, it was possible to make use of the actual data, meaning that the oldest datasets were monitored in 2006 (identification of water body sections) and between 2008-2014 (for biotopes). As for those datasets no significant changes over time can be expected, the overall uncertainties related to temporal differences in the complete dataset of this analysis is comparatively low.

Furthermore, the spatial resolution of the data needs to be considered. For CORINE Land Cover (temporal coverage 2011-2012), the minimal geographic accuracy is ≤ 100 m which means that linear structures, especially rivers and streams cannot be displayed adequately (Büttner and Kosztra, 2007; Büttner et al., 2014). Thus, the data is rather coarse which has a high influence on the results of the assessment of ecosystem services in rivers and floodplains. Hence, for habitat provision here mainly the terrestrial habitat provision in close vicinity of the rivers and streams was described. The resolutions of monitoring data of the aquatic structures which were used as indicator for the water purification, were related to the Wupper catchment scales (>1:50.000). Most of the other datasets (biotope zones, water protection zones etc.) were rather detailed referring to the scale 1:5000. Since the relatively coarse CORINE data is implemented in the aggregated habitat class based on four indicators in total, the uncertainty is reduced by the data with better resolution.

The selection of indicators for the ecosystem service **drinking water provision** was based on a literature research. Mostly the actual use of drinking water was proposed as indicator, for example the drinking water extraction, the final consumption per inhabitant or the water exploitation index (e.g. Grizzetti et al., 2015; Burkhard et al., 2014). Another way to indicate drinking water provision is the availability of surface water (Maes et al., 2014), which corresponded the most to the Wupper catchment where mainly dams and reservoirs supply the inhabitants with drinking water. Within this indicator, not the location of extraction was considered but also the complete catchment supplying the reservoirs with clean water. Hence, the selected indicator for drinking water provision, namely the water protection zones, covered the relevant areas most adequately due to their defined purpose of protecting drinking water catchments. It has to be mentioned that only actual used catchments are considered for protection zones, whereas potentially suitable areas are not considered even though good water quality could be present. Additionally, the management sections 50 and 51 showed a high drinking water provision despite the absence of reservoirs. This can be explained by the underlying aquifer that supplies the adjacent catchment with groundwater. For drinking water provision, the classification based on quantiles turned out to be not meaningful, due to the occurrence of rather extreme ratios. A modification was done A manually adjustment of classification levels in regard to the range of ratios allowed the geographical information system to enhance the visualization of the classes in the Wupper catchment.

The ecosystem service assessment of **water purification** is mainly based on the assumption that a good aquatic structure of the river enhances the potential of self-cleaning and vice versa, according to the method after Albert et al. (2015). In the Wupper catchment, the rivers and streams are highly modified and represent a total number of poor aquatic structures above average in Germany (MKNULV and

LANUV, 2015). For this reason, the method was further developed in the context of this thesis. In contrast to the literature, not the ratio of good structure lengths to the total river or stream length, but the average of aquatic structure in the management sections of the Wupper catchments was applied. Dams and reservoirs show mainly characteristics of lakes and are therefore less mixed and less saturated by oxygen, thus the water purification is very low. Therefore, the water purification could have been defined to the lowest class. Since this definition has not been performed, the ecosystem service water purification in management sections with dams most likely represents too high classifications. The high population density also demands a large capacity of WWTP, whereby their effluents represent an additional pressure on the Wupper and its tributaries. This negative influence of effluents was considered in the assessment of water purification by counting the WWTP per management section. This innovative method could be further improved by taking into account that the effluents are diluted and the pollution degrades exponentially when running downstream. Furthermore, it is known that diffusive sources play a major role in terms of pollution in the Wupper catchment but are hardly to assess (MKNULV and LANUV, 2015).

The most complex assessment was performed for the ecosystem service **habitat provision**, where four different indicators were summed up to one common class for the ecosystem service. The method was mainly adapted from Scholz et al. (2012) and Koenzen (2005) including Natura-2000, biotopes and the land use intensity. However, the datasets used in this thesis differed. In Natura-2000, not only the FFH-areas were included but also the nature protection zones in the Wupper catchment. Additionally, the analysis of land use intensity originally included seven land use categories (Koenzen, 2005), whereas in this thesis only five defined. In addition, that data base differed, Scholz et al. (2012) applied a dataset with a higher resolution than the CLC dataset used here was available. This is clearly a shortcoming of the method applied here as the resolution has clear implications for the interpretation of the results (as explained above). In addition, the method needed to be adjusted to the dataset. As the class “other land use” is not present in the CLC data, the rules for evaluation were changed (see Figure 8, p.10). In addition, the land use category “wetlands” was not found in the Wupper catchment and was therefore not considered in the evaluation. The fourth component of the habitat provision class referred to technical constructions within the rivers or streams. In Scholz et al (2012) solely the presence of backwater was applied to lower the class. Here, the method was advanced by integrating the barriers and their falling heights in order to achieve a more expressive indicator for the negative influence on the habitat quality,. The highest uncertainty in the method regarding barriers is the completeness of the datasets and the evaluation of heights as influence. Firstly, it is known that impoundment heights with 53 m occur in the Wupper catchment (Table 3), but these heights are not represented in the barrier indicator data set (compare Table A 5: Calculated influence by barriers in the land use intensity indicator of the ecosystem service habitat provision). This leads to the assumption that the applied dataset is incomplete and could be further developed. Even though, the inclusion of more specific characteristics than the backwater is performed. Secondly, the evaluation of barriers required a classification. This was done here considering expert knowledge and reflecting the available data. On the one hand, it is not possible to identify heights that cover the characteristics of multiple species as the individual thresholds are very specific. Thus, it was assumed that a barrier lower than 1 m can be passed by larger fish species. In addition, taking 1 m includes also the possibility that the alignment is not vertical (here no further information was available), here even smaller species would be able to pass the barrier. However, it needs to be acknowledged that for several species 1 m represents a clear barrier. Consequently, with more detailed data and additional datasets the class for habitat provision applied in this study could be improved further.

