# Cost-effectiveness analysis of water policy measures for nutrients: a regional model

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**Abstract**: This paper presents a regional economic optimization model, the RegiOptimizer, which is an integrated regional water and economy model that links economic costs to water quality improvements. RegiOptimizer has two strengths compared to similar models. Firstly, the model imposes policy targets on substance concentration levels for water quality (not emissions levels). Secondly, the current model includes the levels of nitrogen and phosphate concentrations of surface water. As a result, the model takes into account the interaction of measures with respect to the reduction of nitrogen and phosphates concentration levels. The results of the RegiOptimizer for the case study region, the Beerze and Reusel river basin in the South of the Netherlands show large synergies between the reduction of nitrogen and phosphates. Furthermore, the water quality will improve locally although the WFD targets will not be reached yet. If the neighbouring countries (Belgium) achieve the WFD objective, Beerze and Reusel river basin will benefit significantly in terms of lower costs for implementing measures.

**Key words**: Cost-effectiveness analysis, Nutrient concentrations reduction, Water-economic model, The Netherlands.

## 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. Earlier ex ante assessment studies conclude that the nutrient emissions will still exceed the WFD objectives in many water bodies in 2015

(PBL, 2008). The agriculture sector is largely responsible for the nutrient emissions in the Netherlands but for regional water managers it remains unclear how cost-effective agricultural technical measures such as buffer strips, and natural banks are compared to other measures (such as measures to improve the effectiveness of wastewater treatment plants). With a cost-effectiveness analysis, the least costs program of measures can be determined given predetermined targets, e.g. threshold values for pollutant loads in surface water (Brouwer *et al*., 2007). The RegiOptimizer is an economic optimization model which is capable of estimating the economic costs of implementation of pollution abatement measures to reach the water quality targets under the WFD at the water body level. The RegiOptimizer includes dose-effects relationships derived from the water and substance flow model WFD Explorer to calculate the effects on the water quality (Delsman, 2007). The advantage of using such a modular framework is that it is flexible and that it is easy to integrate existing data and models. Sufficient and reliable data are a prerequisite for applying RegiOptimizer. Our model minimizes overall costs to reach a target water quality (instead of emissions) and it can handles pollution and emission from non-agricultural sectors.

This paper builds upon earlier work. Linderhof and Reinhard (2009) and Van Soesbergen et al. (2009) apply the RegiOptimizer to one substance, N, but the focus on one substance might lead to biased estimated of the costs. If non-included substances exceed the environmental objectives and N is not, the model would suggest that no measures will be implemented. Therefore, this paper deals with the cost effectiveness analyses for nutrients N and P. In this way, the model explicitly deals with the interaction of nutrients when searching for the least cost programs of measures.

For reasons of available information and data, the Beerze and Reusel river basin in the south of the Netherlands is chosen as case study area. Both the optimization model and the database are not yet fully developed. The number of measures are expanded compared to Linderhof and Reinhard (2009). Therefore, the results presented for the case study are preliminary (it is work in progress) and should be interpreted as a indication of the potential of the integrated model.

## 2. Methodology

The assessment of environmental policies with respect to water quality requires an analysis at the local or regional level. Usually, the economic component is lacking or poorly developed in these bottom-up models especially in the case of water quality (see Reinhard and Linderhof, 2006). For Belgium a bottom-up model exists, namely the Environmental Costing Model (ECM). The ECM was initially developed for the assessment of environmental policy with respect to air quality (see Eykmans et al., 2004). More recently, the ECM model has been applied to the assessment of environmental policy with respect to water quality as well (see Broekx et al., 2006). The ECM model for water quality is actually developed for emissions of pollutants. In contrast with the ECM model, the regional model in this study extends the principle of the ECM model further to include impacts of measures on water quality rather than on emission loads.

## Model structure

The structure of the RegiOptimizer is derived from the hydrological structure of the WFD Explorer. Figure 1 presents the structure of the RegiOptimizer.

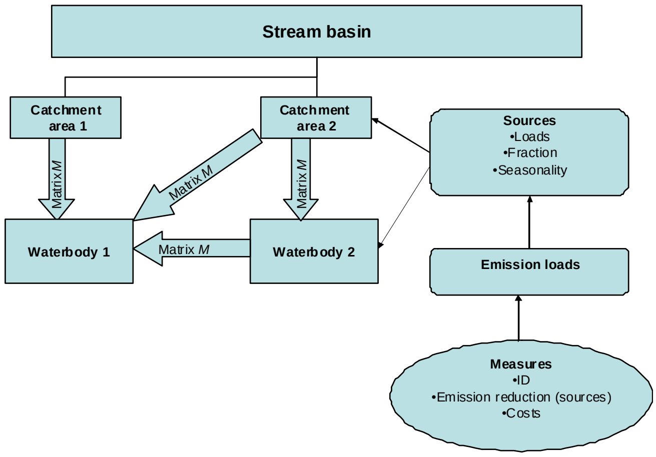


**Figure 1** Model framework

The RegiOptimizer distinguishes two types of hydrological units or areas, 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 one-way to each other. Catchment areas are the areas of land from which water runs off into water bodies. Most polluting economic activities (polluting 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, 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 information on the economic and hydrological structure within a river basin, and knowledge on costs and effects of individual technical measures, the model minimizes costs given a water quality norm. In addition, the model includes measures to reduce emissions at the emission sources, and the model can recalculate the water quality in terms of concentration of emission in the water.

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

$$\sum_{j \in J} \sum_{k \in K} X_{jk} C_{jk} \qquad (1)$$

where $X_{jk}$ is the implementation degree of a measure $j$ in emission source $k$, and $C_{jk}$ is the annual costs of implementing measure $j$ in emission source $k$. We assume that the measures can be implemented partially:

$$0 \le X_{jk} \le 1 \qquad (2)$$

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. While Van Soesbergen et al. (2008) assumed that emissions were calculated by taking the implementation degree and an absolute effect of all individual measures into account, we assume that the effect of measures result in a relative change of emissions. For instance, if there are two measures for the reduction of an emission source with respectively 50 and 40 percent emission reduction potential, the level of emissions from the source will be reduced to 30 percent i.e. (1-0.5)*(1-0.4) of its initial emission. The emission level of the source then is:

$$E_{ks} = E^0_{ks}\left(\prod_{j\in J} 1 - \varepsilon_{jks} X_{jk}\right) \qquad (3)$$

where $E_{ks}$ is the level of emissions, $E^0$ represents the initial level of emissions (when no measures are implemented) and $\varepsilon_{jks}$ represents the emission reduction of substance $s$ in emission source $k$ achieved by full implementation of measure $j$. Emission sources are either located near water bodies or in catchment areas. From the level of pollution sources, we can calculate the emissions at the level of water bodies and catchment areas ( $E_{is}$ ) by adding up the emission sources connected to the water body or catchment area:

$$E_{is} = \sum_{k\in K} E_{ks} Y_{ik} \qquad k=1,\ldots,K \text{ and } s=1,\ldots,S, \qquad (4)$$

Where $Y_{ik}$ is 1 if source $k$ is connected to water body or catchment area $i$, and 0 otherwise.

