Integrated regional-economic modeling of cost-effective programs of measures in the WFD: Development of a demonstration tool

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Integrated regional-economic modeling of cost-effective programs of water quality measures in the WFD: Development of a demonstration tool

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Summary

The Water Economic Modelling for Policy Analysis (WEMPA) project aims to develop and operationalize an integrated water and economy model framework to enable the analysis of the economic effects of measures to reach the Water Framework Directive objectives. This framework is developed on both a national and regional scale.

This report presents the first results of the development of a regional-economic optimization model, the ‘WFD-RegiOptimizer’, linked to the water quality model WFD Explorer. The demonstration model presented in this report aims to clarify and demonstrate the purpose and usefulness of an integrated regional water-and-economy model that can serve as a decision support tool for the selection of a cost-effective program of measures in the context of the implementation of the Water Framework Directive (WFD).

The demonstration tool is applied in a practical case study in the Beerze Reusel river basin in the south of the Netherlands. The case study illustrates the need for more formalized approaches when dealing with complexity in water management, such as the complexity introduced by the WFD where both the environmental objectives and means to achieve them are unknown, to enhance transparency in policy and decision-making. That is, models which aid decision-making by screening cost-effective combinations of measures in situations where multiple pollution sources and pollution abatement measures affect spatially interconnected water bodies in a river basin context. The model exercise presented here is in development, implying that the results should be interpreted with the necessary care. They indicate the potential use and usefulness of the integrated model, rather than serve as a complete and fully researched empirical study in the case study area involved.

1. Introduction

The Water Framework Directive (WFD) requires member states to implement measures to ensure a good ecological and chemical status of all surface and ground waters by 2015. One of the main challenges in the implementation of the WFD is the selection of cost-effective programs of measures to reach these water quality objectives for all water bodies. The purpose of a cost-effectiveness analysis is to find out how predetermined targets, e.g. threshold values for pollutant loads in surface water, can be achieved at least costs (Brouwer et al, 2007). If there were few emission sources and only one single pollutant and environmental objective to consider, a cost-effectiveness analysis would be a fairly straightforward exercise. However, the actual situation regarding water quality of surface waters can be far more complex if there are many (diffuse) emission sources, different interacting pollutants and water bodies, and a whole range of possible pollution abatement measures along the environmental cause-effect chain. To assess the cost-effectiveness of pollution abatement measures under such complex conditions, a comprehensive tool is needed which adequately addresses and integrates all these aspects.

The Water Economic Modelling for Policy Analysis (WEMPA) project aims to develop and operationalize an integrated water-and-economy model (framework), which enables the analysis of the environmental and economic effects of measures to reach the WFD objectives. This framework is developed at national and regional scale. At the national scale, an Applied General Equilibrium model called ‘DEAN-W’ (Dellink and Linderhof, 2008) is coupled to the water quality model WFD Explorer to assess the economic consequences of different emission reduction scenarios and resulting water quality (Stone et al., 2008). At the regional scale, this report presents the results of the development of a regional-economic optimization model that is linked to a regional version of the water quality model WFD Explorer.

The main objective of the study is to develop an economic optimization model which is capable of addressing complex water quality management issues outlined above by helping regional water managers to identify the least cost way to reach the WFD objectives at regional water body scale. This model hence serves as a decision support tool for the selection of the most cost-effective program of measures. This regional optimization model, called ‘WFD-RegiOptimizer’, is connected to the water and substance flow model WFD Explorer to estimate and link the physical effects of emission reductions of pollutants from various sources on water quality to the economic costs involved. For this we use a modular framework. The advantage of using such a modular framework is that it is flexible and that it allows integration of existing data and models in a more comprehensive way. An important prerequisite for applying the WFD RegiOptimizer is that sufficient reliable data are available.

Based on the available data and information, the Beerze Reusel river basin in the south of the Netherlands is chosen as our case study area to demonstrate the purpose and usefulness of an integrated regional water-and-economy model. It is important to note that the optimization model and database are in development. Therefore, the presented case study results are preliminary and should be interpreted as indicative of the potential use and usefulness of the integrated model, rather than as a fully elaborated empirical case study.

This report is organized as follows. Chapter 2 describes the methodology used to build the model. Chapter 3 introduces the case study discusses the results. Chapter 4 concludes and provides suggestions for further research.

2. Methodology

2.1 Introduction

The assessment of WFD policy with respect to water quality improvements requires an analysis at the local and regional level. Usually, the economic component is lacking or poorly developed in existing bottom-up water quality models (see, for example, Reinhard and Linderhof, 2006). For the region Flandres in Belgium, there already exists a bottom-up model, called 'Environmental Costing Model' (ECM). The ECM was initially developed for the assessment of environmental policy with respect to emissions of pollutants into the air and air quality (see Eykmans et al., 2004). More recently, the ECM model has been modified and also applied to the assessment of water quality policy (see Broekx et al., 2006).

The regional model presented in this study extends the principle of the ECM model further to include impacts of measures on emission loads as well as water quality. The base of the regional model is the hydrological structure of a river basin including the hydrological units as described by the WFD Explorer (Delsman et al., 2007). The WFD Explorer distinguishes two types of hydrological units[1], namely water bodies and catchment areas. Water bodies are the actual areas of surface water, such as rivers, lakes, canals etc. Water bodies are connected to each other. Catchment areas are the areas of land from which water runs off into water bodies. Most polluting economic activities (pollution sources) are located in catchment areas, such as agriculture. All activities are defined as emission sources in the model, and one water body or catchment area can have multiple sources. Obviously, this is plausible for point sources, such as manufacturing industries or wastewater treatment plants, but the same procedure is also applied to diffuse sources, such as agriculture, as catchment areas and water bodies are directly linked in the model. Given the available information about the economic activities, sources of pollution, hydrological structure, costs and effects of pollution abatement measures, the model minimizes the total costs to reach a specific water quality norm. The model identifies the least cost way to reduce emissions at the emission sources, and estimates the water quality in terms of concentration of pollutants in the water.

Compared to the national-economic model (Stone et al., 2008), the regional model has two main advantages over the former top-down approach. First of all, the model takes into account the hydrological structure of a river basin, allowing for a more accurate and complete evaluation of measures in terms of their effects on water quality. Secondly, the model applies to substances rather than environmental themes, thereby allowing more details in the modeling of individual pollutants and pollution abatement measures.

2.2 The WFD RegiOptimizer model

As mentioned, the regional model is based on the hydrological structure of the WFD Explorer, and uses the same database. Figure 2.1 shows the relationships between the database, WFD Explorer and the regional optimization model.

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[1] Throughout this report, we will use the phrase 'hydrological units' when we refer to water bodies and catchment areas.

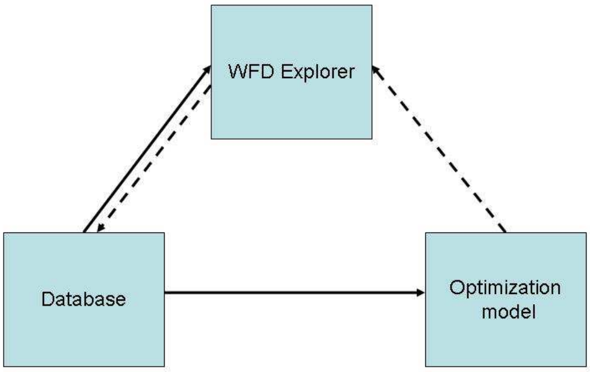

Figure 2.1 Model Framework

The WFD Explorer is a tool to explore the impact of the implementation of WFD measures on the ecological and chemical water quality of an area. In order to quantify the impact of these measures on the water and substance flows, the WFD explorer uses a water and substance mass balance. The Explorer is a static model and works with a timescale of a year, distinguishing between summer and winter.

Because the WFD Explorer is designed to provide quick insights into the environmental consequences of the implementation of emission reduction measures, it uses simplified descriptions of the hydro-morphology and water quality of the water bodies within a river basin based on complex underlying model relationships, hence avoiding lengthy and time consuming model exercises.