The fourth ecosystem service assessed was **tourism & recreation**, which was indicated by trails for walking, hiking or cycling as well as official points of interest, namely baths, kayak routes, observation points and camping sites within the buffer zone of 200 m alongside the water bodies. The results indicated that the water-related tourism & recreation is concentrated on the Wupper which may resulted from the applied dataset. The level of infrastructure near the Wupper is considerably higher wherefore also specific trails, e.g. for tourism, occur more often. There was an unusually low amount of paths and trails in the more natural areas surrounding the tributaries, as such one could well assume that there are probably more trails but these are not labelled properly, thus are not in the dataset. For instance, the Diepentaler Talsperre (ID:37) is known for touristic use but shows only class 5 in tourism & recreation. In order to enhance the validity of this service, it would be recommendable to expand the net of infrastructure specifically suitable for cultural services. Thus, the assessed ecosystem service tourism & recreation is representative by touristic trails in the Wupper catchment. By an additional inclusion of more than only special trails for tourism, also the recreational activities could be considered. This assessment could also be supported by surveys among the inhabitants in the region. In the management section of the Dhünn-Talsperre, the low class contradicts with the literature where information of trails in this area was found. This could be explained by the presence of water protection zones alongside the bank and inside the reservoir. By application of a buffer zone about 200 m, the trails further apart were cut off from the area of interest and consequently, lowering tourism & recreation. When focussing on the inclusion of POI, the indicator would be expandable by weighted relevance for water-related tourism & recreation. In this study area, a counting was sufficient since the presence of POI was investigated to be within the management sections with already high classes due to the trails. Hence, a more detailed analysis on influences by weighted POI was not improving the outcome and therefore not meaningful.

Finally, this thesis makes use of linear regression for the comparison of ecosystem services in the Wupper catchment. The uncertainties and low correlation coefficients could be explained by the fact that discrete classes are represented. In contrast to continuous data, the assignment to only five classes affects the statistical values, such as average and standard deviation. In the comparison of management sections with dams, an extension by other dams in bordering catchments would be reasonable in order to further investigate the correlation of drinking water provision and tourism & recreation as well as ecosystem services and the land use categories, especially grasslands.

The **results of this ecosystem service assessment** in the Wupper showed interesting relations but also differences, which are further interpreted alongside the research hypotheses. Firstly, the assessment of drinking water provision, habitat provision, water purification and tourism & recreation, showed a heterogeneous distribution among the management sections. Despite the inverse hotspots for habitat provision and tourism & recreation (tributaries and Wupper respectively), the overall comparison did not show direct interaction. This is the result of extremely various land use in the study area. While the northern and south-western part of the area is dominated by urban areas, the remaining area shows mostly high shares of the land uses forests and grasslands. Despite this rough trend, the land use diagrams per management sections visualized a further subdivision, where also high urban areas occur in the previously more natural seen parts of the Wupper catchment (Figure 14, p.17).

Regarding the ecosystem services in management sections with dams, the use-profiles showed two contrary types occurring. While half of the management sections is dominated by the ecosystem service tourism & recreation, the other half is only dominated by drinking water extraction. This directly inverse correlation of eight management sections with dams was proven by regression ($R^2 = 0.64$). By comparing ecosystem services to characteristics of the management sections in the Wupper catchment, both trade-offs and synergies were found. The construction of dams in this area changed intensively the environment so that management sections with dams became incomparable to those without dams. Mainly the land use was significantly correlating, as there are water purification and urban areas (trade-off in no dams), habitat provision with urban areas and water bodies (trade-off and synergy in dams respectively), drinking water provision with forests and grassland (synergy and trade-off in dams respectively) as well as tourism & recreation with grasslands (synergy in dams).

The main difference of management sections with and without dams was found in drinking water provision and habitat provision; both services are more represented in management sections with dams than in those without. The land use in the buffer zones of management sections with dams is dominated by either forests or grassland, whereby the Diepentaler Talsperre (ID:37) represents an exceptional high share of urban areas (67 %). The trade-off with grassland in dams was significant, whereby grasslands can be seen as the main agricultural land use due to the low shares of cropfields in the Wupper catchment. The correlation with drinking water provision in management sections with dams can be explained by the protection zones due to drinking water purposes. Here, the exploitation of grasslands is controlled and as a logical consequence, the habitat provision is increased, too. Thus, the construction of dams and reservoirs state a high impact onto the habitat provision due to a decreased connectivity, especially within the water bodies. Another characteristic to be considered is the absence of urban areas. The water-related terrestrial habitat provision is high around large dams but only with low degree of urbanization. Finally, it should not be concluded that the construction of dams increases the habitat provision. In contrast, the water quality is appropriate for drinking water provision due to nature and water protection zones established in functioning ecosystems with a high habitat provision. Therefore, an adaption of drinking water protection zones to other dams could also preserve the habitat provision.