In Equation (5), the water quality in terms of the concentration of a substance in the water is recalculated based on the reduction of concentration of substances for emission sources $k$ due to the reduction of emissions in all water bodies considered:

$$Q_{is} = Q^0_{is}\left[1 - \sum_{i'\in I} M_{ii's}\left(\frac{E^0_{i's} - E_{i's}}{E^0_{i's}}\right)\right] \quad i=1,\ldots,I_w \text{ and } s=1,\ldots,S \qquad (5)$$

Here, $Q_{is}$ is the water quality in water body $i$ (concentration of substance $s$ in the water of water body $i$), $Q^0$ is the initial water quality in water body $i$ (i.e. when no measures are implemented), and $M_{ii's}$ is the ‘water quality matrix’ that reflects the impact of the emission reduction in water body or catchment area $i' \in I$ on the concentration of substance *s* in water body $i \in I_w \subset I$ . Note that for the calculation of the water quality in the water bodies, the emission reduction in catchment areas are taken into account as well.

Finally, Equation (6) presents the water concentration targets per substance for each water body:

$$Q_{is} \leq \tau_{is} \tag{6}$$

where $\tau_{hs}$ is the water quality standard for substance *s* in water body *i*. As all water bodies and catchment areas are linked via the water quality matrix *M*, a measure can have water quality effects in different water bodies simultaneously.

The optimization model RegiOptimizer derives its information about sources, loads, measures, the water system structure and scenarios from the WFD Explorer and determines the least-cost combination of measures to reach the water quality targets by a numerical optimization procedure. With information on initial emission loads and characteristics of the area, the WFD Explorer calculates the water quality in the river basin with or without implementation of measures. To calculate initial concentrations that serve as the base concentration in the optimization routine, the WFD Explorer is run without implementation of measures and the results are stored back in the database as initial concentrations.

### Optimization routine

In the optimization routine, the RegiOptimizer minimizes the total costs of implementing measures subject to a water quality constraint for each water body. The model does not impose water quality restrictions on catchment areas.

The selection of measures is endogenously in the model on the basis of the cost-effectiveness of the measures, where cost-effectiveness (CE) is determined as the cost of the measure *i* per unit of effect. The better the cost effectiveness, the more attractive the measure. As all water bodies are linked via the water quality matrix, a measure can have water quality effects in different water bodies simultaneously. Thus, it may be optimal to implement a more expensive measure in an upstream catchment area, as this will improve water quality both upstream and downstream, whereas a downstream measure will only affect water quality downstream.

More formally, the optimization routine implicitly describes for each measure the cost-effectiveness in terms of the effects for all targets simultaneously. To do this, a Lagrangian is specified:

$$L = \sum_{i \in I} C_{ij} X_{ij} - \sum_{h \in H} \lambda_{hs} \left( Q_{hs} - Q_{hs}^{*} \right) \tag{6}$$

with $Q$ as defined in Equation (3). Here $L$ is the optimand to be minimized; $I$ is the set of all possible measures, $H$ is the set of water bodies, $Q_{hs}$ is the water quality for substance *s* in terms of substance in water body *h* and $Q_{hs}*$ is the associated target for water quality in terms of substance *s* (as defined in the scenario). Water quality is determined by the initial water quality minus any improvement caused by implementing measure *i*: the emission reduction ($E$–$E^*$) associated by measure *i* times the impact (*M*, see equation 3) of one unit emission reduction on water body *h*. The $\lambda$'s represent the shadow value of the constraint for water body *h*, 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 (that gives the impact of the measure on water quality in the different water bodies) and by the shadow values (that give the relative importance of improving water quality in a water body vis-à-vis other water bodies). The results of the optimization routines are the implementation degrees for individual measures.

## 3. Beerze Reusel case study

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.[1] 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%).[2] The numbers on the map in Figure 1 reflect the code of the water bodies. The area around the water bodies are the catchment areas.

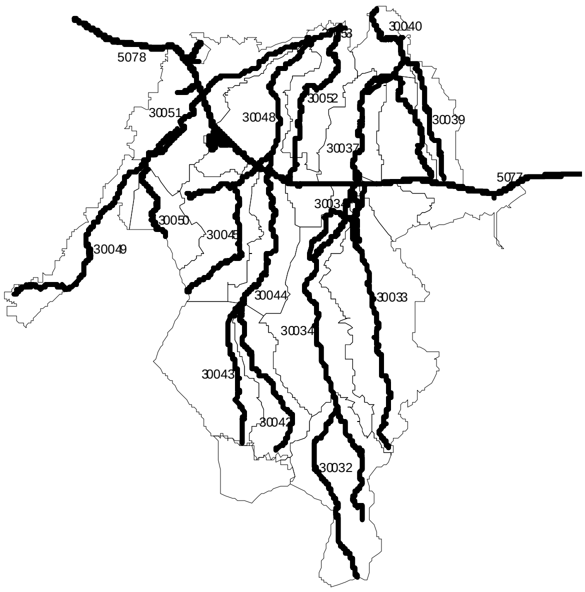


**Figure 1** Map of the case study areas.

[1] The Dommel River basin is part of the Meuse river basin in the Netherlands.
2 See http://www.dommel.nl (only in Dutch)

The Beerze Reusel river basin consists of 19 water bodies and 21 catchments (see Figure 3.1). Figures A.1 and A.2 in the appendix present the water bodies and associated catchment areas. Tables A.1 and A.2 summarize the connectivity between the catchment areas and the water bodies. Water bodies and catchment areas have nutrient pollution sources, see Table A.3 in the Appendix. Table 1 shows that next to agriculture as one of the main polluting emission source for nutrients, there are five point sources of nutrients in the river basin: four communal wastewater treatment plants (WWTP) in the river basin (36.1% and 49.9% for N and P emissions respectively). Three WWTPs directly emit emissions in the water bodies, while one WWTP is located in a catchment area. In addition, the river basin is also largely affected by inflowing nutrient emissions from Belgium and other river basins (45.9% and 37.4% for N and P emissions respectively).