The WFD Explorer has a user-friendly interface, allowing policy and decision-makers to select measures and immediately see how these measures affect the ecological and chemical quality of the water bodies in their river basin.

The database is the core of the model framework as it includes all the necessary information about pollution sources, loads, and pollution abatement measures. The optimization model WFD-RegiOptimizer extracts information from the database and determines the least-cost combination of measures to reach the water quality targets through a numerical optimization procedure. Based on the available information about initial (starting or reference point) emission loads and the hydrological characteristics of the area, the WFD Explorer calculates the water quality in the river basin without the implementation of measures. These initial concentration levels serve as the base concentration in the optimization routine, the results of which are stored in the database.

The WFD Explorer uses more sophisticated estimated relationships between emissions and concentration levels for surface water quality than the WFD-RegioOptimizer. The results of the WFD-RegiOptimizer, including the implementation degree of measures areused as input in the WFD Explorer to check whether the water quality targets are met.

In principle the differences in water quality derived from both models should be small, but due to the use of linear extrapolations between emission and concentration levels the results from the WFD-RegiOptimizer may slightly deviate from those obtained from the WFD Explorer.

Currently, there is no direct automated feedback link from the WFD Explorer to the optimization routine. Modified combinations of measures and policy targets for the optimization routine in the WFD-RegiOptimizer need to be (re)formulated manually. Another model simplification is that the current application version of the demonstration model only includes one pollutant, namely nitrogen (N). However, the different modules of the integrated model are all specified in such a manner that other pollutants can easily be included in the optimization routine and analysis. In the following section the different components making up the model framework will be discussed in more detail.

2.3 Theoretical background

The objective of the model is to minimize costs subjected to water quality constraints in water bodies. However, the water quality in a water body is also affected by the pollution in catchment areas connected to the water bodies and up-stream water bodies. Therefore, the model distinguishes two types of hydrological units, namely water bodies and catchment areas. Moreover, the model incorporates the interconnection of water bodies and catchment areas. So, if there is referred to hydrological units in the remainder of the document, it applies to water bodies as well as catchment areas.

In practice, the emissions in hydrological units can have multiple sources of pollution (pint or diffuse sources). For convenience, the model only distinguishes one source per hydrological unit. Therefore, the measures associated to these pollution sources are automatically associated with hydrological units as well.

The objective of the model is to minimize the total annual costs of implementing measures:

$$\sum_{i \in I} \sum_{j \in J} X_{ij} C_{ij} \qquad i=1,\ldots,I \text{ and } j=1,\ldots,J \qquad (1)$$

where X_{ij} is the degree of implementation of measure j in hydrological unit i, and C_{ij} is the associated annual costs.

We assume that the measures can be implemented partially[2]:

$$0 \leq X_{ij} \leq 1 \qquad (2)$$

As the measures apply to economic activity (as pollution sources), the measures affect the emission of pollutants from economic activity rather than water quality itself. Therefore, emissions are calculated by taking the implementation degree and effect of all individual measures into account:

$$E_{is} = Ein_{is} - \sum_{j \in J} ER_{ijs} X_{ij} \qquad i=1,\ldots,I \text{ and } s=1,\ldots,S \qquad (3)$$

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[2] Alternatively, one could assume that implementation is a binary variable: {yes, no}. For most measures, partial implementation seems the more appropriate choice however.

where E_{is} is the level of emission of pollutant, *s*, in hydrological unit, i, *Ein* represents the initial level of emissions (when no measures are implemented and costs are hence zero) and ER_{ijs} the emission reduction achieved by full implementation of measure *j* in water unit *i*. Note that one measure *j* can affect more than one pollutants. Furthermore, we assume that measure do not interact in terms of emission reduction.

Water quality is only measured in the water bodies. Suppose that I_w is the set of water bodies which is a subset of the hydrological units *I*. The set of catchment areas is I_c, and both subsets cover the set of hydrological units *I*. In Equation (4), the water quality in terms of the concentration of a substance (pollutant) in the water is calculated based on the reduction of the concentration of substance, *s*, in water body *i* due to the reduction of the emission of substance, *s*, in all water bodies considered:

$$Q_{is} = Qin_{is} - \sum_{k \in I} M_{iks}(Ein_{is} - E_{is}) \qquad i=1,\ldots,I_w \text{ and } s=1,\ldots,S \tag{4}$$

Here, Q_{is} is the water quality in water body *i* (concentration of substance, *s*), *Qin* is the initial water quality in water body *i* (i.e. when no measures are implemented and hence costs are zero), and M_{iks} is the 'water quality matrix' reflecting the impact of the emission reduction in water unit *k* on the concentration of substance *s* in water body *i*. Note that for the water quality matrix all hydrological units are considered in terms of emission reduction, water bodies as well as catchment areas.

Finally, Equation (5) presents the water concentration targets per substance for each water body:

$$Q_{is} \leq \tau_{is} \qquad i=1,\ldots,I_w \text{ and } s=1,\ldots,S \tag{5}$$

where τ_{is} is the water quality standard for substance *s* in water body *i*. Note that there are no water quality targets for catchment areas.
As all water bodies and catchment areas are linked via the water quality matrix *M*, a measure can simultaneously have water quality effects in different water bodies. Substituting E_{is} from equation (3) into equation (4) shows that an emission reduction in a catchment area may have an impact on water quality in several other (down-stream) water bodies.

2.4 Optimization routine

In the optimization routine WFD RegiOptimizer, the least cost combination of measures is chosen such that the restrictions on water quality in the different water bodies within a river basin are met. The mathematical model minimizes the total costs of implementing measures, subject to a water quality constraint for each water body. Although possible in principle, the model does not impose water quality restrictions on catchment areas.

The selection of measures is an endogenous process in the model on the basis of the available information about the cost and effect of the individual measures, where cost-effectiveness (*CE*) is determined as the cost of measure, *j*, per unit of effect:

$$CE_j = \frac{C_j}{Effect_j} \tag{6}$$

The lower the value of cost effectiveness (in casu more cost effective), the higher the probability the measure will be selected. In the description of the measures in the database, the effects are given in terms of emission reductions. Ranking the measures in these terms is relatively straightforward. However in the context of the WFD, cost-effectiveness of measures needs to be determined in terms of the effect on water quality in the different water bodies rather than in terms of emission reductions. The optimization model includes estimated causal relationships between emission loads and corresponding concentration levels (Equation 4). For this a ‘water quality matrix’ is used containing transport coefficients, linking all hydrological units (water bodies and catchment areas). So, a measure can have water quality effects in different water bodies simultaneously. This spatial differentiation helps to show that it may be more cost-effective to implement a relatively expensive measure in a water body upstream, as this will improve the water quality of a larger body of water compared to a relatively cheaper alternative measure downstream, which only affects water quality locally downstream.

More formally, the optimization routine describes for each measure its cost-effectiveness in terms of the effects it achieves for all spatially differentiated targets simultaneously. To do this, the following Lagrangian (objective function) is specified:

$$L = \sum_{i \in I} \sum_{j \in J} C_{ij} X_{ij} - \sum_{i \in I_w} \lambda_{is} \left(Q_{is} - \tau_{is} \right) \qquad (7)$$

with Q_{is} as defined in Equation (4). Here L is the optimand to be minimized; I is the set of all water units, J is the set of all possible measures, Q_{is} is the water quality for substance s in water body i and τ_{is} is the associated water quality target. Note that the water quality restriction only applies to water bodies and not for all hydrological units. The effect on water quality is determined by the initial water quality level minus any improvement caused by implementing measure j, i.e. the emission reduction (E_i–Ein_i) associated with measure j times the impact (M) of one unit emission reduction in water unit, k, on water body i. The matrix M links emission reductions generated by measures in hydrological units to water quality in all water bodies and includes information about how the different catchment areas and water bodies are physically connected. The λ’s represent the shadow value of the constraint for water body i, and reflect the relative strictness of the target for this water body compared to the other water bodies. Thus, the desirability of a measure is influenced by the water quality matrix (which gives the impact of the measure on water quality in the different water bodies) and by the shadow values (which give the relative importance of improving water quality in a water body compared to other water bodies).