The results of the ecosystem service water purification showed that this service is only correlating with urban areas in management sections without dams. This trade-off is reasonable according to the land use and the selection of indicators. The general capacity of self-cleaning is known to be very low in reservoirs, wherefore rarely variations in the water purification service occur. The correlation of urban areas with water purification indicates the high influence of population densities in the Wupper catchment. Additionally, the dense population requires a high capacity of closely WWTP, whereby their effluents pose a pressure on the self-cleaning capacity. Furthermore, the indicator aquatic structure is also influenced directly by urbanization. In city areas, the river bed and banks are mostly stabilized to straighten or also piping the water in defined channels. The most extreme example is a management section of the Mutzbach (ID:49) where the total extent of the river is piped towards the tributary Dhünn. Herein, the tourism and habitat provision cannot be considered as water-related. Hence, the trade-off between water purification and urban areas is verified within this thesis. The heavily modified water bodies include management sections with dams. Here, the difference to natural water bodies considering the ecosystem service purification was shown. since more data are assessed and reasonable.

The use-profiles show, that all combinations of ESS exist. Hence, a dam providing drinking water and habitat can also be used for tourism & recreation at the same time efficiently. By comparison with the use of dams found in literature (compare Table 3, p.16), use-profiles may indicate the presence of further uses, which are not included in the assessment yet, such as hydropower, flood protection or water table regulation. With an extended dataset on the relevance and intensity of uses, the assessment could be further developed to achieve a more comprehensive use-profile. Therefore, data on produced energy by hydropower has to be considered. If the outcome of hydropower is comparatively low, a change in management could be considerable since ecosystem services such as drinking water provision may have a larger positive effect on ecosystem services. By inclusion of use-profiles of the smaller dams and reservoirs, which were excluded in this thesis, a comparison may provide further knowledge.

Meaning of grassland is very high since the share of cropfields is exceptionally low for Germany, and even for North Rhine Westphalia (34.7 % according to MKNULV and LANUV, 2015). Hence, besides urban area, the second most intensive land use is represented by grassland. Furthermore, there is no obvious explanation for a significance of forests in management sections with dams but not in those without dams. It has to be considered that a further investigation on other influences is required.

6. Summary and Conclusion

As the purpose of this thesis was the initial assessment of the four ecosystem services drinking water provision, habitat provision, water purification as well as tourism & recreation in the Wupper catchment, North Rhine-Westphalia (Germany), already existing methods were combined and adjusted to the needs and capabilities of this study. The assessment of ecosystem services covers a highly urbanized but still various landscape, which is typical for the western part of Germany. The various land uses of the 52 management sections within a buffer zone alongside the Wupper and its tributaries were driving characteristics of the assessed ecosystem services and their corresponding use-profiles. The high density of dams within the catchment provides a new level for comparison. Concentrating on management sections with dams, drinking water provision and tourism & recreation showed an inverse proportionality whereas other correlations among the total extent of the Wupper catchment were not found. The findings of the ecosystem service assessment can improve the knowledge according to the status of water quality (WFD) with a different perspective.

The use-profiles could illustrate a first and temporary version of an ecosystem service index represented by comparable classes. These use-profiles could be completed by the assessment of further ecosystem services in order to achieve a comprehensive index. Even though the selection of methods and indicators can be further discussed and developed, this thesis provides a very first insight into the Wupper catchment and its ecosystem services. The anthropocentric point of view in the applied concept is perfectly suitable to the study area due to the overly represented density of population as well as the resulting intensive modification and use of the Wupper and its tributaries for different purposes.

In the process of working on the ecosystem assessment in the Wupper catchment, other suggestions and ideas for further investigation came across. The discussion highlighted already some critical questions which should come with further analysis. Of course, completing the set of ecosystem services would be preferable so that a total index could be determined. The EU-funded project River Ecosystem Service Index (RESI) aims to build such a comprehensive index, where the Wupper catchment is one of the concerned study areas. It would also be interesting to concentrate on the water purification in the Wupper. Since an overall bad chemical status still occurs, the need for further investigation on the pollution sources and transport processes to and within the river is obvious and already stated in the management plans of North Rhine-Westphalia (MKNULV and LANUV, 2015). Therein, the divergent influences by diffusive pollution sources, WWTPs and industrial effluents could be analysed and may related in terms of relevance.

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8. Appendix

Table A 1 List of ID, names, and river type of management sections

ID	SURFACE WB ID	NAME	CATEGORY WB	DAM	TYPE	TYPE DESCRIPTION
00	DE_NRW_2736_0	Wupper	HMWB		9	Silikatische, fein- bis grobm
01	DE_NRW_2736_40215	Wupper	HMWB		9	Silikatische, fein- bis grobm
02	DE_NRW_2736_56845	Wupper	NWB		9	Silikatische, fein- bis grobm
03	DE_NRW_2736_5925	Wupper	NWB		9	Silikatische, fein- bis grobm
04	DE_NRW_2736_64866	Wupper	HMWB	dam	9	Silikatische, fein- bis grobm
05	DE_NRW_2736_66964	Wupper	NWB		9	Silikatische, fein- bis grobm
06	DE_NRW_2736_71895	Wupper	HMWB	dam	9	Silikatische, fein- bis grobm
07	DE_NRW_2736_75165	Wupper	HMWB	dam	9	Silikatische, fein- bis grobm
08	DE_NRW_2736_87802	Wupper	HMWB		9	Silikatische, fein- bis grobm
09	DE_NRW_2736_95381	Wupper	HMWB		5	Grobmaterialreiche, silikatis
10	DE_NRW_273612_0	Kerspe	NWB		5	Grobmaterialreiche, silikatis
11	DE_NRW_273612_2037	Kerspe	HMWB	dam,lake	5	Grobmaterialreiche, silikatis
12	DE_NRW_273612_6430	Kerspe	NWB		5	Grobmaterialreiche, silikatis
13	DE_NRW_273614_0	Hönnige	NWB		5	Grobmaterialreiche, silikatis
14	DE_NRW_273616_0	Gaulbach	NWB		5	Grobmaterialreiche, silikatis
15	DE_NRW_273618_0	Neye I	NWB		5	Grobmaterialreiche, silikatis
16	DE_NRW_273618_2444	Neye I	HMWB	dam, lake	5	Grobmaterialreiche, silikatis
17	DE_NRW_273618_5610	Neye I	NWB		5	Grobmaterialreiche, silikatis
18	DE_NRW_27362_0	Bever	HMWB		5	Grobmaterialreiche, silikatis
19	DE_NRW_27362_1760	Bever	HMWB	dam, lake	5	Grobmaterialreiche, silikatis
20	DE_NRW_27362_6225	Bever	NWB		5	Grobmaterialreiche, silikatis
21	DE_NRW_273634_0	Dörpe	NWB		5	Grobmaterialreiche, silikatis
22	DE_NRW_273638_0	Uelfe	NWB		5	Grobmaterialreiche, silikatis
23	DE_NRW_27364_0	Schwelme	HMWB		7	Grobmaterialreiche, karbonati
24	DE_NRW_27364_6793	Schwelme	NWB		7	Grobmaterialreiche, karbonati
25	DE_NRW_27366_0	Morsbach	NWB		5	Grobmaterialreiche, silikatis
26	DE_NRW_273662_0	Leyerbach	NWB		5	Grobmaterialreiche, silikatis
27	DE_NRW_273662_2526	Leyerbach	HMWB		5	Grobmaterialreiche, silikatis
28	DE_NRW_273664_0	Gelpe	NWB		5	Grobmaterialreiche, silikatis
29	DE_NRW_273672_0	Eschbach	NWB		5	Grobmaterialreiche, silikatis
30	DE_NRW_273672_10624	Eschbach	NWB		5	Grobmaterialreiche, silikatis
31	DE_NRW_273672_9106	Eschbach	HMWB	dam	5	Grobmaterialreiche, silikatis
32	DE_NRW_2736732_0	Sengbach	NWB		5	Grobmaterialreiche, silikatis

Continuation Table A 1

ID	SURFACE WB ID	NAME	CATEGORY WB	DAM	TYPE	TYPE DESCRIPTION
34	DE_NRW_2736732_3339	Sengbach	NWB		5	Grobmaterialreiche, silikatis
35	DE_NRW_2736752_0	Weltersbach	NWB		6	Feinmaterialreiche, karbonati
36	DE_NRW_273676_0	Murbach	NWB		6	Feinmaterialreiche, karbonati
37	DE_NRW_273676_2940	Murbach	HMWB	dam	6	Feinmaterialreiche, karbonati
38	DE_NRW_273676_4700	Murbach	NWB		6	Feinmaterialreiche, karbonati
39	DE_NRW_273676_7967	Murbach	NWB		5	Grobmaterialreiche, silikatis
40	DE_NRW_273678_0	Wiembach	NWB		6	Feinmaterialreiche, karbonati
41	DE_NRW_27368_0	Dhünn	HMWB		9	Silikatische, fein- bis grobm
42	DE_NRW_27368_13988	Dhünn	NWB		5	Grobmaterialreiche, silikatis
43	DE_NRW_27368_23581	Dhünn	HMWB	dam, lake	5	Grobmaterialreiche, silikatis
44	DE_NRW_27368_32217	Dhünn	NWB		5	Grobmaterialreiche, silikatis
45	DE_NRW_27368_4784	Dhünn	NWB		9	Silikatische, fein- bis grobm
46	DE_NRW_27368312_0	Kleine Dhünn	NWB		5	Grobmaterialreiche, silikatis
47	DE_NRW_273684_0	Eifgenbach	NWB		5	Grobmaterialreiche, silikatis
48	DE_NRW_273686_0	Scherfbach	NWB		5	Grobmaterialreiche, silikatis
49	DE_NRW_273688_0	Mutzbach	HMWB		14	Sandgeprägte Tieflandbäche
50	DE_NRW_273688_10018	Mutzbach	HMWB		14	Sandgeprägte Tieflandbäche
51	DE_NRW_273688_2154	Mutzbach	HMWB		14	Sandgeprägte Tieflandbäche

Table A 2: Spatial extents of management sections, river length and 200 m buffer zones

ID	MS_AREA (M²)	B200_AREA (M²)	RIVER_LENGTH (M)
00	8796574	2421911	5925
01	71089262	7438468	16630
02	37163796	3542706	8021
03	85022384	14452720	34290
04	12606814	938938	2098
05	5577264	1913670	4931
06	4678074	1306962	3270
07	33151582	6410937	12637
08	17917500	3088539	7579
09	49544077	7708585	21089
10	3012152	719899	2037
11	16546527	4217901	4394
12	11337370	2468271	6072
13	15876132	3662792	9139
14	12034158	3337948	8388
15	2349945	877982	2445
16	4438859	2374626	3166
17	7381936	1677104	4179
18	1180267	755412	1759
19	17686230	4891512	4466
20	7896863	1553618	3762
21	12730395	2561406	6468
22	13855869	3070702	7947
23	17728474	2264864	6793
24	1042593	623336	1618
25	25976493	5529941	15146
26	2740681	910577	2527
27	8387901	1257117	3059
28	10143875	2271781	5779
29	24863145	3532875	9106
30	1810798	575019	1424
31	6563630	842083	1516
32	2134266	491838	1400
33	7289570	1167835	1939