Four upstream water bodies originate in Belgium, making water quality improvements in the area partly dependent on pollution abatement efforts across the border. One water body has inflow from a canal out of another river basin. In this report, the single pollutant version of RegiOptimizer in Van Soesbergen et al. (2008) is expanded to a multiple pollutants model. In this case study, we consider nitrogen and phosphates.

Table 1 Different nutrient emission sources in the river basin

| | Number of sources | Emissions (kg per day) | | Share of emissions (%) | |
|---|---|---|---|---|---|
| | | N | P | N | P |
| Total | 112 | 1606.7 | 119.1 | 100.0 | 100.0 |
| Agriculture | 21 | 114.2 | 9.0 | 7.1 | 7.5 |
| Construction | 21 | 6.0 | 0.8 | 0.4 | 0.7 |
| Industry | 1 | 6.7 | 1.7 | 0.4 | 1.4 |
| WWTP | 4 | 579.8 | 59.5 | 36.1 | 49.9 |
| Sewage system | 21 | 32.3 | 33 | 2.0 | 2.8 |
| Shipping | 17 | 1.7 | 0.3 | 0.1 | 0.2 |
| Atmosperic deposition | 21 | 128.6 | 0.0 | 8.0 | 0.0 |
| Inflowing water from Belgium/other River basins | 5 | 407.4 | 11.4 | 25.4 | 9.5 |
| Inflowing water | 1 | 330.0 | 33.3 | 20.5 | 27.9 |

### Link between emission reduction and water quality

The link of emission reductions to reductions of the concentration levels was derived from calculations with the WFD Explorer. With the WFD Explorer model, we calculated the relative change the concentration levels of a single substance in different water bodies due to a 50% emission reduction of emission sources in one particular water body or catchment area in the river basin. These calculation were repeated for all water bodies and catchment areas with emission sources. This exercise was applied to one single pollutant, namely Nitrogen in summer situation. Based on the calculations, we can construct the matrix M mentioned in Figure 1 and the element of the matrix reflect the relative change of concentration levels of water bodies due to a relative change of emissions in a water body or catchment area, see Table A.4 in the Appendix. Note that the RegiOptimizer model assumes that concentrations reduce proportionally with the reduction of emissions due to the implementation of measures.

Table 2 Concentrations and associated MTR class for nutrients per water body for the initial situation and maximum scenario

| | Initial | | | | Maximum | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | | P | | N | | | P | | |
| | Conc. | MTR | Conc. | MTR | Conc. | MTR | Red. | Conc. | MTR | Red |
| | mg/l | | mg/l | | mg/l | | % | mg/l | | % |
| 5077 | 4,71 | 2 | 0,16 | 3 | 2,35 | 3 | 50,0 | 0,08 | 4 | 51,1 |
| 5078 | 4,39 | 3 | 0,14 | 4 | 3,73 | 3 | 15,2 | 0,12 | 4 | 14,4 |
| 30032 | 2,41 | 3 | 0,07 | 4 | 2,09 | 4 | 13,2 | 0,06 | 4 | 12,3 |
| 30033 | 3,94 | 3 | 0,06 | 4 | 2,37 | 3 | 39,8 | 0,03 | 4 | 42,1 |
| 30034 | 3,62 | 3 | 0,13 | 4 | 1,96 | 4 | 45,9 | 0,07 | 4 | 46,3 |
| 30037 | 5,12 | 2 | 0,09 | 4 | 3,79 | 3 | 25,8 | 0,07 | 4 | 26,8 |
| 30038 | 6,92 | 2 | 0,20 | 3 | 4,16 | 3 | 39,8 | 0,12 | 4 | 41,1 |
| 30039 | 10,76 | 2 | 0,13 | 4 | 9,71 | 4 | 9,8 | 0,11 | 4 | 10,2 |
| 30040 | 4,48 | 2 | 0,10 | 4 | 3,09 | 3 | 31,0 | 0,07 | 4 | 31,4 |
| 30042 | 4,71 | 2 | 0,09 | 4 | 2,81 | 3 | 40,3 | 0,05 | 4 | 42,4 |
| 30043 | 8,59 | 2 | 0,23 | 3 | 7,06 | 2 | 17,8 | 0,19 | 3 | 18,8 |
| 30044 | 7,03 | 2 | 0,13 | 4 | 5,48 | 2 | 22,0 | 0,10 | 4 | 22,4 |
| 30045 | 5,84 | 2 | 0,10 | 4 | 5,12 | 2 | 12,2 | 0,09 | 4 | 13,3 |
| 30048 | 5,56 | 2 | 0,23 | 3 | 3,64 | 3 | 34,4 | 0,14 | 4 | 37,5 |
| 30049 | 9,29 | 2 | 0,17 | 3 | 7,96 | 2 | 14,3 | 0,15 | 3 | 13,8 |
| 30050 | 9,02 | 2 | 0,26 | 3 | 7,49 | 2 | 17,0 | 0,22 | 3 | 14,4 |
| 30051 | 7,43 | 2 | 0,17 | 3 | 5,74 | 2 | 22,7 | 0,13 | | 4 |
| 30052 | 3,80 | 3 | 0,27 | 3 | 2,38 | 3 | 37,2 | 0,18 | | 3 |
| 30053 | 5,97 | 2 | 0,33 | 2 | 4,28 | 3 | 28,2 | 0,23 | | 3 |

Remark: MTR is the maximum tolerable risk classification which is explained for N and P in Table 3 below.

The aim of RegiOptimizer 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). Nutrient concentration levels in the surface water are still high, see Table 2. The nitrogen concentration in the surface water ranges from 2.41 to 10.76 mg per litre. In term of the MTR classification for nitrogen, five water bodies have moderate water quality (MTR 3) and the remaining 14 water bodies have poor water quality (MTR 2), see Table 3. Phosphate concentrations are lower compared to the MTR classification. Three water bodies have very good quality (MTR 4) for phosphates and 10 water bodies have moderate water quality (MTR 3). Six water bodies have poor water quality (MTR 2).