The results of the optimization routine are the implementation degrees for individual measures. One important simplification of the WFD RegiOptimizer model compared to the WFD Explorer is the assumed linear relationship between emission reduction and emission concentration used to evaluate the final effects of the measures on water quality. In the WFD Explorer, these links are more complex, and the result for water quality based on the latter model may therefore differ from the approximation in the optimization routine in WFD RegiOptimizer model.

The optimal package of measures calculated by the WFD RegiOptimizer could be imputed into the WFD Explorer to obtain a more accurate estimation of the associate water quality in all water bodies. Based on whether the water quality computed by the WFD Explorer is above or under the target, the package of measures should be adapted.

It is important to point out that the WFD-RegiOptimizer presents the most cost-effective program of measures based on the available information on emission reduction and costs of the measures. If information is somehow missing or incomplete, this will obviously reduce the applicability and hence usefulness of the WFD RegiOptimizer . The reliability of the results depends on the reliability of the underlying data.

The results are based on cost minimization given environmental targets (as prescribed by the WFD). In principle, the WFD requires that programs of measures be justified based on their cost-effectiveness and we expect that policy makers will always want to know how they can achieve their objectives in the least cost way. Here, we consider the list of measures identified as cost-effective in the optimization routine as an important starting point for ultimately deciding upon the most preferred program of measures based on multi-criteria and objective considerations. The model is to be used as a decision support tool, not as a meta-decision-making instrument. Other practical and political criteria may be considered important in the decision-making process as well, like a preference for source-oriented measures instead of effect-oriented models, the time needed for results to manifest themselves or the distribution of costs across different economic sectors, which may result in a more expensive but perhaps considered fairer or socially more just set of measures.

2.5 WFD Explorer database

The WFD Explorer database contains information about the river basin, pollution sources and abatement measures and forms the base of the model. Figure 2.2 presents the structure of the database. The WFD RegiOptimizer requires some additional data compared to the WFD Explorer. The RegiOptimizer database is built in MS Access and both the WFD Explorer and the optimization routine are directly linked to the database.

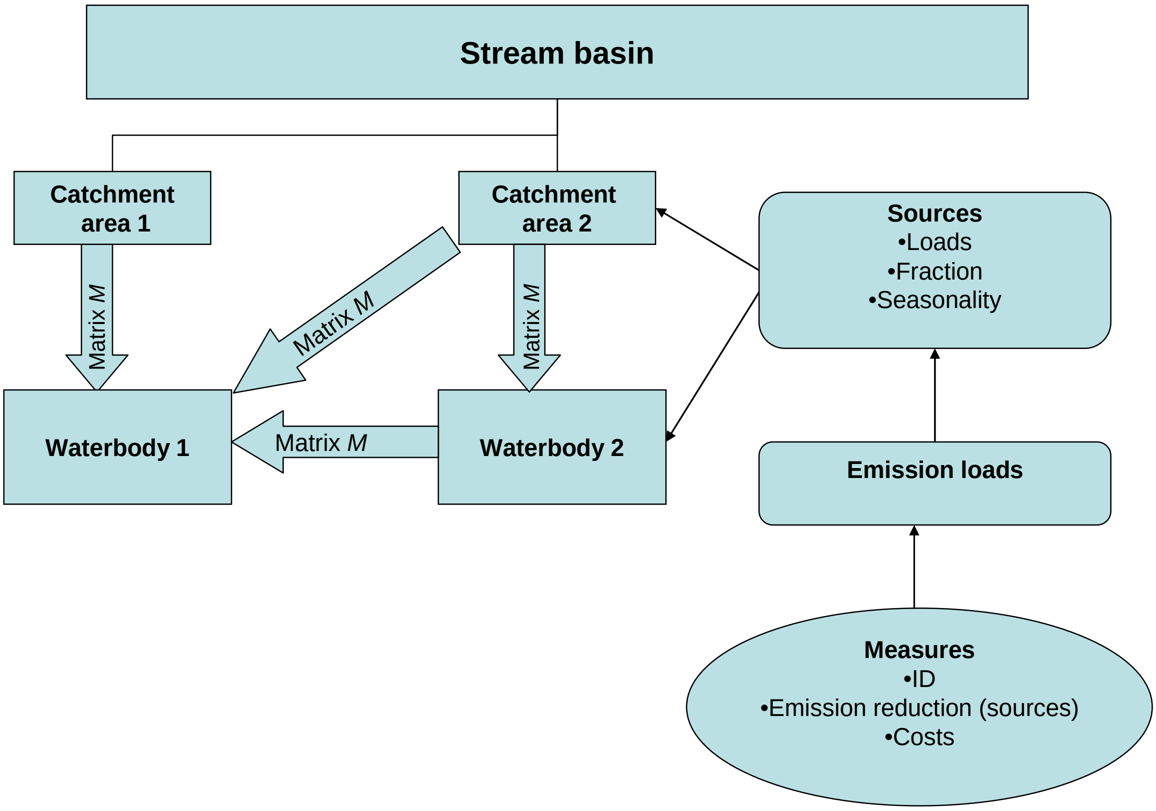

Figure 2.2 Schematic overview of the database structure

The different elements of the database are explained in more detail below.

Sources, Catchment areas and Water bodies

Different types of sources are distinguished within the model. Pollution sources are divided into several types such as industry, agriculture and communal wastewater treatment plants. Sources are connected to catchment areas or directly to water bodies. Each catchment area is connected to a water body. Water bodies are linked to each other through the (modeled description of the) flow of water.

However, the database does not explicitly distinguish between point sources (e.g. manufacturing industries and wastewater treatment plants) and diffuse sources (e.g. agriculture). At the level of a catchment area, diffuse sources like agriculture are considered as one source of emissions. The location of farms within the catchment area is assumed to not have any influence on the water quality problem within this spatial unit. The database distinguishes between seasonal differences too, namely sources in Winter and Summer. The emission load of each source for different pollutants is given in a separate table.

Measures

In the database, technical measures to reduce emissions in the water system are included at the level of sources, meaning that all measures in the database are connected to a source in a specific hydrological unit. The database includes several types of measures, such as measures aimed at preventing pollution at the source, manure policy measures. For each measure, the database contains information on the type of pollutants it reduces, the magnitude of the emission reduction, the investment and exploitation costs. In practice, the available information across river basins is rather limited in the Netherlands, also in our well researched case study area, which has important implications for the reliability of the outcomes. The WFD RegiOptimizer handles partial implementation of the measures endogenously; different degrees of implementation do not have to be addressed as different measures. The WFD RegiOptimizer points out the relevance of properly accounting for possible economies of scale.

From emission loads to concentration levels and water quality

In order to link emission reduction to an improvement of water quality (concentration levels) in the optimization routine, a water quality matrix, M, is used describing how an emission reduction in a water unit (water body or catchment area) affects water quality in different water bodies. The matrix is constructed through calculations carried out with the WFD Explorer model (the effect on the emission concentration due to a 50% emission reduction of a single pollutant, namely BOD in summer situation) and the results are stored in the database for use with the WFD RegiOptimizer. Note that the WFD RegiOptimizer model assumes that concentrations reduce proportionally with the reduction of emissions due to the implementation of measures. The results of WFD RegiOptimizer may be slightly different than those obtained from the WFD Explorer for the implementation of a specific program of measures (see paragraph 2.4).

Policy scenarios

The database can also describe certain policy scenarios in terms of water quality norms. These are formulated as water quality targets per water body. In a separate table, different scenarios can be stored. These scenarios can then be used in the optimization routine to identify the optimal set of measures.

3. Case study

3.1 Description of the study area

The Beerze Reusel river basin is part of the larger Dommel river basin, managed by the Dommel waterboard authority in the south of the Netherlands and bordered upstream by Belgium. The basin consists of the sub-basins De Beerze, De Reusel and De Nieuwe Leij. All of these rivers flow into the Essche Stroom. The basin covers about 45.000 ha and is dominated by agricultural land use (55% of the area), followed by nature and forests (30%), and built up area (15%). There are three communal wastewater treatment plants (WWTP) in the basin, which besides agriculture, are an important source for the high nutrient levels in the area's surface waters. Nitrogen is considered the most important water pollutant. There is not much industry in the area, so the effect of industrial wastewater on water quality is limited. There is, however, a substantial inflow of pollutants from Belgium, which is at the south border of the river basin area in Figure 3.1. The various sub-catchments within the case study area are presented as well.[3]

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[3] Figure A.1 in Appendix I shows the water bodies and catchment areas codes. Water bodies have 5-digit codes, while catchment areas have 6-digit codes.