Continuation Table A 2

ID	WB_AREA (M²)	B200_AREA (M²)	RIVER_LENGTH (M)
34	4901667	1558372	4091
35	10253566	3104671	8390
36	1476929	947397	2938
37	1475008	829048	1761
38	10286458	1303489	3268
39	4783859	1279790	3138
40	21538662	3968620	10534
41	9378600	1951256	4785
42	22485363	3592868	9593
43	25811533	10544604	8634
44	21145178	2955029	7819
45	32061882	3765199	9203
46	13792187	2572991	7809
47	31503025	7508909	20528
48	16849217	3420994	9709
49	1144621	641078	2154
50	4531609	1900875	5081
51	18909687	3034097	7864

Table A 3: Calculated water protection zones, ratios per management section and corresponding ecosystem service class of drinking water provision

ID	MS_AREA (M²)	WPZ_AREA (M²)	WPZ/WB (%)	CLASS
00	8796574	984758	11,19	4
01	71089262	0	0,00	5
02	37163796	5836585	15,71	4
03	85022384	672950	0,79	5
04	12606814	24144	0,19	5
05	5577264	57149	1,02	5
06	4678074	250029	5,34	4
07	33151582	97326	0,29	5
08	17917500	85694	0,48	5
09	49544077	233427	0,47	5
10	3012152	47530	1,58	5
11	16546527	16352546	98,83	1
12	11337370	11166575	98,49	1
13	15876132	92634	0,58	5
14	12034158	15883	0,13	5
15	2349945	0	0,00	5
16	4438859	0	0,00	5
17	7381936	13402	0,18	5
18	1180267	0	0,00	5
19	17686230	33625	0,19	5
20	7896863	99554	1,26	5
21	12730395	115687	0,91	5
22	13855869	33422	0,24	5
23	17728474	0	0,00	5
24	1042593	0	0,00	5
25	25976493	4186	0,02	5
26	2740681	0	0,00	5
27	8387901	0	0,00	5
28	10143875	0	0,00	5
29	24863145	122700	0,49	5
30	1810798	1792848	99,01	1
31	6563630	3236824	49,31	3
32	2134266	14916	0,70	5
33	7289570	7097422	97,36	1

Continuation Table A 3

ID	MS_AREA (M²)	WPZ_AREA (M²)	WPZ/WB (%)	CLASS
34	4901667	4822255	98,38	1
35	10253566	0	0,00	5
36	1476929	0	0,00	5
37	1475008	0	0,00	5
38	10286458	18226	0,18	5
39	4783859	2509	0,05	5
40	21538662	0	0,00	5
41	9378600	0	0,00	5
42	22485363	40319	0,18	5
43	25811533	25186902	97,58	1
44	21145178	21043813	99,52	1
45	32061882	21449	0,07	5
46	13792187	13708229	99,39	1
47	31503025	244192	0,78	5
48	16849217	54580	0,32	5
49	1144621	0	0,00	5
50	4531609	4225837	93,25	1
51	18909687	12594178	66,60	2

Table A 4 Calculated areas of natura 2000 zones, land use categories and biotopes of management sections for assessing the ecosystem service habitat provision

	NATURA 2000	LAND USE INTENSITY					BIOTOPES
ID	**natura/b200 (%)**	**crop/b200 (%)**	**urban/b200 (%)**	**fores/b200 (%)**	**grass/b200 (%)**	**water/b200 (%)**	**biotope/b200 (%)**
00	5,41	6,45	25,86	11,65	55,96	0,09	52,28
01	1,78	0	89,65	10,35	0	0	4,13
02	22,59	0	38,86	60,61	0,53	0	33,08
03	32,98	5,61	14,22	64,50	15,67	0	43,06
04	7,99	0	34,20	53,67	12,13	0	11,18
05	30,25	0,15	27,92	68,51	3,42	0	36,49
06	42,41	0,51	24,38	64,02	11,09	0	47,81
07	19,79	0	9,49	36,59	18,81	35,11	22,25
08	20,16	4,02	53,40	0,08	42,50	0	22,51
09	17,06	0	20,98	36,73	42,29	0	19,89
10	0,20	0	0,93	28,71	70,35	0	43,10
11	0,37	0	0	61,24	4,20	34,55	4,82
12	13,33	0	22,77	32,08	45,15	0	16,36
13	10,75	0	14,28	22,91	62,81	0	23,63
14	0	0,08	22,32	8,62	68,98	0	8,52
15	0,08	0	9,64	49,44	40,92	0	32,69
16	89,51	0	0	68,03	4,26	27,71	91,54
17	20,29	0	0	51,69	48,31	0	23,86
18	11,28	65,73	15,91	0	18,36	0	18,15
19	0	3,23	7,70	31,64	17,13	40,31	8,48
20	0	0,13	3,84	17,37	78,67	0	29,95
21	20,74	0	15,95	31,56	51,01	1,49	24,27
22	16,67	0	15,61	43,25	41,14	0	38,52
23	0	0	89,56	8,14	2,30	0	5,80
24	0	5,67	30,61	60,89	2,83	0	8,34
25	14,63	0	30,82	58,09	11,10	0	30,80
26	16,61	2,16	35,77	60,32	1,75	0	21,97
27	0	2,96	67,88	29,16	0	0	7,83
28	32,51	0	3,45	75,94	20,61	0	44,33
29	6,80	0	6,49	93,51	0	0	14,02
30	5,61	0	0,94	84,25	14,81	0	28,69

Continuation Table A4

	NATURA 2000	LAND USE INTENSITY					BIOTOPES
ID	**natura/b200 (%)**	**crop/b200 (%)**	**urban/b200 (%)**	**fores/b200 (%)**	**grass/b200 (%)**	**water/b200 (%)**	**biotope/b200 (%)**
31	2,21	0	3,35	90,63	6,02	0	27,79
32	13,12	0	0	100,00	0	0	20,46
33	20,61	0	0,81	99,12	0,07	0	23,52
34	43,37	0	10,57	83,64	5,79	0	56,87
35	11,20	7,54	23,04	42,59	26,83	0	48,46
36	0,05	9,22	9,36	42,14	39,29	0	47,98
37	0	7,84	61,60	24,21	6,34	0	10,63
38	0	0	26,36	36,66	36,98	0	45,52
39	0,20	0	25,72	48,60	25,68	0	30,88
40	9,89	10,13	43,95	21,98	23,94	0	22,76
41	3,91	0	77,48	1,89	20,62	0	16,83
42	35,18	0	11,39	80,88	7,73	0	49,29
43	47,24	0	0	57,38	4,28	38,34	25,44
44	23,87	0	0	57,20	42,80	0	30,08
45	13,83	15,59	43,58	24,28	16,54	0	27,51
46	27,87	0	6,65	66,77	22,41	4,17	36,56
47	34,94	0,54	4,15	70,48	24,82	0	24,99
48	18,28	0	3,80	32,89	63,31	0	19,96
49	0,08	0	100,00	0	0	0	0,08
50	0,00	0	63,25	17,15	19,60	0	17,13
51	4,35	6,47	45,82	35,87	11,85	0	20,07

Table A 5: Calculated influence by barriers in the land use intensity indicator of the ecosystem service habitat provision

ID	N_BARRIERS	SUM_FALLING HEIGHT (M)	PLUS 1-CLASS <5M	PLUS 2-CLASS >5M
00	1	2,00	-1	0
01	3	10,60	0	-2
02	1	0,30	0	0
03	4	12,00	0	-2
04	1	6,50	0	-2
05	1	2,00	-1	0
06	1	10,00	0	-2
07	1	0,04	0	0
08	2	5,00	-1	0
09	24	8,40	0	-2
10	0	0,00	0	0
11	1	0,35	0	0
12	7	2,00	-1	0
13	9	2,40	-1	0
14	14	2,22	-1	0
15	3	0,15	0	0
16	2	0,75	0	0
17	2	0,60	0	0
18	2	5,50	0	-2
19	0	0,00	0	0
20	4	0,78	0	0
21	1	0,50	0	0
22	9	7,05	0	-2
23	2	0,95	0	0
24	3	1,75	-1	0
25	23	11,10	0	-2
26	1	0,40	0	0
27	6	1,73	-1	0
28	4	1,70	-1	0
29	19	14,65	0	-2
30	0	0,00	0	0
31	3	6,15	0	-2
32	7	1,50	-1	0

Continuation Table A 5

ID	N_BARRIERS	SUM_FALLING HEIGHT (M)	PLUS 1-CLASS <5M	PLUS 2-CLASS >5M
33	0	0,00	0	0
34	0	0,00	0	0
35	6	3,45	-1	0
36	8	3,95	-1	0
37	13	8,20	0	-2
38	4	0,81	0	0
39	5	1,70	-1	0
40	7	4,35	-1	0
41	0	0,00	0	0
42	6	1,20	-1	0
43	0	0,00	0	0
44	2	0,50	0	0
45	5	1,60	-1	0
46	5	5,05	0	-2
47	8	2,05	-1	0
48	5	0,90	0	0
49	2	0,20	0	0
50	3	1,45	-1	0
51	2	0,65	0	0

Table A 6: Determined classes for the ecosystem service habitat provision

ID	CLASS NATURA 2000	CLASS LAND USE INTENSITY	CLASS BIOTOPES	SUM OF CLASSES	MALUS (BARRIER)	TOTAL CLASS HABITAT
00	4	5	2	**4**	-1	**5**
01	4	5	4	**4**	-2	**5**
02	4	4	3	**4**	0	**4**
03	3	4	3	**3**	-2	**5**
04	4	4	4	**4**	-2	**5**
05	3	2	3	**3**	-1	**4**
06	3	2	3	**3**	-2	**5**
07	4	1	4	**3**	0	**3**
08	4	5	4	**4**	-1	**5**
09	4	3	4	**4**	-2	**5**
10	4	3	3	**3**	0	**3**
11	4	1	4	**3**	0	**3**
12	4	3	4	**4**	-1	**5**
13	4	5	4	**4**	-1	**5**
14	5	3	4	**4**	-1	**5**
15	4	3	3	**3**	0	**3**
16	1	1	1	**1**	0	**1**
17	4	2	4	**3**	0	**3**
18	4	4	4	**4**	-2	**5**
19	5	2	4	**4**	0	**4**
20	5	3	3	**4**	0	**4**
21	4	5	4	**4**	0	**4**
22	4	5	3	**4**	-2	**5**
23	5	5	4	**5**	0	**5**
24	5	4	4	**4**	-1	**5**
25	4	4	3	**4**	-2	**5**
26	4	4	4	**4**	0	**4**
27	5	5	4	**5**	-1	**5**
28	3	1	3	**2**	-1	**3**
29	4	1	4	**3**	-2	**5**
30	4	1	3	**3**	0	**3**
31	4	1	3	**3**	-2	**5**
32	4	1	4	**3**	-1	**4**

Continuation Table A 6

ID	CLASS NATURA 2000	CLASS LAND USE INTENSITY	CLASS BIOTOPES	SUM OF CLASSES	MALUS (BARRIER)	TOTAL CLASS HABITAT
33	4	1	4	**3**	0	**3**
34	3	2	2	**2**	0	**2**
35	4	5	3	**4**	-1	**5**
36	4	5	3	**4**	-1	**5**
37	5	5	4	**5**	-2	**5**
38	5	3	3	**4**	0	**4**
39	4	3	3	**3**	-1	**4**
40	4	5	4	**4**	-1	**5**
41	4	5	4	**4**	0	**4**
42	3	2	3	**3**	-1	**4**
43	3	1	3	**2**	0	**2**
44	4	2	3	**3**	0	**3**
45	4	5	3	**4**	-1	**5**
46	3	1	3	**2**	-2	**4**
47	3	1	4	**3**	-1	**4**
48	4	3	4	**4**	0	**4**
49	4	5	4	**4**	0	**4**
50	5	5	4	**5**	-1	**5**
51	4	5	4	**4**	0	**4**

Table A 7: Counting of aquatic structure measurements, WWTP, mean aquatic structure and resulting class in management sections for the ecosystem service water purification (n.d. = no data available)

ID	N_AQ_STRUCTURE ELEMENTS	N_WWTP	MEAN_AQUATIC_STRUCTURE	CLASS_PURIFICATION
00	12	0	4,91666666667	4,916666667
01	33	1	4,90909090909	4,501683502
02	16	0	3,66666666667	3,666666667
03	68	2	3,08955223881	1,794866248
04	4	0	5,00000000000	5
05	10	1	3,50000000000	2,928571429
06	11	0	4,55555555556	4,555555556
07	96	1	5,00000000000	4,6
08	36	0	n.d.	n.d.
09	195	1	3,19680851064	2,571184551
10	18	0	2,00000000000	2
11	43	0	3,00000000000	3
12	61	0	3,44827586207	3,448275862
13	92	0	2,17777777778	2,177777778
14	81	0	3,31250000000	3,3125
15	25	0	2,84000000000	2,84
16	31	0	4,48387096774	4,483870968
17	42	0	2,71428571429	2,714285714
18	18	0	4,94444444444	4,944444444
19	44	0	5,00000000000	5
20	38	0	2,94736842105	2,947368421
21	57	0	2,54385964912	2,543859649
22	80	0	2,75000000000	2,75
23	68	1	4,91176470588	4,504579077
24	17	0	2,46666666667	2,466666667
25	143	0	3,20422535211	3,204225352
26	25	0	2,60000000000	2,6
27	31	0	4,50000000000	4,5
28	58	0	1,98275862069	1,982758621
29	88	0	n.d.	n.d.
30	14	0	n.d.	n.d.
31	14	0	n.d.	n.d.
32	14	0	3,92857142857	3,928571429

Continuation Table A 7

ID	N_AQ_STRUCTURE ELEMENTS	N_WWTP	MEAN_AQUATIC_STRUCTURE	CLASS_PURIFICATION
33	19	0	5,00000000000	5
34	42	0	1,82857142857	1,828571429
35	85	0	2,69411764706	2,694117647
36	30	0	2,86666666667	2,866666667
37	17	0	4,823529412	4,823529412
38	33	0	2,30303030303	2,303030303
39	32	0	2,68750000000	2,6875
40	100	0	3,73737373737	3,737373737
41	48	1	3,93750000000	3,429563492
42	93	0	3,11827956989	3,11827957
43	84	0	5,00000000000	5
44	77	0	3,50000000000	3,5
45	89	1	3,84090909091	3,320199032
46	51	1	3,00000000000	2,333333333
47	191	1	3,45789473684	2,879508131
48	98	0	2,40625000000	2,40625
49	17	0	5	5
50	50	0	3,68	3,68
51	75	0	4,266666667	4,266666667

Table A 8: Calculated lengths of trails in buffer zones, counting of POI and resulting class for the ecosystem service tourism & recreation

ID	TOTAL TRAIL LENGTH (M)	RATIO TRAIL/RIVER	N OBSER-VATION	N CAM-PING	N BATH	FORB. KAYAK	ALLOW. KAYAK	CLASS
00	10377,33	17,09	0	0	0	0	1	**1**
01	32669,52	201,91	0	0	0	0	0	**1**
02	17535,12	69,39	0	0	0	0	0	**1**
03	65149,96	212,98	0	1	0	1	1	**1**
04	5166,66	8,94	1	0	0	0	0	**1**
05	8241,48	57,88	0	0	0	0	0	**1**
06	6435,56	42,45	0	0	0	0	0	**1**
07	37620,43	194,02	1	1	2	1	1	**1**
08	22824,91	55,79	0	0	0	0	0	**1**
09	64235,72	364,77	0	1	0	0	0	**1**
10	1465,91	4,49	0	0	0	0	0	**2**
11	555,32	1,77	0	0	0	0	0	**3**
12	0,00	0,00	0	0	0	0	0	**5**
13	3178,54	3,27	0	0	0	0	0	**2**
14	2809,67	13,04	0	0	0	0	0	**1**
15	773,13	1,52	0	0	0	0	0	**3**
16	6441,17	8,19	0	0	0	0	0	**2**
17	838,63	0,92	0	0	0	0	0	**4**
18	1734,76	2,07	0	0	0	0	0	**2**
19	10850,28	10,30	0	4	6	0	0	**1**
20	4419,39	2,15	0	0	0	0	0	**2**
21	3656,68	2,41	0	0	0	1	0	**2**
22	692,74	0,80	0	0	0	0	0	**4**
23	638,40	0,80	0	0	0	0	0	**4**
24	0,00	0,00	0	0	0	0	0	**5**
25	702,00	2,39	0	0	0	0	0	**2**
26	0,00	0,00	0	0	0	0	0	**5**
27	0,00	0,00	0	0	0	0	0	**5**
28	0,00	0,00	0	0	0	0	0	**5**
29	120,14	0,15	0	0	0	0	1	**3**
30	0,00	0,00	0	0	0	0	0	**5**
31	0,00	0,00	0	0	0	0	0	**5**
32	156,66	0,17	0	0	0	0	0	**4**

Continuation Table A 8

ID	TOTAL TRAIL LENGTH (M)	RATIO TRAIL/RIVER	N OBSER-VATION	N CAM-PING	N BATH	FORB. KAYAK	ALLOW. KAYAK	CLASS
33	0,00	0,00	0	0	0	0	0	**5**
34	0,00	0,00	0	0	0	0	0	**5**
35	248,92	0,26	0	0	0	0	0	**4**
36	293,56	1,67	0	0	0	0	1	**2**
37	0,00	0,00	0	0	0	0	0	**5**
38	0,00	0,00	0	0	0	0	0	**5**
39	0,00	0,00	0	0	0	0	0	**5**
40	406,92	0,83	0	0	0	0	0	**4**
41	6062,48	10,23	0	0	0	0	0	**2**
42	8903,33	2,60	0	0	0	0	0	**2**
43	651,78	0,39	0	0	0	0	0	**4**
44	1711,95	5,24	0	0	0	0	0	**2**
45	11467,51	36,22	0	0	0	0	0	**1**
46	0,00	0,00	0	0	0	0	0	**5**
47	814,12	1,82	0	0	0	0	0	**3**
48	0,00	0,00	0	0	0	0	0	**5**
49	0,00	0,00	0	0	0	0	0	**5**
50	0,00	0,00	0	0	0	0	0	**5**
51	0,00	0,00	0	0	0	0	0	**5**

Table A 9: Water quality indicators of the management sections in the Wupper catchment, according to WFD (MZB = macrozoobenthos; MP = macrophytes; PBSM = plant protection products; ACP = general chemical and physical parameters)

ID	MZB	MP	METALS	PBSM	ACP	ECOLOGICAL STATE	CHEMICAL STATE
00	4	2	5	2	3	4	5
01	3	5	1	2	2	5	5
02	2	3	1	1	2	3	5
03	5	3	5	2	3	5	5
04	0	0	0	1	0	0	5
05	3	3	1	1	3	4	5
06	3	0	2	1	2	3	5
07	0	0	2	1	2	0	5
08	3	2	2	1	2	3	5
09	2	3	1	1	2	4	5
10	3	2	1	1	2	3	5
11	0	0	1	2	2	0	5
12	2	3	1	1	2	3	5
13	3	0	1	1	2	3	5
14	3	2	1	1	2	3	5
15	3	4	2	1	2	5	5
16	0	0	0	0	0	0	5
17	2	2	1	2	2	3	5
18	4	1	1	1	2	4	5
19	0	0	0	0	0	0	5
20	2	2	1	1	2	3	5
21	2	2	1	1	3	3	5
22	2	1	2	1	2	3	5
23	5	5	2	0	5	5	5
24	2	0	3	0	5	2	5
25	3	1	1	1	2	3	5
26	4	1	1	0	2	4	5
27	3	0	1	0	2	5	5
28	2	1	0	0	2	2	5
29	2	0	1	0	5	3	5
30	2	1	1	1	2	2	5
31	0	0	0	0	0	0	5
32	2	1	1	1	2	2	5

Continuation Table A 9

33	**0**	**0**	**0**	**0**	**0**	**0**	**5**
34	1	1	1	1	2	2	5
35	2	1	1	1	2	3	5
36	3	3	1	1	2	3	5
37	5	3	1	1	2	5	5
38	2	1	1	0	2	2	5
39	3	0	1	1	2	3	5
40	3	0	1	1	2	3	5
41	3	4	5	2	2	4	5
42	2	2	1	1	2	4	5
43	0	0	1	2	2	0	5
44	2	2	1	1	2	3	5
45	3	2	1	1	2	3	5
46	2	1	1	2	2	3	5
47	2	2	2	1	2	3	5
48	2	0	1	1	2	3	5
49	3	4	1	1	0	4	5
50	3	4	1	1	2	4	5
51	3	0	1	1	5	4	5

Table A 10: River types of the management sections for comparison, average classes and sum of ecosystem services (ESS)

RIVER TYPE	DRINKING WATER PROVISION	HABITAT PROVISION	WATER PURIFICATION	TOURISM & RECREATION	SUM OF ESS
5 (N = 31)	3,90	3,86	3,20	3,35	14,32
6 (N = 5)	5,00	4,80	3,28	4,00	17,08
7 (N = 2)	5,00	5,00	3,49	4,50	17,99
9 (N = 11)	4,73	4,52	3,87	1,09	14,20
14 (N = 3)	2,67	4,56	4,32	5,00	16,54

Table A 11: Heavily modified water bodies (HMWB) and natural water bodies (NWB) for comparison, average classes and sum of ecosystem services (ESS)

	DRINKING WATER PROVISION	HABITAT PROVISION	WATER PURIFICATION	TOURISM & RECREATION	SUM OF ESS
NWB (N = 21)	4,32	4,16	2,79	3,23	14,50
HMWB (N = 31)	3,90	4,19	4,41	2,86	15,36

Table A 12: Management sections with and without dams for comparison, average classes and sum of ecosystem services (ESS)

	DRINKING WATER PROVISION	HABITAT PROVISION	WATER PURIFICATION	TOURISM & RECREATION	SUM OF ESS
DAM (N = 9)	3,44	3,41	3,65	3,00	13,51
NO DAM (N = 43)	4,30	4,33	3,20	3,09	14,92