Table 3 MTR class definition for nutrients

| Judgement | N concentration (mg/litre) | P concentration (mg/litre) |
|---|---|---|
| 5 Very good | < 1.0 | <0.05 |
| 4 Good | 1.0-2.2 | 0.05-0.15 |
| 3 Moderate | 2.2-4.4 | 0.15-0.30 |
| 2 Poor | 4.4-11.0 | 0.30-0.75 |
| 1 Very poor | >11.0 | >0.75 |

**Policy scenarios and abatement measures**

Since the RegiOptimizer is developed for demonstration purposes, the information put in the model might not reflect all aspects of water management. To demonstrate the usefulness of the RegiOptimizer as good as possible, we will present the changes of nutrient concentrations rather than changes of MTR classification. Obviously, these changes in MTR classes can be derived from the resulting nutrient concentrations for the different scenarios. In addition, we present policy scenarios with relative environmental restrictions rather than absolute restrictions, because the results of the maximum scenario (all possible measures in the database of the model) in Table 2 show that the MTR 1 class is never attained not even if all available measures would be implemented.

Next to the initial situation we present a 10% and 25% nutrient concentration reduction policy. In addition, we also present scenarios with 25% N and P concentration reductions respectively. With those scenarios, we can demonstrate the synergy between the environmental policies with respect to N and P. Furthermore, we formulate an alternative baseline policy scenario where inflowing water from Belgium is halved, because the water quality in the river basin depends to a large extent on the quality of inflowing water from Belgium. The reason to present an alternative baseline is that the Belgian part of the river basin will have to comply to WFD targets as well,

**Table 4 Types of measures included in the case study model**

| **Type of measure** | **Emission reduction capacity (%)** | **Number of measures** |
|---|---|---|
| *Agriculture and atmospheric deposition (catchments)* | | |
| Manure free corridor | 5 | 21 |
| Buffer strips (crop free corridors) special crops | 5 | 21 |
| Crop free corridors with paths open for public | 10 | 21 |
| Buffer strips (crop free corridors) grassland | 8 | 21 |
| Buffer strip (crop free corridors) arable land | 8 | 21 |
| Helofytefilters with reed | 5 | 21 |
| Natural banks (5 meters wide) | 5 | 21 |
| Subtotal Agriculture | | 147 |
| *Upgrade of WWTP (four WWTP)* | | |
| Fourth stage of WWTP | 90 | 4 |
| Helofytefilters with reed (additional stage) * | 5-8 | 4 |
| Additional N-filters* | 56-90 | 3 |
| Additional chemicals to remove P emissions* | 20-55 | 3 |
| Additional P filters* | 14-89 | 3 |
| Subtotal WWTP | | 17 |
| *Sewer improvements (catchments)* | | |
| Separate sewage system for rain water | 80 | 21 |
| Sewer improvement: decoupling of stormwater overflow | 50 | 21 |
| Reconstruct stormwater overflow facilities | 75 | 21 |
| Sewer improvement: larger storage settling tanks | 50 | 21 |
| Sewer improvement: increasing the flowing of rain water | 50 | 21 |
| Subtotal Sewer | | 105 |
| Total number of measures | | 269 |

* The reduction percentage depends on the capacity of WWTP or the size of the measure.

The model only considers technical measures. Seventeen different types of measures are relevant for this case study; see Table4. The measures for the WWTPs relate to four different WWTP's. The agricultural and sewage system measures are all measures at the level of the 21 catchments. In total, 269 mutually exclusive alternative measures are included in the RegiOptimizer. Different from Van Soesbergen et al. (2008), the investment costs of the measures are not fixed and similar to the operational costs the investment costs depend on the degree of implementation. For WWTP measures, this assumption might not be realistic, but WWTPs have some flexibility in the size of expanding its treatment capacity. Cost information of the measures is mainly derived from Reinhard et al. (2009), Van der Bolt et al. (2008) and the Water Board authority "De Dommel". 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.

For the costs estimate of the measures, we use the present value calculation of reinvesting in the measure over a 50-year period. The discount rate is 2.5%. For convenience, the costs of acquiring land are treated as investments. Since land costs are only once costs, we will have to adjust the present value calculation in the future, However, a closer look at the data learns us that the costs for acquiring land are low compare to investments. If all measure would be implemented the present value of the annual costs would amount 175.6 million Euro.

**Results of scenarios for baseline**

The baseline situation (BAU) uses the actual description of water quality from monitoring data of the Water board. For the first scenarios we assume that that there will be no reduction of the N and P 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 initial concentration. As the number of reduction measures in this case study is limited, these targets cannot be met for all water bodies all the time. Therefore, we use policy scenarios wit relative concentration targets:

- BAU: Baseline scenario or initial situation;
- RED10%: Policy scenario with a 10 percent reduction of the concentration levels of N and P for all water bodies;
- RED25%: Policy scenario with a 25 percent reduction of the concentration levels of N and P for all water bodies;
- RED25%N: Policy scenario with a 25 percent reduction of the concentration levels of N for all water bodies;
- RED25%P: Policy scenario with a 25 percent reduction of the concentration levels of P for all water bodies.

Next to the policy scenarios with targets for both N and P concentrations, we also show policy scenarios with a single target for the concentrations of either N or P. With these scenarios, we can indicate the synergy between the policy scenarios for N and P.

The RED10% scenario sets a target of a 10 percent concentration reduction for nitrogen en phosphates in all water bodies. The annual costs of improving water quality with 10 percent amount to almost 10 million Euro. To achieve this 10 percent reduction, 88 of the 269 additional measures have to be partly or fully implemented: 62 agricultural measures, 10 WWTP measures, and 16 sewage system measures. Two-third of the costs are spent on agricultural measures.

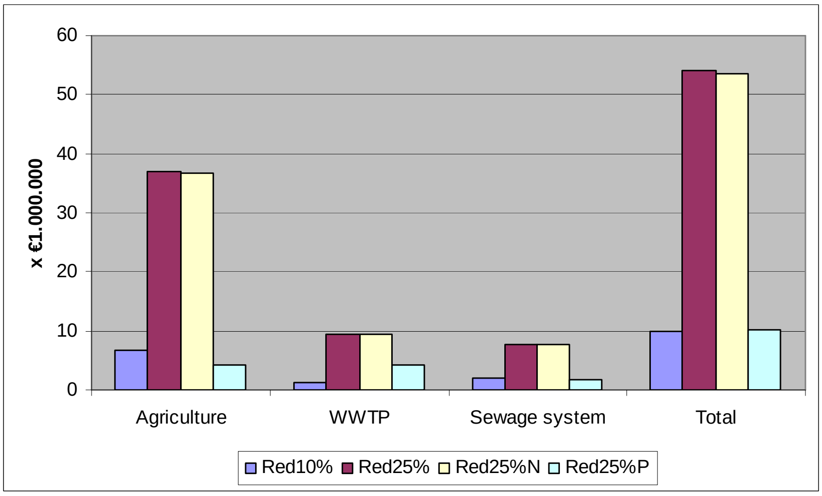


**Figure 3 Total annual costs per sector for the different scenarios**

In the RED25% scenario, the levels of nutrient concentration are reduced with 25 percent. However, even if all measures are implemented, a 25 percent concentration reduction cannot be achieved in nine water bodies. The main reason for this is that those water bodies are largely affected by emission sources out of the Water Board area, either abroad or in another water board area. Nevertheless, we calculated the costs of this scenario. The costs of measures amount 54.0 million Euro, see Figure 3, which corresponds to 169 measures partly or fully implemented. As in the 10% reduction scenario, two-third of the cost s are associated with agricultural measures.