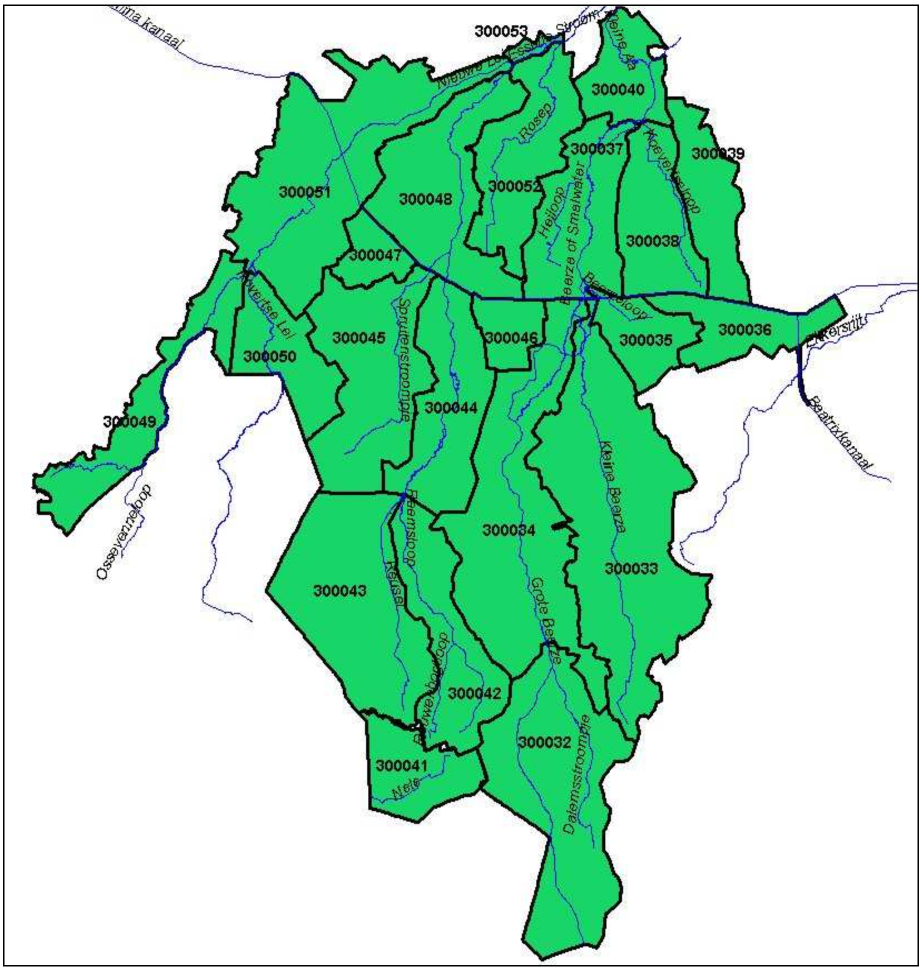

Figure 3.1 The Beerze Reusel basin study area

3.2 The integrated Beerze Reusel model

The Beerze Reusel river basin model is based on the WFD Explorer model for the Meuse river basin. All information for the Beerze Reusel river basin is taken from the database for this larger Meuse river basin and complemented with additional information from other studies and information provided by De Dommel waterboard authority. The Beerze Reusel river basin consists of 19 water bodies and 21 catchments (see Figure 3.1). Four upstream water bodies originate in Belgium, making water quality improvements in the area partly dependent on pollution abatement efforts across the border. In this case study, the model WFD RegiOptimizer focuses on one pollutant only, namely nitrogen from agriculture and communal WWTP. The water quality conversion matrix is given in Appendix I.

3.3 Policy scenarios

The aim of the demonstration model is to formulate and analyze a number of policy scenarios for water quality improvement based on existing water quality standards referred to in the Netherlands as MTRs (maximum tolerable risk). Given the fact that the database and WFD-RegiOptimizer represent work in progress and the main objective is to demonstrate the model's usefulness, the identified policy scenarios are fairly simple (also due to the fact that the WFD objectives are still unknown), including a Business As Usual (BAU) scenario, i.e. no improvement in water quality required, and a 5, 10, 15 and 20 percent improvement in water quality, i.e. specified as a 5 to 20 percent reduction in N concentration levels, and a maximum water quality scenario where all possible measures reducing concentration levels are implemented.

Given furthermore that the water quality in the different water bodies depends to a large extent on the inflow from Belgium, and the WFD will also have to be implemented in the Belgian part of the river basin, we also formulate an alternative baseline policy scenario where inflowing water from Belgium does not exceed MTR values.

3.4 Pollution abatement measures

The model only considers technical measures. Five possible types of measures are relevant for this case study; see Table 3.1. Most but not all of these measures can be implemented at the level of individual catchment areas, resulting in a total of 72 mutually exclusive alternative measures for inclusion in the model database[4]. The investment costs of the measures are fixed while the operational costs are variable and depend on the degree of implementation. Cost information for upgrading WWTP is taken from an study on costs and effects of measures in the Beerze Reusel area (DHV, 2003).

Table 3.1 Types of measures included in the case study model

Type of measure	**Emission reduction capacity (%)**
Crop free corridors grassland	10
Crop free corridors arable land	10
Upgrade of WWTP	22
Sewer improvement: decoupling of stormwater overflow	50
Sewer improvement: larger storage settling tanks	50

The list of available measures in the database is limited and this will have, as we will show, some important consequences for the model exercise.

3.5 Results

3.5.1 Baseline

The baseline situation uses the actual description of water quality from the database and assumes that there will be no reduction of the N concentration levels of inflowing waters from Belgium. The subsequent policy scenarios are in principle based on a comparison of water quality levels in each water body with the MTR. As the number of reduction measures in this case study is limited, these targets cannot be met for all water bodies all the time. First, a 5 percent decrease in N concentration levels is simulated, then, in a series of additional simulations water quality targets are increased step by step with 5

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[4] Originally the database contained around 2,300 measures, many of which consisted of similar measures with different removal efficiencies. Measures about which we did not have enough information regarding their cost or effect, or were linear extensions of other measures were omitted from the database.

percent-points in order to find out how the reduction costs increase with increasingly strict target levels. Finally, a scenario is run where water quality is maximized regardless of the costs involved. This reflects the maximum achievable reduction in N concentration levels to see what is technically feasible given the exemption possibilities in Article 4 in the WFD.