With the next two policy scenarios we can show the synergy of attaining the objectives for N and P. We consider the policy scenario RED25%N with a 25 percent reduction of the concentration of N and no restriction on the concentration reduction of P, and the policy scenario RED25%P with no restriction on the concentration reduction of N and a 25 percent reduction of the concentration of P. The results on the costs of both policy scenarios show that the RED25%N scenario has almost a similar pattern of cost as the RED25% scenario. The costs of the RED25%P scenario amount € 10 million. The reduction of P is cheaper than the reduction N, because the concentration levels of N are relatively high (which results in lower MTR scores for good water quality) in the river basin, while the concentration levels of P are relatively low (reflected in higher MTR scores for P). The additional cost of attaining the 25% reduction of P concentration after attaining the objective for N is only € 400,000, see Table 5 below. As a result it is beneficial to consider N and P concentration reductions simultaneously.

**Table 5 (Additional) Cost (€ million) of reducing N, or P, or both**

| | Costs | Additional costs *Difference in costs with RED25%* | Total costs of RED25% |
|---|---|---|---|
| | | | |
| RED25%N | 53.6 | 0.4 | 54.0 |
| RED25%P | 10.2 | 43.8 | 54.0 |

In the case of the RED25%N scenario, the share of agricultural measures is 68 percent of the total costs, while in the case of the RED25%P scenario, the shares of the agricultural and WWTP measures are both slightly more than 40 percent. WWTPs are responsible for 50 percent of the emissions in the river basin, and the reduction of P concentration of surface water can be effectively done by WWTPs.

Another important outcome is the spatial distribution of pollution abatement measures and costs. Figure 4 shows that in the case of the red25%N scenarios with 25 percent reduction of N concentration the measures with associated costs are allocated in the upstream (or southern) part of the river basin (near the Belgian border): 30032, 30034, 30043, 30045, 30049, and 30050. For all those water bodies the costs for the 25 percent N reduction scenarios amount €3 to €6 million per year. One exception is the western part of the Wilhelmina canal (water body 5078). This water body is hardly affected by the emission levels in the river basin except for its catchments (300046 and 300047), and it includes a wastewater treatment plant. The measures for upgrading this WWTP are expensive.

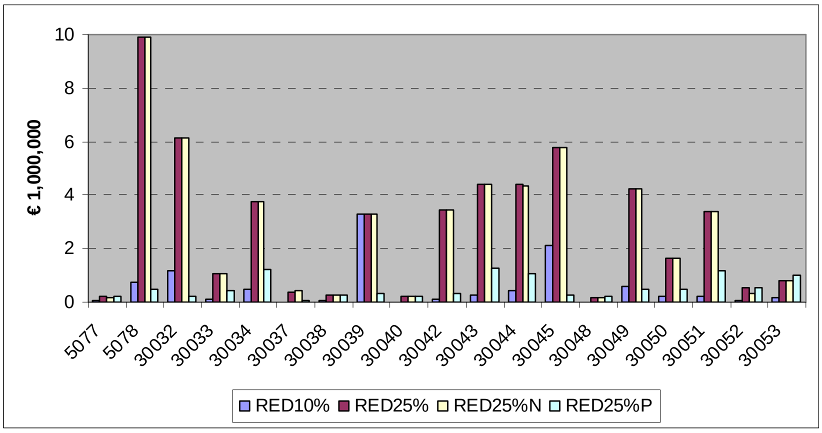


**Figure 4 Annual costs of measures per water body (including catchments, see Table in Appendix) per scenario**

Figure 3 shows the annual costs for measures per water body. The costs include the costs of measures in the catchments connected to the different water bodies.

**Results of scenarios for alternative baseline**

The results for the alternative baseline projection (BAU$^+$) start from the premise that the nutrient emissions from inflowing water from Belgium are halved, see Table A.3 in Appendix. In addition, the inflow of nutrients in water body 30037 is halved as well for the same reason. The water bodies in other upstream river basins (either Belgium or other river basins in the Netherlands) have to comply to the WFD as well. Next to the results of the alternative projection, we consider three policy scenarios:

- RED25% $^+$ scenario with 25 percent concentration reductions for N and P: with the alternative projection;
- RED25%N$^+$ scenario with 25 percent concentration reduction for N with the alternative projection;
- RED25%N$^+$ scenario with 25 percent concentration reduction for N with the alternative projection.

**Table 6 Nutrient concentrations, and nutrient concentration reductions per water body for the initial situation and the alternative projection**

| | BAU | | | | BAU$^+$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | | P | | N | | | P | | |
| | Conc. | MTR | Conc. | MTR | Conc. | MTR | Red. | Conc. | MTR | Red |
| | mg/l | | mg/l | | mg/l | | % | mg/l | | % |
| 5077 | 4.71 | 2 | 0.16 | 3 | 4.71 | 2 | 0.0 | 0.16 | 3 | 0.0 |
| 5078 | 4.39 | 3 | 0.14 | 4 | 3.08 | 3 | 30.0 | 0.10 | 4 | 30.0 |
| 30032 | 2.41 | 3 | 0.07 | 4 | 1.65 | 4 | 31.5 | 0.05 | 4 | 31.5 |
| 30033 | 3.94 | 3 | 0.06 | 4 | 3.94 | 3 | 0.0 | 0.06 | 4 | 0.0 |
| 30034 | 3.62 | 3 | 0.13 | 4 | 3.04 | 3 | 16.0 | 0.11 | 4 | 16.0 |
| 30037 | 5.12 | 2 | 0.09 | 4 | 3.90 | 3 | 23.8 | 0.07 | 4 | 23.8 |
| 30038 | 6.92 | 2 | 0.20 | 3 | 6.92 | 2 | 0.0 | 0.20 | 3 | 0.0 |
| 30039 | 10.76 | 2 | 0.13 | 4 | 6.69 | 2 | 37.8 | 0.08 | 4 | 37.8 |
| 30040 | 4.48 | 2 | 0.10 | 4 | 3.86 | 3 | 13.8 | 0.09 | 4 | 13.8 |
| 30042 | 4.71 | 2 | 0.09 | 4 | 4.71 | 2 | 0.0 | 0.09 | 4 | 0.0 |
| 30043 | 8.59 | 2 | 0.23 | 3 | 6.19 | 2 | 27.9 | 0.17 | 3 | 27.9 |
| 30044 | 7.03 | 2 | 0.13 | 4 | 4.86 | 2 | 30.9 | 0.09 | 4 | 30.9 |
| 30045 | 5.84 | 2 | 0.10 | 4 | 3.73 | 3 | 36.2 | 0.06 | 4 | 36.2 |
| 30048 | 5.56 | 2 | 0.23 | 3 | 4.84 | 2 | 12.9 | 0.20 | 3 | 12.9 |
| 30049 | 9.29 | 2 | 0.17 | 3 | 6.44 | 2 | 30.7 | 0.12 | 4 | 30.7 |
| 30050 | 9.02 | 2 | 0.26 | 3 | 6.69 | 2 | 25.8 | 0.19 | 3 | 25.8 |
| 30051 | 7.43 | 2 | 0.17 | 3 | 5.30 | 2 | 28.6 | 0.12 | 4 | 28.6 |
| 30052 | 3.80 | 3 | 0.27 | 3 | 3.80 | 3 | 0.0 | 0.27 | 3 | 0.0 |
| 30053 | 5.97 | 2 | 0.33 | 2 | 5.16 | 2 | 13.6 | 0.28 | 3 | 13.6 |