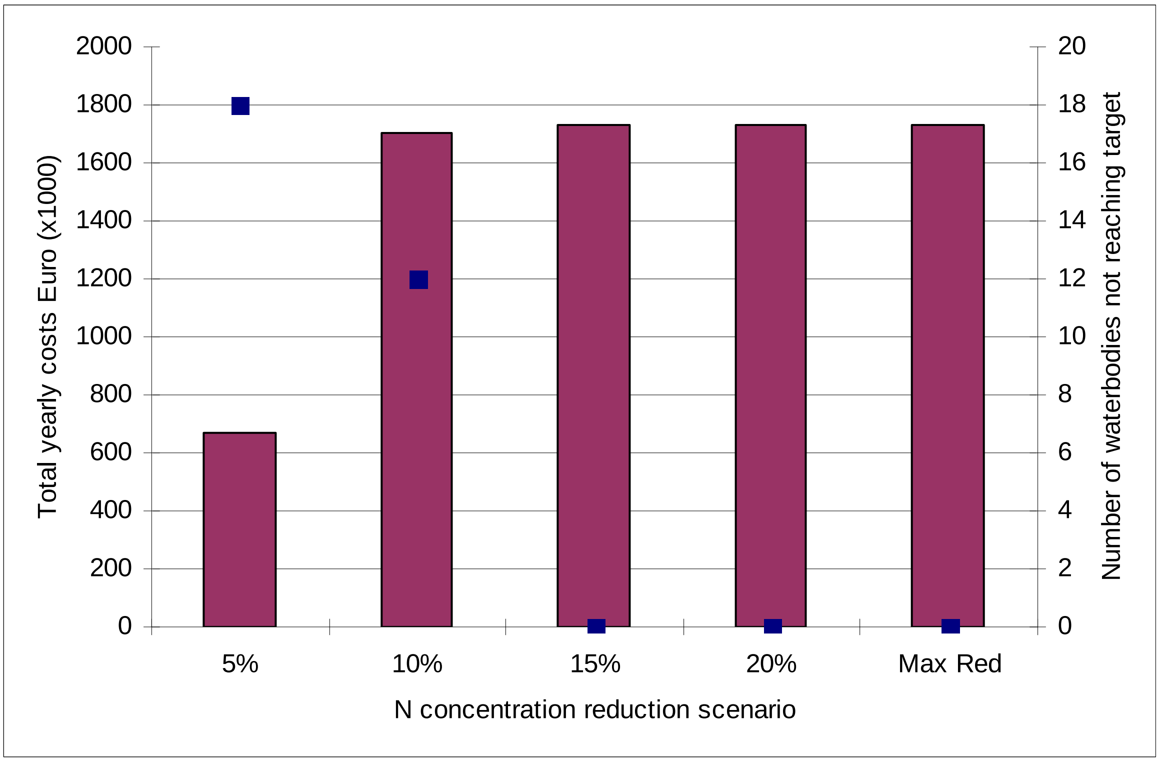

Figure 3.2 Total annual costs (stacked bars; left axis) and number of water bodies reaching the imposed water quality targets (squares; right axis) for the Beerze Reusel river basin under different emission reduction scenarios

The annual costs of improving water quality with 5 percent (the targeted policy scenario is 5% nitrogen reduction) amount to almost 700 thousand Euro. It is, however, not possible to improve water quality in all water bodies. This target is met in 18 water bodies. For three water bodies there are virtually no options available to improve water quality at all[5] In order to achieve a 10 percent reduction, almost all measures have to be implemented, leaving very little opportunity for further water quality improvement. To achieve this 10 percent reduction, 29 additional measures have to be implemented on top of the 41 measures that are already implemented under the 5 percent reduction scenario. The limitation to further improvement is reflected in the fact that the annual costs for a further 15 or 20 percent concentration reduction in Figure 3.2 are the same as for a 10 percent reduction. Also the maximum water quality (Max Red) scenario is almost

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[5] For water body 5078 (Wilhelminakanaal) the reduction potential is zero, while for water bodies 30033 (NAME?) and 30050 (Nieuwe Leij Voorste Stroom) concentration levels can only be reduced by 4 percent

identical to the 10 percent reduction scenario.[6] This result clearly demonstrates that the model results crucially depend on the provided input: only of 72 N reduction measures complete information on costs and effects is available in the database. These measures and incorporated in the optimization routine. Other possible measures, were lacking information on the cost and effects. While these limitations in the availability of reduction measures prevents a fuller evaluation of the feasibility of further water quality improvement, the modeling framework shows that the optimization routine can provide useful insight into the most cost-effective combination of measures.

Furthermore, the results show the technical robustness of the routine: when water quality targets cannot be met, the routine does not break off, but rather provides useful information regarding the identification of bottlenecks and the maximum achievable reduction. Another important outcome is the spatial distribution of pollution abatement measures and costs. Figure 3.3 shows how the costs of the implemented measures are distributed over the different water units (water bodies and catchment areas). The numbers refer to the water basins shown on the map in Figure 3.1. As the 10 percent scenario is almost the same as the maximum reduction scenario, only the 5 percent and maximum reduction scenario are presented. Under the 5 percent scenario only a limited number of upstream measures are selected. Relatively cheaper measures are available for many catchment areas, and it is cheaper to implement these local measures than to improve water quality further upstream and accounting for their trickle-down effect. It has to be pointed out that the limited number of upstream measures in the database somewhat undermines this conclusion. Further analysis based on a richer empirical database may show a more pronounced interaction effect.

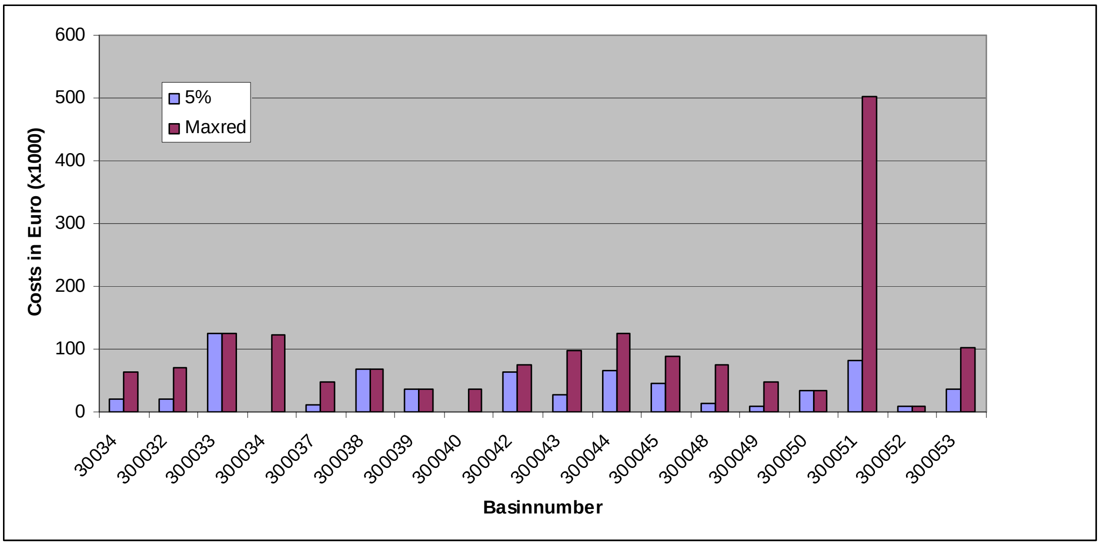

Figure 3.3 Total annual cost per water unit for the 5% and maximum reduction ("Max red.") scenario

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[6] The Max Red scenario reflects the level of water quality if all measures in the database would be implemented regardless the costs of implementation. In fact it is the maximum potential if the MTR level is not achieved.

The exceptionally high costs in catchment area 300051 (Nieuwe Leij Voorste Stroom basin) are caused by the WWTP Tilburg Oost and the costs to upgrade this WWTP in this particular catchment area (almost a quarter of a million Euro, while it reduces nitrogen concentration levels in water body 30051 (Nieuwe Leij Voorste Stroom) with less than one percent!). It should be noted that as the database describes the situation in 2005 (including price levels), this WWTP is present in the database, but the WWTP was removed from the specific case study area and merged with another river basin in 2006 and therefore excluded from the more updated list of potential measures for the river basin. It is clear that the cost-effectiveness of this measure is extremely low (i.e. costs are extremely high compared to the effect in terms of water quality improvement). From a policy perspective, it seems logical that these costs are deemed excessive (‘disproportionate’) and the measure will therefore be excluded from the list of realistic measures to be implemented under the WFD. But in view of the fact that the measure contributes to the improvement of water quality, however small, it is included as a possible measure in the database and optimization routine.

Using the link with the WFD Explorer, it is possible to show the impact of the pollution abatement measures on water quality also geographically. Figures 3.4a and b present the water quality in the different water bodies in the initial baseline situation and under the scenario where water quality is maximized. Comparison of the two figures reveals that for many water bodies concentration levels do not change much and stay in the same water quality class. In order to better show how and where the water quality improves, Figure 3.4c shows the relative change in water quality. In line with the results presented before, the changes are mostly in the order of a 5 to 10 percent improvement. Remarkable is the finding that the water body with the largest relative improvement in water quality already has an acceptable quality in the baseline situation, whereas for some water bodies with the worst baseline water quality hardly any improvements are possible, largely due to the limited number of possible pollution abatement measures in the database for these water bodies and the connected catchment areas.

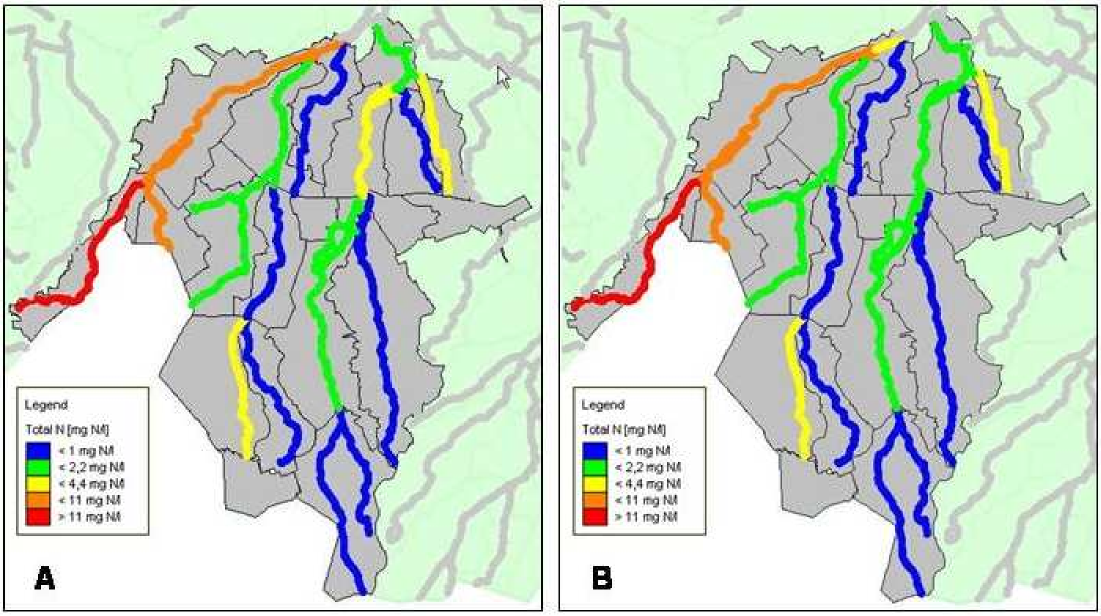

Figure 3.4a&b Water quality before and after implementation of all measures in the Beerze Reusel river basin

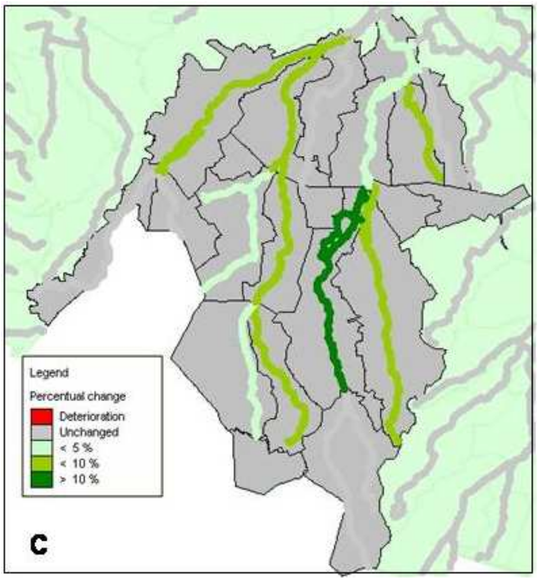

Figure 3.4c Changes in water quality after implementation of all possible measures in the Beerze Reusel river basin compared with the baseline situation

It is clear from Figure 3.4 that the implementation of all possible measures (at least of those for which we have complete information in the database) is insufficient to reach the desired MTR water quality levels (i.e. blue colour in Figure 3.4 a and b). Although the water quality improves to an acceptable level for some water bodies, many remain too polluted, illustrating the need to consider a reduction of N concentration levels of the inflow from Belgium.

3.5.2 Alternative baseline

The results for the alternative baseline projection start from the premise that the inflowing water from Belgium does not exceed the existing MTR levels. This means that in order to calculate the initial nitrogen concentration levels in the water system, the concentration of the inflowing water at the boundary is set at the maximum MTR level in the WFD Explorer.

Figures 3.5a, b and c show the impact of the maximum water quality scenario in the different water bodies for this alternative baseline projection where we assume that the inflow from Belgium meets the MTR level. Although the information about the pollution abatement measures has not changed, the modified baseline projection does influence the cost-effectiveness of the measures as the inflow from abroad has an important impact on water quality. For most water bodies, the concentration levels are now acceptable even without implementation of any WFD measure in the Dutch part of the river basin. However, some measures are still needed to reach the imposed water quality targets for all water bodies.

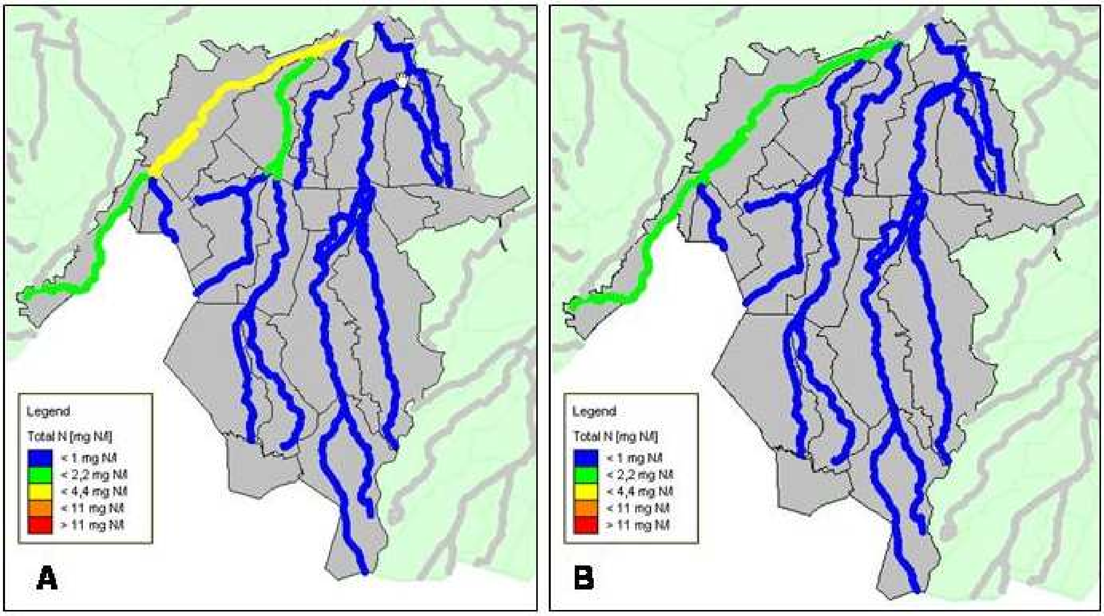

Figure 3.5a&b Water quality before and after implementation of all measures in the Beerze Reusel river basin under the alternative baseline projection where the inflow from Belgium is set at MTR level

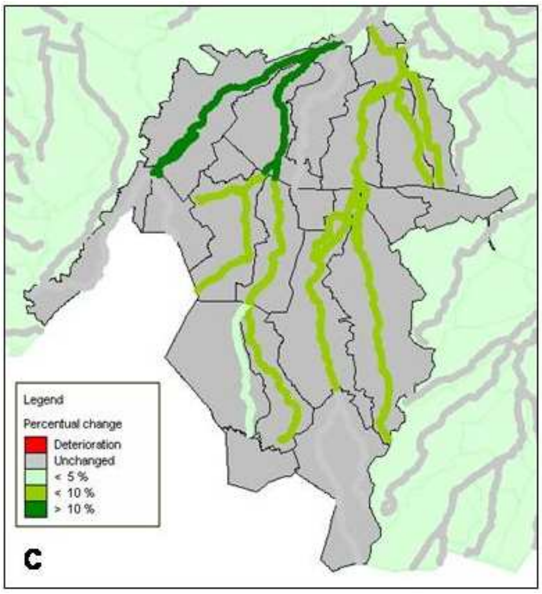

Figure 3.5c Change in water quality after implementation of all measures in the Beerze Reusel river basin under the alternative baseline projection where the inflow from Belgium is set at MTR level

3.5.3 Comparison between the baseline and its alternative

Table 3.2 lists the costs and reduction in emission levels per catchment area when all possible measures are implemented (maximum water quality scenario) two different baseline situations. Note that if a water body achieves the MTR level for water quality further emission reductions are unnecessary. Moreover, if the water quality of the inflow from Belgium does not meet the MTR level, only 7 water bodies achieve the MTR level (see Figure 3.5) after implementing all available measures in the database. If the inflow from Belgium does meet the MTR level, 14 water bodies in the Beerze Reusel river basin will meet the MTR level as well (see Figure 3.5 b).

Table 3.2 Annual costs and N emission reduction levels per water unit under the maximum water quality scenario for the Beerze Reusel river basin compared with the two alternative baseline projections

	Baseline Situation where the N inflow from Belgium does not meet the MTR		**Baseline Situation where the N inflow from Belgium meets the MTR**	
Catchment areas	**Annual cost (1,000€)**	**Emission reduction N (x1,000 kg)**	**Annual cost (1,000€)**	**Emission reduction N (x1,000 kg)**
300032	70.5	1.8	70.5	1.8
300033	125.4	4.3	125.4	4.3
300034	187.8	16.4	123.2	5.5
300037	47.4	1.9	47.4	1.9
300038	69.0	1.5	69.0	1.5
300039	36.0	1.2	36.0	1.2
300040	36.2	0.6	16.2	0.6
300042	75.4	1.9	75.4	1.9
300043	96.9	3.3	96.9	3.3
300044	125.3	23.4	125.3	23.4
300045	88.6	2.9	88.6	2.9
300048	75.9	2.0	75.9	2.0
300049	47.1	0.8	47.1	0.8
300050	33.2	0.3	5.7	0.3
300051	502.0	102.0	254.0	91.7
300052	9.4	0.7	9.4	0.7
300053	102.3	15.5	77.6	15.4
Total	**1,728.3**	**180.6**	**1,343.6**	**159.1**

The total costs for the Beerze Reusel river basin under the original baseline situation where the inflow from Belgium does not meet the MTR level are higher because there is more need to improve water quality. If all available measures are implemented in the Beerze Reusel river basin, the total costs will be 1.7 mln Euro if we assume that the nitrogen inflow from Belgium does not meet the MTR and 1.3 mln Euro if we assume that it does. Less emission reduction efforts are required if the inflow from Belgium already meets the MTR levels.

The implementation of pollution abatement measures in four catchment areas (300034, 300040, 300050, 300051 and 300053) is basically responsible for the observed difference between the two alternative baseline definitions. Especially, the costs for catchment areas 300040 and 300050 are high, although the emission reductions achieved are negligible. Furthermore, the effectiveness of the measures might differ as well. For example, the abatement costs in catchment areas 300033 (Kleine Beerze) and 300044 (Reusel) are very similar, but the reduction effect is much larger in the latter catchment area.

4. Conclusions and future research recommendations

The main objective of this report is to present and discuss an integrated regional-economic demonstration model developed in the project WEMPA to support policy and decision-making related to the selection of a cost-effective program of measures in the WFD at local and regional water body scale. This model, called 'WFD RegiOptimizer', is particularly useful when water managers deal with complex water quality issues, where long lists of possible pollution abatement measures exist, targeting different pollution sources and pollutants in a spatially interconnected system of water bodies. The model framework offers under these conditions and circumstances a structured and transparent approach to handle this complexity and identifies the least cost way to achieve specific water quality objectives as required by the WFD.

The developed optimization routine can not and will not give a definitive answer to the question which measures should be implemented. The model is a stylized representation of the actual circumstances. Furthermore, besides cost-effectiveness, other political considerations may play an important role in the final decision–making with respect to the final selection of measures too, for instance the allocation of the costs of WFD implementation across different economic sectors and water bodies or sub-basins. The identified set of measures by the WFD RegiOptimizer serves in this sense as a starting point for deciding upon the final most preferred set of measures. Another important issue is data availability and reliability. The integrated model framework is only useful and only generates reliable results if the necessary input data are of sufficient quality. Ecological control variables are for example not yet part of the integrated model development and application due to the fact that we currently simply lack enough knowledge and information to be able to include this important component in the model exercise. The model framework presented here is generic and allows for easy inclusion of such control variables, but if the underlying input data is missing, the model can simply not be run. Equally, the model output is as reliable as the model input. Future development and extension of the model will focus more specifically on the uncertainty surrounding the input data, the model structure and parameterization, and the model results. Limited input data affected the practical model application in the Beerze Reusel river basin in the south of the Netherlands. Nitrogen runoff from agriculture and wastewater treatment plants is one of the most important water quality problems in the Beerze Reusel river basin and hence the central focal point of the practical model application. As the model is still under development, and the database far from complete, the results presented in this report should be interpreted with the necessary care. They serve more as an indication of the usefulness of the integrated model than as a fully elaborated empirical case study.

In the case study, two alternative baseline projections were modeled, one which assumes that there will be no reduction of nitrogen concentration levels in inflowing water from Belgium and alternatively one which starts from the premise that the inflowing water from Belgium does not exceed the existing water quality MTR levels at the border. The latter baseline scenario assumes that in the international river basin approach advocated by the WFD member states collaborate in order to be able to comply with the imposed water quality targets in all European water bodies. These different baseline conditions have important implications for the selection of a cost-effective program of measures. Under the former scenario, substantial additional pollution abatement is needed in the Dutch part of the river basin compared to the latter scenario, having - as expected - significant cost implications.

Perhaps the most important conclusion that can be drawn from the case study application is that the model exercise shows that without considerable abatement efforts in neighbouring Belgium, reaching water quality targets in the Beerze Reusel river basin will be a difficult and costly operation. The total costs are 30 percent higher if we assume that water quality at the border does not meet the existing MTR levels. Even though water quality improves in several water bodies under both baseline situations, many are still too polluted. The case study hence demonstrates that even if all available measures are implemented the desired water quality can not be achieved. This result is expected to provide useful input into the article 4 exemptions discussion under the WFD. A caveat surrounding this conclusion, however, is the limited number of possible pollution abatement measures in the database. The optimization routine demonstrates that there are no measures left to select after water quality is improved with 5 10 percent suggesting that with the available list of 72 pollution abatement measures water quality cannot be improved more than 10 percent. Additional effort into the development of a more complete database with pollution abatement measures may change this result.

In terms of future research directions, several activities can be undertaken to improve the robustness and completeness of the developed model, and transform the current demonstration version into a fully operational integrated regional-economic water model. These include first of all the extension to include other relevant priority pollutants under the WFD. The database and the WFD Explorer already contain these other pollutants, and the WFD-RegiOptimizer optimization routine can easily be extended to these other pollutants too, taking into account possible interactions between pollutants when including pollution abatement measures in the database, which simultaneously affect multiple pollutants. Secondly, the link between the WFD-RegiOptimizer and the WFD Explorer can be improved. An automated link between both modules can overcome the simplified linear relationships currently underlying the water quality matrix, and ensure convergence of the outcomes from both models. Thirdly, the optimization routine currently only focuses on chemical control variables and water quality measures, i.e. measures that reduce the emission of chemical substances from economic activities. An important component of the WFD objectives consists, however, of ecological target variables and reaching these targets involves the implementation of ecological restoration measures. As mentioned, the generic framework also allows for the inclusion of ecological control variables and restoration measures in the model, but data requirements pose an empirical challenge in this respect.

Finally, given the uncertainties surrounding the implementation of the WFD, including the definition of the environmental objectives and the identification of cost-effective programs of measures to reach these objectives, much if not most of the decision-making process can be described in terms of risk: the risk of setting environmental objectives at levels which are technically not feasible or disproportionately costly (WFD article 4) and the risk of not meeting the imposed environmental objectives, and the environmental, socio-economic and political implications associated with this. Ideally, the decision-support framework accommodates the evaluation of the risks involved. For this, various approaches are available, which will be explored in the project follow-up, further enhancing the transparency of the choices and decisions involved with the ultimate aim of producing more robust and acceptable end results.