Source: Own calculations on monitoring data of water quality from the Water board authority “De Dommel”)

Table 6 lists the nutrient concentrations of the BAU and $BAU^+$ scenarios and the concentration reduction of the $BAU^+$ scenario. Although there are six nutrient emission sources (in catchment areas 300032, 300037, 300043, 300045, 300049, and 300050) halved in the alternative projection (PLUS), water quality in fourteen of the nineteen water bodies is significantly improved. Trivially, the major reduction of nutrient concentrations is observed in the water bodies with the emission sources from outside the river basin (30032, 30037, 30043, 30045, 300049, and 30050). The concentration reductions in those water bodies range from 25 to 38 percent. The concentration reduction in the down stream water bodies ranges from 12 to 30 percent. Five water bodies are not affected at all.

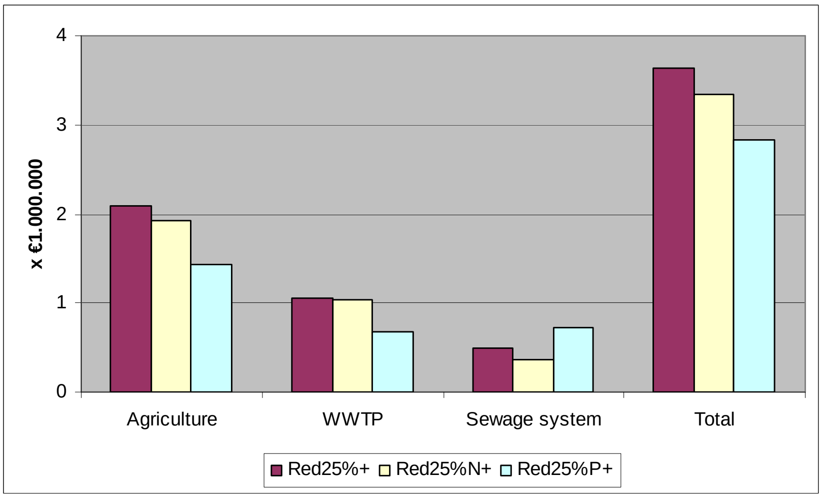


**Figure 5** **Total annual costs per sector for the different scenarios in the case of the alternative projection**

Due to the significant impact of the PLUS scenario on the nutrient concentrations in the water bodies, a fewer number of measures will be necessary to attain the 25 percent nutrient concentration reductions. As a result, the costs will be significantly lower as well. Note that in all water bodies, the 25 percent concentration reduction can be attained, see Table 7.

The total costs for all three policy scenarios in the case of the alternative projection amount less than €4 million. The share of agricultural measures in the annual costs is approximately 50 percent. This means that the total of WWTP and sewage system measures also accounts for 50 percent of the costs. In all scenarios, the share of sewage system measures in the annual costs is significantly smaller than the share of WWTP measures except for the $RED25\%P^+$ scenario. Apparently, it is more cost effective to implement more sewage system measures if there is only a restriction imposed on P concentration in surface waters.

Table 7 Concentrations, associated MTR class, concentration reduction for scenarios with the alternative projection

| | Red25%$^{+}$ | | | | | | Red25%N$^{+}$ | | | | | | Red25%P$^{+}$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **N** | **MTR** | **Red** | **P** | **MTR** | **Red** | **N** | **MTR** | **Red** | **P** | **MTR** | **Red** | **N** | **MTR** | **Red** | **P** | **MTR** | |
| | mg/l | | % | mg/l | | % | mg/l | | % | mg/l | | % | mg/l | | % | mg/l | | % |
| 5077 | 3,53 | 3 | 25,0 | 0,12 | 4 | 25,0 | 3,53 | 3 | 25,0 | 0,13 | 4 | 17,2 | 4,02 | 3 | 14,7 | 0,12 | 4 | 25,0 |
| 5078 | 3,08 | 3 | 30,0 | 0,10 | 4 | 30,0 | 3,08 | 3 | 30,0 | 0,10 | 4 | 30,0 | 3,08 | 3 | 30,0 | 0,10 | 4 | 30,0 |
| 30032 | 1,65 | 4 | 31,5 | 0,05 | 4 | 31,5 | 1,65 | 4 | 31,5 | 0,05 | 4 | 31,5 | 1,65 | 4 | 31,5 | 0,05 | 4 | 31,5 |
| 30033 | 2,95 | 3 | 25,0 | 0,04 | 4 | 27,4 | 2,95 | 3 | 25,0 | 0,04 | 4 | 27,4 | 3,12 | 3 | 20,8 | 0,04 | 4 | 23,7 |
| 30034 | 2,71 | 3 | 25,0 | 0,10 | 4 | 26,5 | 2,71 | 3 | 25,0 | 0,10 | 4 | 25,0 | 2,95 | 3 | 18,3 | 0,10 | 4 | 25,0 |
| 30037 | 3,59 | 3 | 29,8 | 0,06 | 4 | 30,7 | 3,59 | 3 | 29,8 | 0,06 | 4 | 30,0 | 3,77 | 3 | 26,3 | 0,06 | 4 | 29,8 |
| 30038 | 5,19 | 2 | 25,0 | 0,15 | 3 | 25,0 | 5,19 | 2 | 25,0 | 0,16 | 3 | 22,5 | 5,32 | 2 | 23,1 | 0,15 | 3 | 25,0 |
| 30039 | 6,69 | 2 | 37,8 | 0,08 | 4 | 37,8 | 6,69 | 2 | 37,8 | 0,08 | 4 | 37,8 | 6,69 | 2 | 37,8 | 0,08 | 4 | 37,8 |
| 30040 | 3,36 | 3 | 25,0 | 0,07 | 4 | 25,0 | 3,36 | 3 | 25,0 | 0,07 | 4 | 24,5 | 3,43 | 3 | 23,5 | 0,07 | 4 | 25,0 |
| 30042 | 3,53 | 3 | 25,0 | 0,07 | 4 | 27,1 | 3,53 | 3 | 25,0 | 0,07 | 4 | 27,1 | 3,64 | 3 | 22,6 | 0,07 | 4 | 25,0 |
| 30043 | 5,54 | 2 | 35,5 | 0,15 | 3 | 34,8 | 5,54 | 2 | 35,5 | 0,15 | 3 | 34,8 | 5,69 | 2 | 33,8 | 0,15 | 3 | 33,2 |
| 30044 | 4,46 | 2 | 36,6 | 0,08 | 4 | 36,8 | 4,46 | 2 | 36,6 | 0,08 | 4 | 36,5 | 4,52 | 2 | 35,7 | 0,08 | 4 | 38,0 |
| 30045 | 3,73 | 3 | 36,2 | 0,06 | 4 | 36,2 | 3,73 | 3 | 36,2 | 0,06 | 4 | 36,2 | 3,73 | 3 | 36,2 | 0,06 | 4 | 36,2 |
| 30048 | 4,17 | 3 | 25,0 | 0,17 | 3 | 25,1 | 4,17 | 3 | 25,0 | 0,17 | 3 | 24,9 | 4,29 | 3 | 22,8 | 0,17 | 3 | 25,0 |
| 30049 | 6,27 | 2 | 32,5 | 0,11 | 4 | 32,4 | 6,27 | 2 | 32,5 | 0,11 | 4 | 32,4 | 6,27 | 2 | 32,5 | 0,11 | 4 | 32,4 |
| 30050 | 5,94 | 2 | 34,2 | 0,17 | 3 | 32,9 | 5,94 | 2 | 34,2 | 0,17 | 3 | 32,9 | 5,94 | 2 | 34,2 | 0,17 | 3 | 32,9 |
| 30051 | 4,96 | 2 | 33,2 | 0,11 | 4 | 32,8 | 4,96 | 2 | 33,2 | 0,11 | 4 | 32,8 | 5,03 | 2 | 32,3 | 0,10 | 4 | 38,5 |
| 30052 | 2,77 | 3 | 27,0 | 0,21 | 3 | 25,0 | 2,85 | 3 | 25,0 | 0,21 | 3 | 23,2 | 2,77 | 3 | 27,0 | 0,21 | 3 | 25,0 |
| 30053 | 4,48 | 2 | 25,0 | 0,25 | 3 | 25,0 | 4,48 | 2 | 25,0 | 0,25 | 3 | 24,9 | 4,66 | 2 | 21,9 | 0,25 | 3 | 25,0 |

## Conclusions and recommendations

This report presents and discusses 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 '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 cannot 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. Moreover, there are other considerations besides cost-effectiveness that may play an important role in the final decision–making with respect to the final selection of measures.

First of all, the allocation of the costs of WFD implementation across different economic sectors and water bodies or sub-basins might be an important aspect. In this respect, the use of (economic) policy instruments might be considered as well. The identified set of measures by the 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. 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 and phosphates 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 baseline scenarios were modelled. For the first baseline scenario we assumed that there will be no reduction of nutrient emissions in inflowing water from Belgium. For the alternative projection of the baseline scenario, we assume that the nutrient emissions in inflowing water from Belgium are halved. This alternative projection of the baseline scenario anticipates on 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 baseline 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.

An important conclusion drawn from the case study exercise is that considerable abatement efforts in neighbouring Belgium will have significant impact on the water policy for the Beerze Reusel river basin.. The total costs are more than ten times higher if we assume that emission sources from abroad remain unaffected. Even though water quality improves in several water bodies under both baseline situations, many water bodies will remain too polluted.

The case study showed the possible synergies between policy scenarios for more than one pollutant. In the case of nutrients, implemented measures affected both nitrogen and phosphates levels simultaneously. This is also reflected in the relatively low additional costs between one and two pollutant policy scenarios. The synergy between nitrogen and phosphates was expected to be significant. The number of pollutants in the RegiOptmizer can be expanded easily whenever the necessary information on emissions, concentration levels, measures, impacts and costs are present.

Furthermore, the case study demonstrated that even if all available measures are implemented the water quality improvement is limited. Note that the list of pollution abatement measures in the model is not exhaustive and can be expanded in future research.

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# Appendix

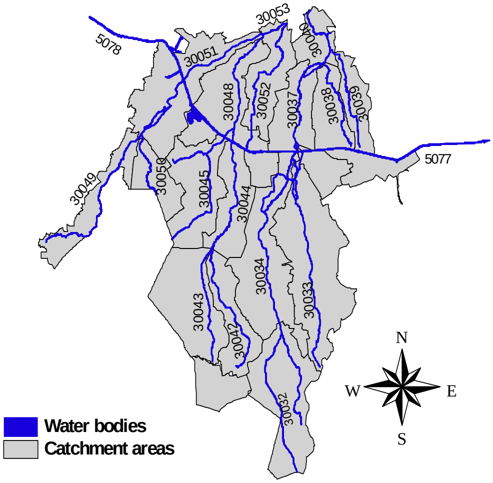


Figure A.1 Coding of water bodies in the Beerze Reusel river basin

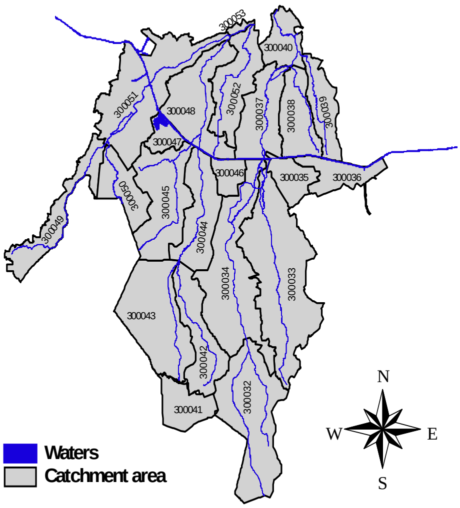


Figure A.1 Coding of catchment areas in the Beerze Reusel river basin

Table A.1 List of water bodies with associated catchment areas in the Beerze Reusel river basin