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Appendix I. Case study area

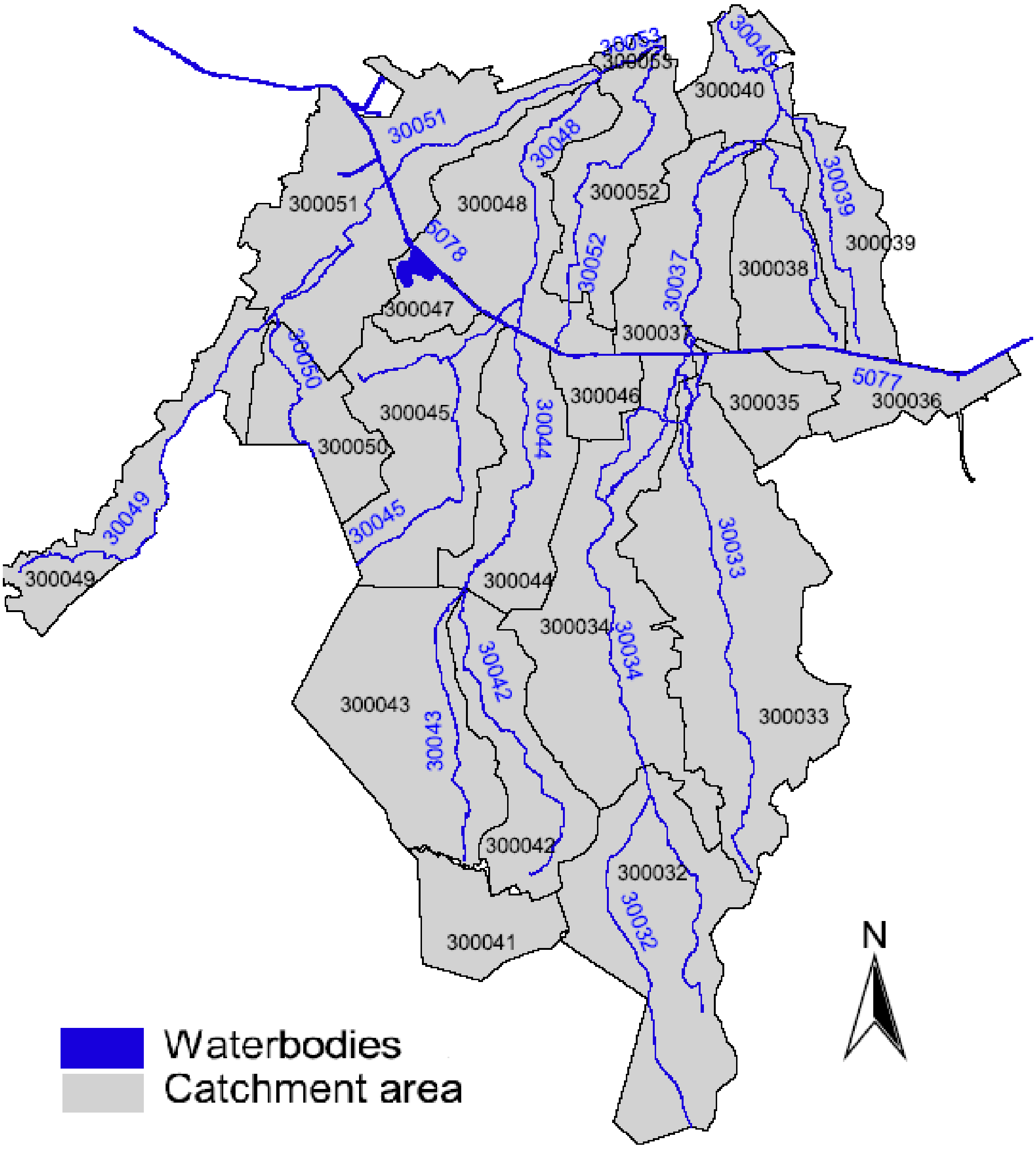

Figure A.1: Water bodies and catchment areas in the Beerze Reusel River basin (Water bodies have 5-digit codes, while catchment areas have 6-digit codes).

Appendix II. Water quality matrix

Change in concentration level in one water body as a result of a one unit emission reduction in another water unit (water body or catchment area)

Water	**30032**	**30033**	**30034**	**30037**	**30038**	**30039**	**30040**	**30042**	**30043**	**30044**	**30045**	**30048**	**30049**	**30050**	**30051**	**30052**	**30053**	**5077**	**5078**
30032	0.32																		
30033		0.35																	
30034	0.16		0.16																
30037	0.08	0.08	0.08	0.08															
30038					0.35														
30039						0.38													
30040	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05											
30042																			
30043									0.28										
30044									0.10	0.10									
30045											0.36								
30048									0.07	0.07	0.07	0.07							
30049													0.31						
30050														0.26					
30051													0.09	0.09	0.09				
30052																0.32			
30053									0.04	0.04	0.04	0.04	0.04	0.04	0.04		0.04		
5077	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5078																			0.18

Change in concentration level in one water body as a result of a one unit emission reduction in another water unit (continued)

Catchment area	300032	300033	300034	300035	300036	300037	300038	300039	300040	300042	300043	300044	300045	300046	300047	300048	300049	300050	300051	300052	300053
Water body																					
30032	0.19																				
30033		0.15																			
30034	0.09		0.08																		
30037	0.05	0.05	0.05			0.08															
30038							0.15														
30039								0.12													
30040	0.03	0.03	0.03			0.05	0.03	0.02	0.05												
30042										0.15											
30043											0.22										
30044										0.04	0.08	0.06									
30045													0.14								
30048										0.03	0.05	0.04	0.03			0.04					
30049																	0.19				
30050																		0.24			
30051																	0.07	0.09	0.07		
30052																				0.18	
30053										0.01	0.03	0.02	0.01			0.02	0.02	0.04	0.02		0.03
5077	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5078														0.18	0.18						

Note: the numbers relate to the hydrological units presented in Figure 3.1 and Figure A.1

Publications from the project "Water Economic Modelling for Policy Analysis"
(see www.ivm.falw.vu.nl/watereconomics):

WEMPA report

Reportnumber	*Authors*	*Title*
WEMPA Report-01	Roy Brouwer	Toekomstige beleidsvragen en hun implicaties voor de ontwikkeling van een integraal water-en-economie model
WEMPA Report-02	Paul Baan Aline te Linde	Inventory of water system models
WEMPA Report-03	Stijn Reinhard Vincent Linderhof	Inventory of economic models
WEMPA Report-04	Rob van der Veeren	Development of policy scenarios and measures

WEMPA report

Working paper	*Athors*	*Title*
WEMPA working paper-01	Paul Baan	Households and recreation: use and value of water
WEMPA working paper-02	Paul Baan	Emissiereductie RWZI's en Huishoudens
WEMPA working paper-03	Sjoerd Schenau	Data availability for the WEMPA project
WEMPA working paper-04	Rob Dellink Vincent Linderhof	Dynamic AGE model for water economics in the Netherlands (DEAN-WEMPA): first results
WEMPA working paper-05	Rob Dellink Vincent Linderhof	Dynamic AGE model for water economics in the Netherlands (DEAN-WEMPA): an update
WEMPA working paper-06	Frans Oosterhuis	Ervaringen met verhandelbare rechten in het waterkwaliteitsbeleid van de Verenigde Staten
WEMPA working paper-07	Frans Oosterhuis	Opportunities for the use of tradeable permits in Dutch water quality policy
WEMPA working paper-08	Paul Baan	Assessing the cost-effectiveness of pollution abatement measures in communal wastewater treatment plants
WEMPA working paper-09	Petra Hellegers Nico Polman	Assessing the cost-effectiveness of pollution abatement measures in agriculture
WEMPA working paper-10	Arnout van Soesbergen	Assessing the cost-effectiveness of pollution abatement measures in industry

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