| Water body ID | Water body name | Associated catchment areas |
|---|---|---|
| 5077 | Wilhelminakanaal,sluis V tot IV (Haghorst) | 300035, 300036 |
| 5078 | Wilhelminakanaal,sluis IV tot III | 300046, 300047 |
| 30032 | Groote Beerze | 300032 |
| 30033 | Kleine Beerze | 300033 |
| 30034 | Groote Beerze | 300034 |
| 30037 | Groote Beerze | 300037 |
| 30038 | Koevoortseloop | 300038 |
| 30039 | Heerenbeekloop | 300039 |
| 30040 | Groote Beerze | 300040 |
| 30042 | Reusel | 300042 |
| 30043 | Reusel | 300043 |
| 30044 | Reusel | 300044 |
| 30045 | Spruitenstroompje/ Roodloop | 300045 |
| 30048 | Reusel | 300048 |
| 30049 | Nieuwe Leij-Pop.L-Pov.L-VoorsteStroom | 300049 |
| 30050 | Nieuwe Leij-Pop.L-Pov.L-VoorsteStroom | 300050 |
| 30051 | Nieuwe Leij-Pop.L-Pov.L-VoorsteStroom | 300051 |
| 30052 | Rosep | 300052 |
| 30053 | Essche Stroom | 300053 |

Table A.2 Water system structure: connectivity of water bodies upstream with water bodies downstream

| Water bodies/catchment areas upstream | Connected to water body downstream |
|---|---|
| *Water bodies* | |
| 5077 | 5078 |
| 30032 | 30034 |
| 30033; 30034 | 30037 |
| 30037; 30038; 30039 | 30040 |
| 30042; 30043 | 30044 |
| 30044; 30045 | 30048 |
| 30048; 30051 | 30053 |
| 30049; 30050 | 30051 |

Table A.3 Emissions of N and P per water body (including catchment areas) in the Beerze Reusel river basin (Source: WFD Explorer for the river basin)

| Water body | N | | P | |
|---|---|---|---|---|
| | Total emission sources | Emission sources elsewhere | Total emission sources | Emission sources elsewhere |
| | kg per day | kg per day | kg per day | kg per day |
| 5077 | 22.21 | | 0.37 | |
| 5078 | 25.01 | | 0.31 | |
| 30032 [1] | 19.54 | 8.5 | 1.01 | 0.2 |
| 30033 | 30.83 | | 1.41 | |
| 30034 | 73.30 | | 5.73 | |
| 30037 [2] | 340.52 | 330.0 | 33.86 | 33.3 |
| 30038 | 9.15 | | 0.50 | |
| 30039 | 12.96 | | 2.07 | |
| 30040 | 5.96 | | 0.22 | |
| 30042 | 11.26 | | 0.65 | |
| 30043 [1] | 51.04 | 32.0 | 2.26 | 1.2 |
| 30044 | 109.01 | | 9.89 | |
| 30045 [1] | 28.66 | 16.8 | 1.01 | 0.2 |
| 30048 | 17.09 | | 0.58 | |
| 30049 [1] | 200.00 | 194.8 | 4.78 | 4.4 |
| 30050 [1] | 158.35 | 155.3 | 5.53 | 5.4 |
| 30051 | 411.45 | | 36.59 | |
| 30052 | 10.22 | | 0.34 | |
| 30053 | 70.10 | | 12.05 | |
| Total | 1606.67 | | 119.14 | |

[1] Those water bodies have emission sources in the water body or associated catchment areas

[2] This water body has inflowing nutrient emissions from the eastern part of the Wilhelmina canal that flow from the East to West of the river basin.

Table A.4 Water system structure: connectivity of catchment areas and water bodies upstream with water bodies downstream (Source: WFD Explorer)

| | 5077 | 5078 | 30032 | 30033 | 30034 | 30037 | 30038 | 30039 | 30040 | 30042 |
|---|---|---|---|---|---|---|---|---|---|---|
| 30032 | | | 63 | | 32 | 16 | | | 9 | |
| 30034 | | | | | 32 | 16 | | | 9 | |
| 30037 | | 60 | | | | 32 | | | 9 | |
| 30039 | | | | | | | | 76 | 9 | |
| 300032 | | | 37 | | 19 | 9 | | | 5 | |
| 300033 | | | | 100 | | 6 | | | 4 | |
| 300034 | | | | | 17 | 9 | | | 5 | |
| 300035 | 50 | | | | | | | | | |
| 300036 | 50 | | | | | | | | | |
| 300037 | | | | | | 12 | | | 7 | |
| 300038 | | | | | | | 100 | | 4 | |
| 300039 | | | | | | | | 24 | 3 | |
| 300040 | | | | | | | | | 35 | |
| 300042 | | | | | | | | | | 100 |
| 300045 | | | | | | | | | | |
| 300046 | | 20 | | | | | | | | |
| 300047 | | 20 | | | | | | | | |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

Table A.4 Water system structure: connectivity of catchment areas and water bodies upstream with water bodies downstream continued (Source: WFD Explorer)

| | 30043 | 30044 | 30045 | 30048 | 30049 | 30050 | 30051 | 30052 | 30053 |
|---|---|---|---|---|---|---|---|---|---|
| 30042 | | | | | | | | | 7 |
| 30043 | 56 | 62 | | 13 | | | | | 7 |
| 30044 | | | | | | | | | 7 |
| 30045 | | | 72 | 13 | | | | | 7 |
| 30048 | | | | | | | | | 7 |
| 30049 | | | | | 61 | | 19 | | 7 |
| 30050 | | | | | | 52 | 38 | | 7 |
| 30051 | | | | | | | | | 7 |
| 300042 | | 9 | | 6 | | | | | 3 |
| 300043 | 44 | 16 | | 10 | | | | | 5 |
| 300044 | | 13 | | 8 | | | | | 4 |
| 300045 | | | 28 | 5 | | | | | 3 |
| 300048 | | | | 46 | | | | | 4 |
| 300049 | | | | | 39 | | 12 | | 4 |
| 300050 | | | | | | 48 | 18 | | 6 |
| 300051 | | | | | | | 13 | | 5 |
| 300052 | | | | | | | | 100 | |
| 300053 | | | | | | | | | 11 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |