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MASTER THESIS REPORT

Wat-IF: Decision-Support Tool for Sustainable Wastewater Treatment Plants in the Netherlands

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AF: Assessment Factor

AFRL: (Air Force Research Laboratory)

AHP: Analytical Hierarchy Process

ANP: Analytical Network Process

AOPs: Advanced oxidation processes

APC: Advanced Process Control

ARAS: Additive Ratio Assessment System

ASP: Activated Sludge Process

AWWT: Advanced Wastewater Treatment

BEQ: Bioanalytical equivalent

CH_4: Methane

CO_2: Carbon Dioxide

COD: Chemical Oxygen Demand

DEMATEL: Decision Making Trial and Evaluation Laboratory

DM: Decision Making

DO: Dissolved Oxygen

DUSD S&T: Deputy Under Secretary of Defence, Science and Technology

EBT: Effect-Based Trigger

EU: European Union

GRE: Gross Energy Requirement

GWPs: Global Water Potentials

LCA: Life Cycle Assessment

MCDM: Multiple Criteria Decision Making

N: Nitrogen

NASA: National Aeronautics and Space Administration

N_2O: Nitrous oxide

P: Phosphorus

PAC: Powdered Activated Carbon

PACAS: Powdered Activated Carbon on Activated Sludge

P.E: population equivalents

PROMETHEE: Preference Ranking Organization Method for Enrichment Evaluation

SIMONI: Smart Integrated Monitoring

TOPSIS: Technique for Order Preference by Similarity to an Ideal Solution

TRLs: Technology Readiness Levels

WAVES: Waterschappen Analyse en Verbeter Systeem (Waterboards analysis and improvement system)

WTP: Waste Treatment Plant

WWT: Wastewater treatment

WWTPs: Wastewater Treatment Plants

ABSTRACT

This research presents a Decision Support Tool (Wat-IF model) for managers of Dutch wastewater treatment plants in order to address sustainability challenges through the implementation of new wastewater technologies and monitoring scenarios efficiently and effectively. These challenges are associated with reducing the carbon footprint of these plants as well as removing contemporary pollutants such as micropollutants and macropollutants before discharging effluents. Managers at WWTPs have been utilizing renewable energy to minimize the carbon footprint of this industry. However, dealing with micropollutants requires more energy consumption, which can increase the carbon footprint and costs substantially. Additionally, new wastewater treatment technologies and monitoring scenarios are required to address these pollutants, which might also increase the costs. Therefore, water managers need to take decisions on the implementation of new wastewater technologies and monitoring scenarios to eliminate pollutants and improve the water quality at the lowest possible energy consumption and costs. Accordingly, The Wat-IF model can assist water managers in evaluating technologies and in deciding which one(s) should be implemented. In this respect, this research investigated a Decision Support Tool comprised of three main blocks to help water managers at WWTPs. This research firstly focused on the main characteristics of all WWTPs in the Netherlands to build the default settings for the model by collecting data from the WAVES database and performing a descriptive analysis. Next, the most promising technologies and monitoring concepts were investigated by conducting interviews with wastewater treatment experts and using a TRL analysis method to be embedded in the second block of the model. Finally, the third block of Wat-IF model was designed to address the main challenges of water managers at WWTPs: cost per m^3 of treated wastewater, carbon footprint and water quality. This third block calculates the impact of treatment technologies and monitoring scenarios on the (default) starting point as defined in the previous blocks. The results of the default settings for small, medium, and large Dutch WWTPs were presented in Section 3.5. Additionally, the results of desk research and semi-structured interviews demonstrated that PACAS and APC are currently the most promising wastewater treatment technology and monitoring concept to be incorporated into the second block of the model. The Wat-IF model illustrates the total costs of the implemented technologies and scenarios to be compared by the user to decide which one is worth implementing. In addition to costs, the Wat-IF model calculates the CO_2eq of implemented technologies and monitoring scenarios using the CIF software. Moreover, two water quality quantification methods, namely

SIMONI and Water Quality Index (WQI) were studied and analyzed by means of a SWOT analysis method for the calculation of water quality changes as a result of newly implemented technologies and monitoring scenarios.

Overall, it can be concluded that for all the essential parts of the Wat-IF model, sufficient scientific and empirical data, methodologies and concepts are available to ensure its credibility and usability. Given that this research only studied the initial setup of the Wat-IF model, recommendations for further improvements include the addition of other innovative technologies for the removal of microplastics and the recovery of phosphorous, as well as the inclusion of combined ozone and sand filtration as an advanced treatment step for the removal of pharmaceuticals and other ecologically harmful substances.

Key words: WWTPs, water quality, carbon footprint, sustainability improvements, new wastewater technologies and scenarios

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1 INTRODUCTION

1.1 Background

Researchers claim that the degradation of the environment is not so much associated with overpopulation but is due to direct and indirect overconsumption of resources in an irresponsible way by the wealthy, thereby causing pollution (Hughes & Johnston, 2005; Weinzettel et al., 2013). The incremental rate of industrialization is deemed as the main reason for environmental pollution, which is a direct consequence of economic development (Nazeer et al.,2016). In this respect, the United Nations World Conference stated the term sustainable development on the Environment and Development (UNCED) in Rio de Janeiro (1992). This hallmarked a new era in global awareness to address environmental issues caused by human activities (Shaker, R. R,2015). It emphasizes the development based on sustainability, which implies that the present generation`s needs have to be satisfied while safeguarding the future demands of the next generation (Beltrán-Esteve and Picazo-Tadeo 2015; WCED 1987, p. 43). In this regard, eco-innovation over the past few years has attempted to develop strategies and policies of organizations to mitigate the adverse impact of production and consumption activities of human on the environment (Jo et al., 2015). The products, services, and processes of an organization that lead to sustainable development are referred to as eco-innovation. This means the industrial processes can be improved by the implementation of available knowledge or technologies to protect environment (Shakhovska, 2017). Bleischwitz et al. (2009) mentioned that the most important goals of eco-innovation is to reduce the negative impacts of human activities on the environment and enhance sustainability objectives. Basically, the increase in volume of consumption should be decoupled from the increase in pollution. Eco-innovation consists of activities that companies, politicians, and general communities must conduct to develop new ideas, processes, or behavior to significantly minimize environmental impact to achieve sustainable objectives (Rennings, 2000). Therefore, eco-innovation is deemed a valuable option to reduce environmental impact, costs, and enhance the economic performance of companies (Arundel & Kemp, 2009). As a result, this innovation enables companies to increase environmental awareness within their organizations while reducing their carbon footprint (Díaz-García et al., 2015).

Companies are often influenced by internal and external drivers or barriers when a decision is to be made regarding eco-innovations (Kiefer et al., 2018). Hojnik & Ruzzier (2016) elaborated on the internal and external drivers for companies; the most prominent internal drivers are cost-reduction and environmental concerns, whereas customer pressure, competition, and regulatory pressure are deemed the main external drivers. In addition to the investment needed for eco-innovation implementation is the most commonly experienced internal barrier whereas, legislation is the most important external barrier (Hojnik & Ruzzier, 2016). Thus, the most desirable outcome of eco-innovation from a company's point of view seems to be cost-reduction in compliance with legislation. Similarly, the aforementioned barriers also exist in the water and wastewater industry regarding the implementation of innovative technologies, and their hampering effects toward achieving sustainability objectives are not well understood (Wehn & Montalvo, 2014). The implementation of innovative technologies at WWTPs has been studied with the aim of meeting sustainability objectives, however, multi-dimensional concept has been incorporated in sustainability, which comprises social, environmental and economic targets at WWTPs (Sweetapple et al., 2015). Each component of this concept consists of a large number of elements. In this research, carbon footprint and water quality are considered the key elements of sustainability at WWTPs.

According to research by Kiparsky et al (2016), the most commonly reported barriers by water managers at WWTPs in California regarding the implementation of innovative technologies are costs and regulatory compliance. Understandably, water managers at WWTPs have experienced being squeezed between the necessity to meet the strict regulatory requirements, especially in terms of water quality or carbon footprint, and the need to keep the costs per household as low as possible. Short-term costs (capital investment) and life-cycle costs such as chemical use/re-use and energy consumption for a given innovative technology should be considered (Kiparsky et al., 2016). However, based on the outcome of the survey by Kiparsky et al. (2016), the majority of water managers at WWTPs in California believe the implementation of innovative technologies will eventually give rise to cost reductions at their plants.

Water quality regulation compliance is another serious barrier that needs to be considered by water utilities. In the Netherlands, if a wastewater treatment plant is classified as a water production facility, the product needs to meet the quality requirements of the discharge permit to keep good quality of the receiving water (STOWA, 2010). To ensure this, Council Directive 91/271/EEC was adopted with the objective of protecting receiving surface waters in the EU from the adverse impact of urban wastewater treatment discharges (Garrone et al., 2018). This Council Directive states that discharges of WWTPs need to be treated in case of agglomerations of >2,000 population equivalents (p.e.), and secondary treatment should be carried out for discharges with agglomerations of >2,000 p.e. as well. Advanced Wastewater Treatment steps should also be carried out for agglomerations >10,000 p.e. in designated sensitive areas (Garrone et al., 2018). The EU later finalized the Directive 2000/60/EC regarding the development of the integrated water management plan; this became known as the EU Water Framework Directive (WFD, 2000). Directive 2000/60/EC focused on integrated water management plans to prevent groundwater and surface water sources being polluted by wastewater. As the EU had been concentrating on contemporary pollutants in water, Directive 2013/39/EU [1]was adopted regarding pollutants and pharmaceuticals which needed to be prioritized for monitoring, and Directive 2015/495/EU[2], contained a watch list of new contaminants including the natural hormone oestrone, pesticides, antibiotics and antioxidants used as food additives (Marek et al., 2017).

Carbon footprint is considered one of the suitable measures of sustainability at WWTPs, and represents another barrier for WWTPs because of its impact on climate change (Delre et al., 2019). In this regard, to achieve the climate objectives of Dutch government, all water boards in the Netherlands have been attempting to utilize renewable energy (STOWA, 2018). However, based on Arcadis (2018), despite the increased use of renewable energy, the carbon footprint production of Dutch water boards increased by 7% in 2017 compared to 2016. Additionally, 25 kilotons of CO2-equivalents of biogas and 220 kilotons of CO2-equivalents of methane and nitrous oxide were excluded from the overall calculations (Arcadis, 2018). So, by adding these calculations, the total production of carbon footprint increases by more than a third. Targeted reduction in CO_2 have been acquired by Dutch water boards (Arcadis, 2018), however, further measures are still required to minimize energy consumption. Dutch water boards have been relatively successful to deploy

[1] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:226:0001:0017:EN:PDF
[2] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015D0495&from=PT

renewable energy in water industry and reducing the carbon footprint so far, but finally reduction in energy consumption is still deemed the most sustainable approach. For example, no emissions are produced by wind technology during operation; nevertheless, a wind turbine does have an environmental impact during its life cycle from production to dismantling (Guezuraga et al., 2012).

Moreover, as mentioned above, to enhance water quality of receiving water, more severe quality obligations are being determined for effluent of WWTPs, especially in terms of pharmaceuticals and other micropollutants. Accordingly, more treatment should be performed, which requires much extra energy. Consequently, it is more likely that the production of carbon footprint increases. Therefore, the implementation of innovative technologies or interventions can help to minimize energy consumption. For example, the implementation of new sensor technologies and smart monitoring programs such as sensors for dissolved oxygen and ammonia can support a further optimization of the aeration of active sludge processes, and energy can be saved by 20 % (O'Brien et al., 2011). As more than 70 % of energy consumption corresponded to the activated sludge process at WWTPs, 20 % reduction in energy consumption gains cost savings and environmental profits. However, outcomes of pilot projects at one WWTP cannot always be translated to another WWTP with different characteristics. This hampers an exact calculation of the impact of eco-innovation implementation and may introduce an additional barrier to technology adoption.

1.2 Problem statement

To deal with the sustainability challenges of WWTPs, more specifically reducing the carbon footprint and enhancing the quality of the effluent, the application of innovative technologies is deemed to be indispensable. However, as mentioned above, in order to make a decision regarding the implementation of these technologies at WWTPs, there are barriers and uncertainties for water managers in terms of costs, carbon footprint and water quality. A better insight into the costs and benefits of different types of eco-innovations tailored to a specific WWTP can help clarify their impact and support water managers in building a business case for the adoption of innovative technologies. A dedicated Decision Support Tool is likely to help them to remove the barriers and foster acceptation and application of these technologies at WWTPs in the Netherlands.

1.3 Research objective

The objective of this research was to set the scientific foundation for the development of a dedicated Decision Support Tool for eco-innovation at WWTPs in the Netherlands.

1.4 Research questions

Based on the objective of the research, the following research questions were formulated and elaborated during this study.

The main question of this study is as follows:

How can the Decision Support Tool build upon existing knowledge and incorporate new insights regarding the implementation of eco-innovations at WWTPs in the Netherlands?

In order to answer the main question, it is broken down to three sub-questions defined below:

1. What is the general configuration of WWTPs in the Netherlands, and which characteristics can be used as standardized representatives ("default settings") for a Dutch WWTP in the Decision Support Tool?
2. What are the most important innovative technologies and scenarios that should be addressed by the Decision Support Tool?
3. What are the main challenges of water managers at WWTPs in the Netherlands and how can these be effectively incorporated into the Decision Support Tool?

1.5 Reading guide

Chapter 1 contains the introduction and comprises the background of the research, the research problem, objective and questions. The methodology of research is elaborated on in Chapter 2. The first research sub-question is answered in Chapter 3. Likewise, the second and the third research sub-questions are respectively answered in Chapters 4 and 5. Based on the results and findings of the previous chapters, the initial schematic set-up of the Decision Support Tool is described as the conclusion of the research in Chapter 6, which is the answer of the main research question. Chapter 6 also contains recommendations for further research.

2 RESEARCH METHODOLOGY

This chapter elaborates on the activities which should be accomplished step by step to find the answers to the research questions as described in Section 1.4.

2.1 Research framework

In this section, the research framework is described according to suggestions by Verschuren & Doorewaard (2010) with regard to topics to elaborate while developing a research framework.

Step 1: Characterizing the objective of the research concisely

The aim of this research was to build a solid scientific basis for the development of a Decision Support Tool called Wat-IF (Water utility Impact Forecast), which can help water managers to take decisions regarding the implementation of innovative technologies at WWTPs in the Netherlands.

Step 2: Defining the research object

The research object in this research is the population of wastewater treatment plants [3]in the Netherlands.

Step 3: The nature of the research perspective

There are three main blocks are required to develop the Decision Support Tool. The first block is based on the main characteristics which are used to derive realistic default values for Dutch WWTPs. These standard values are deemed to be crucial as they provide a solid starting point and input for the Decision Support Tool to be developed. The main descriptive characteristics of WWTPs used in the Decision Support Tool can be divided into two different types:

1. Essential treatment-related characteristics, including volume of influent, commonly used wastewater treatment steps, nitrogen (N), phosphorus (P) and chemical oxygen demand (COD) in influent and effluent (Hammer, 1986).
2. Management-related characteristics, including costs per m^3, carbon footprint and water quality improvements (as treatment efficiency).

[3] The main characteristics of WWTPs are described elsewhere in this research.

To run the tool, the main characteristics of the utility's treatment plant should be first entered into the tool. If no characteristics are available, default standard values are used. The calculation of the default standard values is elaborated in Chapter 3.

In addition, the calculated outcome of the implementation of innovative technologies and scenarios in a second block within the tool can be compared with the standard status in the first block to evaluate the effect of implemented scenarios and technologies.

Innovative technologies and scenarios are embedded in the second block to be applied at WWTPs in order to make them more sustainable, specifically in terms of carbon footprint and water quality improvement. The third block within the tool is designed to calculate the costs, carbon footprint and water quality improvement in the implementation of various innovative scenarios in the second block. The combination of design-oriented research and evaluation research was applied as research method.

Step 4: The sources of the research perspective

Firstly, this research used recorded available data from the database of the Dutch Union of Waterboards ("Unie van Waterschappen") to build the first block of the tool. This database is called WAVES and contains recorded data of Dutch WWTPs such as costs per cubic meter of water treated, energy consumption, size, wastewater treatment steps, quality parameters, etc. Scientific reports and peer-reviewed literature were used to identify and embed the most important eco-innovative scenarios or technologies in the second block of the tool. In the third block of the tool, in addition to using scientific literature, preliminary research was used to determine and incorporate the best strategy to express water quality improvements in a numerical way, as well as the calculation of costs and carbon footprint of the implemented technologies. Theories used are presented in Table 1.

Table 1. Source of Research Perspective

Key concepts	Theories and documentations
-Eco-innovation -Water quality -Carbon footprint -Decision-making process	-Dutch Union of Waterboards database (WAVES) -Theory on eco-innovative scenarios and technologies -Theory on water quality quantification methods -Preliminary research -Theory on costs and carbon footprint calculation strategies at WWTPs

Step 5: Making a schematic presentation of the research framework

The research framework is described in the following flowchart:

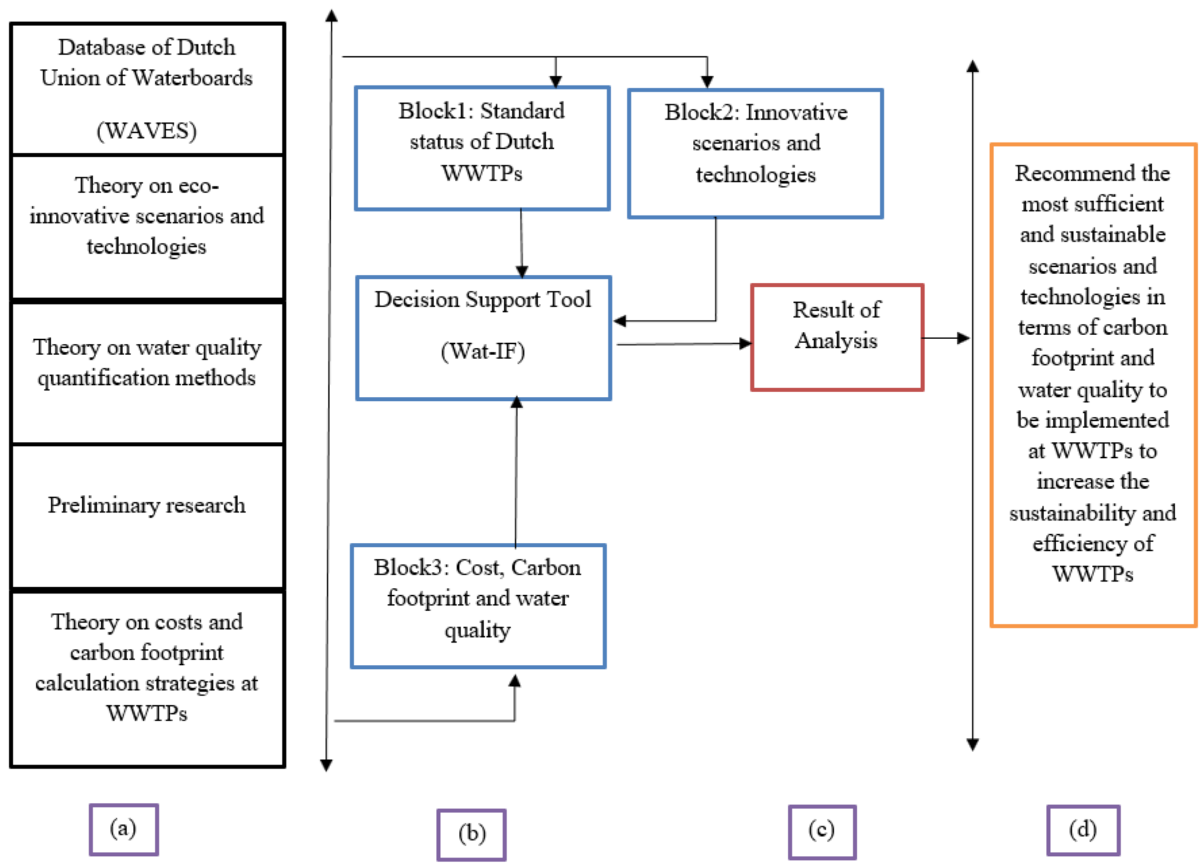

Figure 1: A Schematic Presentation of Research Framework

Step 6: Formulating the research framework in the form of explained arguments

This step comprises the following activities:

(a) Collecting and carrying out quantitative analysis of the available data in terms of the main characteristics of all WWTPs in the Netherlands from the WAVES database, as well as qualitative analysis of scientific literature and interviews in terms of eco-innovative scenarios or technologies, water quality numeric determination methods, costs and carbon footprint calculation methods at WWTPs and consulting with water quality experts (preliminary research), **(b)** by means of which the required blocks to develop the tool are constructed, **(c)** the tool becomes able to calculate the outcome of implemented scenarios in terms of costs, carbon footprint and water quality improvement, based on the results of these calculations, **(d)** the most efficient scenarios or technologies regarding the aforementioned criteria are recommended for inclusion in the Decision Support Tool.

Step 7: Assessing whether this model requires changing

As the model is developed, it may be necessary to make changes on the basis of views expressed by interviewees.

2.2 Defining key concepts

-Wastewater: water which has been polluted and contaminated by human activities (Englande et al., 2015) such as domestic effluent containing urine, faecal sludge or bathing and kitchen wastewater. Additionally, industrial, agricultural and hospital effluent with stormwater and another urban run-off are considered as wastewater (Corcoran et al., 2010).

-WWTP: a facility that treats wastewater, with the use of physical, biological and chemical processes or a combination thereof (Englande et al., 2015).

-Carbon footprint: carbon footprint consists of the sum of greenhouse gases with a global warming potential, namely carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which can be produced directly and indirectly by an individual, organization, event, or product (Krishna et al., 2009).

-Water quality: the characteristics of water, namely chemical, physical and biological are referred to water quality (Diersing & Nancy, 2009). Water quality is deemed a criterion of the condition of water in relation to the requirements of one or more biotic species to meet human purpose or need

(Johnson et al., 1997).

-Decision-making process at WWTPs: the process in which a person or group of people make decisions regarding changes, improvements and maintenance at a WWTP.

2.3 Research strategy

The multi-case study approach was used in this research as a strategy.

2.3.1 Research unit

The research units of this research are the wastewater treatment plants throughout the Netherlands. This research focused on the main characteristics of all Dutch WWTPs, firstly, the essential treatment-related characteristics to build the first block for the tool. Secondly, the most important available eco-innovative scenarios and technologies were inventoried and studied to be embedded in the second block of the tool. Thirdly, the main challenges of Dutch WWTPs including cost per m^3 of treated wastewater, carbon footprint and water quality were studied to be addressed in the third block of the Decision Support Tool.

2.3.2 Research boundary

In order to finish this research within the defined period, this research was limited to building the required blocks for the Decision Support Tool to be used only, at WWTPs in the Netherlands. A graphical version of this tool which is more map-based, is not considered in this research, although the ultimate goal is to incorporate this feature.

2.3.3 Research limitation

This research was carried out during a global pandemic (COVID-19) which imposed some obstacles to the research process. As an illustration, the interviews with Dutch water board officials were conducted online instead of face-to-face. Due to these restrictions, many people from the water boards were reluctant to participate in online interviews. Also, regarding lockdown situation, the research had some difficulties to access the people involved in this project to obtain more information.

2.4 Research materials and accessing method

The research materials for this research were scientific literature and documents based on the objectives of the research, as well as selected experts' interviews based on semi-structured questionnaires. The literature sources are categorized into three main parts:

- Published scientific papers
- Secondary literature (review journals, books, handbooks, manuals)
- Grey literature (MSc, Ph.D. theses and dissertations, technical reports)
- Official websites of the Union of Dutch waterboards and relevant EU departments

The internet was used as the main access tool or method in order to carry out the desk research, as it is the cheapest and fastest tool to access scientific papers or documents which can be studied online or downloaded to computers (Verschuren et al., 2010). To find necessary data and information on the topic of the research, key words such as WWTPs, water quality, carbon footprint and decision support process at WWTPs are used.

In-depth interviews were conducted with various stakeholders at the Dutch Waterboards, water experts specializing in WWTPs and optimization processes, and specialists in the field of model or tool development. Interviews were conducted with the aim of evaluating the results and findings from literature and defining further steps to develop the Decision Support Tool. The key potential interviewees include:

- One interviewee with a managerial position at *Waterschap Brabantse Delta* (Brabant waterboard) and one interviewee with a technical position at *Waterschap Aa en Maas* (’s Hertogenbosch waterboard) in the Netherlands.
- A wastewater treatment expert from the UK and another technical expert from the United States and Spain, specifically with regard to the various optimization scenarios to be included in the tool.
- One interview with an expert in the field of numerical expressions of water quality improvements at *Waternet* (Amsterdam Water Company) in the Netherlands.
- Interviews with specialists in the field of model or tool development specifically in terms of Decision Support Tool, one from the United States and one from *Aquafin* in Belgium.
- It is important to point out during interviewing the “snowballing technique[4]” is applied in

[4] Snowballing implies study subjects can introduce through their social networks future informants to be involved in

order to find more informants who have valuable knowledge and the perspective to share with the researcher regarding the topic of the research, and avoid any bias involved in this research. Thus, the list of interviewees might be updated.

The names of participants who are interviewed, are presented in Table 2.

Table 2: List of interviewees, their organization, position and specialization

Name	**Organization, position and specialization**	**Target information**
Dr. Arthur Meuleman	General Manager of the *Brabantse Delta* (The Netherlands)	The most important challenges that water managers at WWTPs have in the Netherlands to make decisions in terms of implementing eco-innovative scenarios or technologies
Judith Herschell Cole	Wastewater treatment expert at *Sensileau* (USA)	The most important challenges that water managers at WWTPs have in the U.S. to make decisions in terms of implementing eco-innovative scenarios or technologies; technical insight into the implementation of novel technologies at WWTPs in general
Ron van der Oost	Toxicologist at *Waternet* (The Netherlands)	Information on strategies to convert data regarding water quality to the numeral type, and determining specific units for them
Dr. Leo Carswell	Lead of the Technology Business Area at WRc plc, and responsible for testing and evaluation of water technologies (UK)	The most efficient eco-innovative scenarios or technologies which can be embedded in Decision Support Tool to be applied at WWTPs
Stefan Kroll	Research & development engineer and model developer at *Aquafin* (Belgium)	Overall feedback on the structure and foundation of Decision Support Tool, important further steps to develop the Decision Support

a study where available (Goodman,1961)

		Tool and eliminate any potential defects of the tool
Mirabella Mulder	Mirabella Mulder Wastewater management company	The most efficient eco-innovative scenarios or technologies which can be embedded in Decision Support Tool to be applied at WWTPs

The required data and information and its accessing method in this research were identified through the set of sub-research questions, as displayed in the following Table 3.

Table 3: Required data/ information and accessing method

Main research question	Sub-research questions	Required data/information to answer the questions	Source of data	Accessing data
How does the Decision Support Tool build upon existing knowledge and incorporate new insights regarding the implementation of eco-innovations at WWTPS in the Netherlands?	1. What is the general configuration of WWTPs in the Netherlands, and which characteristics can be used as standardized representatives ("default settings") for a Dutch WWTP in the Decision Support Tool?	Available recorded data about essential treatment-related characteristics of Dutch WWTPs.	Secondary data: Dutch water board database (Union of Waterboards database WAVES)	Content analysis and search method
	2.What are the most important eco-innovative scenarios that should be addressed by the model?	Find the best and most important eco-innovative scenarios and technologies to be incorporated into Decision Support Tool	Primary data: Interview with wastewater technical experts	Questioning: face to face interview
			Secondary data: Scientific literatures and documents	Content analysis and search method

	3. What are the main challenges of water managers at WWTPs in the Netherlands and how can these be effectively incorporated into the Decision Support Tool?	Information regarding the main challenges of water managers at Dutch WWTPs and place these challenges in the tool	Primary data: interviews with various stakeholders at the Dutch Waterboards	Questioning: face-to-face interview
			Secondary data: Scientific literature and documents	Content analysis and search method

2.5 Ethical statement

Since the results of the research might influence interviewees or informants, the attitude of the researcher toward participant in this research is of paramount importance (Touitou et al., 2004). First of all, the content of the research was explained for participants to make him/her able to decide on taking part in the interview. To do this, before the interview, a brief description of the project and its objective were sent to the interviewees. Since the interviews are recorded, permission and the consent of participants in the interviews were obtained first, by means of a consent form to be filled and signed by the interviewee before the interview. All interviewees have the right to withdraw from the research at any time without any problem or consequences. The researcher ensured the confidentiality and the safety of data by securing them on a laptop with password protection and protect the information from hackers or viruses by using security software. Additionally, information obtained is not shared with anyone, and when the information is no longer required, the information is deleted.

2.6 Data Analysis

One of the most important parts of any research or study is data analysis. Data analysis refers to the data evaluation process through a logical and analytical framework.

2.6.1 Method of Data Analysis

In this research, both qualitative and quantitative analysis methods were used to obtain the required information to answer the research questions.

Firstly, to answer the first sub-research question, numerical data regarding the essential treatment-related characteristics of Dutch WWTPs were collected from the WAVES database. These data were descriptively analyzed by a statistical measure, which is a measure of central tendency. A measure of central tendency includes the mean, median and mode which are further elaborated below. Next, to answer the second and third sub-research questions, the combination of semi-structured interviews and desk research was used. The Qualitative Content Analysis method was used to make valid inferences by understanding and interpreting scientific literature and documents. Narrative data analysis which is a qualitative analysis method was applied to analyze the interviewees' data. The data retrieved from interview transcripts were labelled and coded (interpreted) in terms of eco-innovative scenarios and technologies, as well as in terms of costs and carbon footprint calculation strategies to be embedded in the Decision Support Tool. Additionally, the Technology Readiness Levels (TRLs) method was also used to analyze the maturity of technologies and consider the consistent comparison of maturity between available technologies associated with WWTPs to choose the best ones to incorporate into Decision Support Tool. The TRLs method is elaborated below.

To determine the best strategy to express the water quality improvement in a numerical way, the SWOT (Strengths-Weaknesses-Opportunities-Threats) analysis was used. This is a qualitative data analysis tool which has been applied for more many years in the field of management and is deemed a very powerful technique for decision-making processes (Gürel, 2017). It enables the user to give meaning to the data. Therefore, after providing the scientific foundation for the Decision Support Tool and conducting interviews, SWOT was used to identify and analyze the internal and external factors which seemed promising to develop the tool.

2.6.2 Descriptive data analysis method

A descriptive analysis uses descriptive statistics to summarize the data with the objective of describing patterns that may emerge from the data (Thompson, 2009). In other words, descriptive analysis makes the generalization limited to a specific group of observed individuals (Kedutso, 1993). With the assistance of descriptive analysis, a considerable amount of data and related information can be ordered and organized in a manner that exposes the essence of the data; basically, the data are grouped in a manner that makes sense to elaborate a research question. To determine the normality of the distribution for a group of data, the description of data is needed. This can be demonstrated by applying numeric values or graphical techniques. To carry out descriptive data analysis, the data are grouped by descriptive analysis and various statistical methods can be utilized to analyze the data and make a proper conclusion (Kedutso, 1993). In this research, the Measures of Central Tendency have been used.

2.6.2.1 Measures of central tendency

To find an estimate of the “center” of a distribution value, the central tendency of a distribution is applied. The main types of measures of central tendency are the mean, median and mode. In the following research regarding the distribution pattern of data, the mean and median are considered to be the best methods to measure the accurate average of values. The mode of a dataset is the numeric value that occurs most frequently in the population. Given the aim and research questions the mode is less relevant.

For instance, when there is a perfectly symmetrical distribution for continuous data, the mean and median give equal value. However, in the case of a skewed distribution of data, the median method is deemed the best method to obtain a representative value. The median value provides better representation for most of the WWTPs as it assigns less weight to (extreme) outlier values than the arithmetic mean.

2.6.2.1.1 The mean

The most well-known measure of the average is the mean or, to be more exact, the arithmetic mean. By dividing the sum of a set of observations by the number of observations, the average is calculated (Fowler et al., 1998). In this case, the symbol of the mean is $\bar{x}$(x bar). The mean calculation formulae is:

$$\bar{x}=\frac{\sum x}{n}$$

X is each observation and $\sum$ is the ‘sum of’, n is the number of observations.

All values are incorporated in data by calculation of the mean, thus when values start to change, the mean changes. In the symmetric distribution of data, the mean demonstrates the center accurately.

2.6.2.1.2 The median

The middle observation in a set of observations which have been set from smallest to largest is the median value (Fowler et al., 1998). To locate the median value, the datapoint that has an equal number of values above it and below it should be found. When the number of observations is an even number, the median value is determined by the arithmetic mean of the values of the middle pair (Fowler et al., 1998). Skewed data has a very small effect on the median (unlike the mean).

That is why the median is considered the best method to show the central location for the skewed data in this case, as the data in the WAVES database are generally starkly skewed to the right. This is the result of a large number of average-sized WWTPs combined with a small number of very large WWTPs in the Netherlands.

2.6.3 Qualitative Content analysis method

Qualitative analysis is considered as a means to produce knowledge which includes the separation of elements of data based on a data-derived system, and it also involves the break up or break down of the data (Sandelowski,1995). Content analysis can provide a mechanism which contributes to a useful theoretical generalization with the least loss of information from the original data (Downe-Wamboldt, 1992). Content analysis is used for almost all forms of linguistic communication to discover the answers to questions such as who says what to whom, how, why (Babbie, 1986, p. 268). Consequently, this analysis provides the means to create true inferences out of verbal, visual, or written data with the objective of describing specific phenomena.

2.6.4 Technology Readiness Levels (TRLs)

In 1970, the National Aeronautics and Space Administration (NASA) in the United States developed a method called Technology Readiness Levels (TRLs) to evaluate to what extent special technologies are mature to be used as a specific purpose (Mankins, 1995). For many years, the TRLs method has been used in space technology planning by NASA. The TRLs approach has been adopted to be applied in every kind of technology, from communication technology and informatics to nanotechnologies (Heder, 2017).

TRLs are a measurement or metric system that supports the evaluation and the assessment of particular technologies. Also, this method is used to compare the maturity of different types of technologies to choose the best option (Mankins, 1995). Through a Technology Readiness Assessment, (TRA) the TRL of a technology is determined to investigate technology capabilities and requirements (Heder, 2017). The approach of TRLs is based on a scale from 1 to 9, TRL 1 is considered the lowest of the maturity of a technology, while TRL 9 is the most mature technology (Heder, 2017). A description of each technology readiness level to characterize each TRL is presented in the following paragraphs.

Various classifications of different technologies have been appearing in the literature for many years (Altunok & Cakmak, 2010). According to the current needs, different kinds of technologies, complicated systems with their enormous budget have been drawing the attention, thus the science of technology management needs to be contemplated by both experimental and analytical processes (Altunok & Cakmak, 2010). As mentioned earlier, TRL is a metric system to determine the maturity of technologies being used in (Air Force Research Laboratory) AFRL, National Aeronautics and Space Administration (NASA), Deputy Under Secretary of Defence, Science and Technology (DUSD S&T) in the US (Altunok & Cakmak, 2010). The maturity of technology needs to be measured to provide one measure that can be an indicator of program risk (US General Accounting Office, 1999). When the Technology Readiness Level of technology has been determined, the risks or benefits of incorporating that technology in product development can be evaluated (Nolte et al., 2003). TRLs method is comprised of nine levels to assess the maturity of a specific technology which are elaborated below.

TRL 1 (basic principles observed)

The lowest maturity of a technology is presented as TRL 1. Scientific studies need to be translated into applied studies at this level. At TRL 1 level, the basic principles of a technology or basic properties of materials such as performance, strength, tensile, etc. are considered and reported (Mankins,1995).

TRL 2 (technology concept formulated)

After the observation of the basic principles and characteristics, the practical application of observed characteristics should be identified. At TRL 2, experimental proof and analysis of the conjecture are not considered, and this is just speculative (Mankins, 1995)

TRL 3 (experimental proof of concept)

Research and development (R&D) is carried out based on analytical studies and laboratory-based studies. Technology is placed into an appropriate context by analytical studies, and the validation of the analytical predictions in a physical way is carried out by laboratory-based studies. These studies are supposed to form a "proof-of-concept" verification of the concepts/ implementations which was carried out at TRL 2. (Mankins, 1995).

TRL 4 (technology validated in a lab)

Following the accomplishment of TRL 3, all basic elements of technology must be tested to be worked together in order to obtain acceptable performance for a component. This verification should support the formulated concept in the earlier stage, and it also needs to be consistent with the requirements of potential system applications (Mankins, 1995).

TRL 5 (technology validated in a relevant environment (industrially relevant environment in the case of key enabling technologies)

At this level, the basic elements of a technology must be integrated to have the total technology checked and tested in a simulated environment or very similar to the real environment to ensure the validity of a considered technology (Mankins, 1995).

TRL 6 (the demonstration of a technology in a relevant environment (industrially relevant environment in the case of key enabling technologies)

After the completion of TRL 5, a considered technology needs to be tested in a real environment. Although, to represent a true TRL 6 the technology demonstration should be successful, not all technologies need to go through a TRL 6 demonstration (Mankins,1995).

TRL 7 (system prototype demonstration in an operational environment)

TRL 7 is deemed a momentous step, as an actual system prototype demonstration in an operational environment is required. The significance of this level is on account of ensuring system engineering and make a confident development (Mankins, 1995).

TRL 8 (system complete and qualified)

To implement all technologies in the real systems, all technologies go through TRL 8, which is relatively considered as the end of ‘system development’ for most technologies (Mankins, 1995).

TRL 9 (actual system proven in an operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

At this level, some small fixes and changes as the last step of true ‘system development’ are carried out, and problems found during the implementation of the technologies can be addressed. Importantly, the planned product improvement does not include TRL 9 (Mankins,1995).

2.6.5 SWOT

The SWOT is a qualitative analysis data tool which is applied to assess the Strengths, Weaknesses, Opportunities and Threats involved in a plan, organization, project or business activity (Gürel, 2017). Initially, the SWOT tool was developed in 1960 by the Stanford Research Institute (SRI) with the objective of enhancing organization management strategies (Panagiotou, 2003). However, some scholars attributed the invention of this tool to Harvard Business School. This tool consists of analyzing internal factors which are embedded in strategies or projects under study as strength and weakness, and also analyzing external factors as opportunities and threats which can influence the project or strategy to achieve its objectives. In this research, the SWOT analysis tool was applied to analyze water quality quantification methods. However, as this tool might generate too much information which is not useful, it is confined to analyzing the strength and weakness of different water quality quantification strategies to choose the best one to be incorporated into Decision Support Tool.

2.7 Validation of Data Analysis

The methodological triangulation method was used to ensure the quality and validity of collected data and information, as well as avoiding any potential biases. Methodological triangulation is a method involving multiple qualitative and/or quantitative methods to accomplish research (Guion, 2002). In this research, interviews and desk research were applied as data and information collection methods. The results and findings from each method were compared to see whether they are similar or the same, and the validity of obtained information and data were established. Additionally, after conducting individual interviews with each interviewee, the answers of each interviewee were compared to check different ideas, opinions, agreement or disagreement on the same specific problem. When the results of interviews in terms of specific challenges or issues of the research are similar, this match is considered a validation of information and data analysis.

3 THE DEFAULT SETTINGS OF WWTPS IN THE NETHERLANDS

Data are often considered the lifeblood of an organization or a system, and high-quality data contributes to a great comprehension of the performance of a system, and concrete decision-making for its improvement (Wynn & Sedigh, 2019). Authors argue that unrepresentative data or low-quality data as input for any kind of organization or system are likely to give rise to erroneous outcomes following the garbage-in-garbage-out principle. Research by Rose & Fischer (2011) also showed that the success of any data-use framework is significantly dependent on the usefulness of the data included in it. Thus, it would be significant to ensure high quality input data for the Decision Support Tool (Wat-IF model) for it to become a useful tool for water managers. When the user of the Wat-IF model has no utility-specific data at hand, meaningful alternatives (i.e. default values) need to be provided to enable equally meaningful outcomes to evaluate the effect of the various different scenarios included in the modelling tool. To this end, realistic values of the main characteristics of Dutch WWTPs were collected from the WAVES database to develop a set of default values for the Wat-IF model which provides meaningful outcomes, and also gain the user's confidence in using the model.

In this chapter, the default settings were determined which need to be predetermined and assigned to the Wat-IF model. This also makes a strong initial point for the development of the model. Additionally, the outcome of the implementation of innovative scenarios and technologies in the further step of the tool for WWTPs can be compared with the current, unchanged status of WWTPs.

The default settings are standard values of the main characteristics of WWTPs in the Netherlands which were built to be incorporated into the first block of the Wat-IF model. To do this, firstly, the characteristics of WWTPs in the Netherlands which define wastewater treatment and those which are most likely to change by the implementation of different innovative scenarios and technologies in the further blocks of the tool were collected. These characteristics of WWTPs include Nitrogen (N), Phosphorus(P), Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) in influent from a water quality perspective, the volume of influent to each WWTP, which is considered the size of a WWTP, and commonly used wastewater treatment (WWT) steps.

Moreover, default values for the costs and energy consumption per m^3 of treated wastewater corresponding to the current size and commonly used WWT steps at Dutch WWTPs were calculated before the implementation of new technologies and scenarios. Thus, these data can be compared with new costs and energy consumption values after the implementation of innovative technologies and scenarios and new size of WWTP. Therefore, the efficiency of newly implemented scenarios and technologies and thus the efficiency of WWTPs can be evaluated by comparing new results with default values.

From the water quality perspective, BOD and COD are the most consistently used parameters in the wastewater treatment industry to characterize the influent and effluent quality and assess the efficiency of wastewater treatment processes (Aziz, 1980). COD and BOD have been measured as the most significant organic pollutants in wastewater (Henze & Comeau, 2008). Both parameters indicate the strength of the oxygen demand of wastewater which directly affects the amount of dissolved oxygen in receiving water. This implies that the greater the amount of COD and BOD in wastewater, the more oxygen is depleted in receiving water, which destroys the eco-system (APHA, 1992). On the other hand, Behave et al. (2019) evaluated the performance efficiency of a sewage treatment plant applying a biological treatment method (Rotating Media Bio-Reactor) by analysing the variation of COD and BOD parameters before and after the treatment processes. These parameters are additionally employed to design the kinetics of biological processes to simulate and model wastewater treatment processes. BOD is used as the main criteria to determine the size of the trickling filter and activated sludge units (EPA, 2000). While the measurements of COD are required to do mass balances in wastewater treatment, and the fractions of the COD content are considered to be helpful to make wastewater treatment processes (Henze & Comeau, 2008).

N and P are other important parameters in terms of water quality that cause eutrophication, oxygen depletion, and they might be toxic for ecosystem services (Diaz & Rosenberg, 2008; Zhang et al., 2010). Also, eutrophication not only affects freshwater, but due to decay of algal biomass, it affects adversely on coastal seas (Diaz and Rosenberg, 2008; Kemp et al., 2009; Gilbert et al., 2010). Consequently, European Council Directive 91/271/EEC strictly obliges WWTPs in the EU to monitor N, P, COD, and BOD as the major parameters in their effluent from the water quality standpoint.

The size of WWTPs is another key characteristic that should be considered to run the Wat-IF model, as wastewater treatment operation and maintenance costs are highly dependent on the size of WWTPs (Balmér & Mattsson, 1994). Size is mostly expressed as population equivalents and volume of flow; however, it is sometimes expressed as the actual load or design figures (Balmér& Mattsson, 1994). In this report, the volume of wastewater supplied in m^3 is used to indicate the size of a WWTP.

The assessment of the WWTP's costs is a prominent aspect that must be contemplated. There are investment, maintenance, and operating costs at WWTPs. The major maintenance costs include repairs on electrical, mechanical, civil parts, and small or large replacements for pumps, blowers, or motors (Turkmenler & Aslan, 2017). Also, material expenses, external services, and purchasing deals or quantities of spare parts kept in stock are included as maintenance costs (Turkmenler & Aslan, 2017). Maintenance costs are dependent on the physical size of the plant, proper design (including the selection of appropriate devices and equipment), machinery, inspection, and the number of basins (Balmér& Mattsson,1994; Wendland, 2005). On the other hand, there are operating costs, the most important of which are personnel costs, sludge disposal costs, chemicals, and energy consumption (Haslinger et al., 2016). Operating costs are dependent on the volume of wastewater supplied in m^3 (influent) and it`s pollution, geographical situation of the site (e.g. effecting pumping energy costs), technologies and the selected treatment process, energy supply and energy recycling (Bohn, 1993). Investment costs are comprised of industrial buildings constructing, the application of treatment technologies, computer equipment, and the depreciation of capital assets (Moral Pajares et al., 2019).

In this study, the aforementioned maintenance costs are not considered, whereas operating and investment costs associated with the installation of new treatment technologies and scenarios are considered. Energy consumption costs are deemed to be more significant than the operation and maintenance costs of WWTPs (Trapote et al., 2014). More than 50% of total operating costs are represented as energy costs in a WWTP. That is why energy consumption is believed to be of paramount importance at WWTPs. Based on De Martinio (1969), at WWTPs the costs per unit decrease as the size of the treatment plant increases. Additionally, Trapote et al. (2014) investigated WWTPs in Spain and demonstrated when the size of WWTPs increases, the energy consumption per volume of treated wastewater decreases, and thus costs decrease as well. This is due to the fact that when the volume of influent increases, equipment and devices used during the process can operate with higher efficiency, and the treatment environment relatively stabilizes (Tao & Chengwen, 2012). Additionally, when the more treatment environment is stable, the fewer changes happen in the amount of water entering and pollution concentration, thus a better condition will be provided for microorganisms to grow in the sludge, which improves the treatment efficiency (Tao & Chengwen, 2012).

Tao & Chengwen, (2012) observed the data of energy consumption and the influent volume of 1856 WWTPs in China. The results demonstrated when the volume of influent is 0.36×10^4 m^3/day, energy consumption is 0.5 kWh/m^3, while when the volume of influent increases to 32.3×10^4 m^3/day, energy consumption decreases to approximately 0.25 kWh/m3.

Over and above size, energy consumption at WWTPs is considerably dependent on the type of treatment steps and technologies applied at WWTPs (Trapote et al., 2014). As every step of wastewater treatment requires energy, WWTPs are deemed one of the most energy-intensive industries (Li, 2019). As an illustration, approximately 70% of energy consumption is related to biological treatment steps (Xie & Wang, 2012), while almost 14% of the total energy consumption is in sludge thickening and the dewatering process (Chen & Chen, 2013). Therefore, commonly applied wastewater treatment steps are another key characteristic of WWTPs which need to be taken into consideration to develop the Wat-IF model.

A descriptive analysis method for the individual quantitative variable was used with respect to the numerical type of collected data from the WAVES database. To conduct this analysis, based on the collected data, histograms were created to determine the distribution pattern of data. Ultimately, as regards the distribution pattern of data, Measures of Central Tendency (the mean and median) were used to derive the default values to be used as the default settings for the Wat-IF model.

3.1 Commonly used wastewater treatment steps by Dutch WWTPs

All wastewater treatment (WWT) steps applied by almost 331 of WWTPs in the Netherlands were examined in the WAVES database, which is open-source with free access via the internet. This was done to determine the most frequently used wastewater treatment steps by all Dutch WWTPs. According to table in the Appendix A, physical purification, biological P, N removal, and chemical P removal were applied by the majority of Dutch WWTPs as major treatment steps. As table in the Appendix A denotes, 324 WWTPs out of 331 used physical purification: lattice removal as a preliminary treatment step. The most commonly applied secondary treatment step is biological P and N removal in the main current: bypass circuit. This method was used by 250 Dutch WWTPs out of 331. From the chemical removal treatment step point of view, 147 WWTPs used chemical P removal: dosage in activated sludge tank for phosphate removal. 139 WWTPs out of 331 did not apply any type of chemical P removal treatment step.

3.2 Default values of water quality parameters namely, Nitrogen, Phosphorus, COD and BOD in influent and effluent at Dutch WWTPs

To derive the default water quality values, initially, the available data regarding the annual amount of N, P, COD and BOD in kg in influent and effluent of WWTPs in the Netherlands were collected from the WAVES database in Table B1 in the Appendix B. By dividing the annual amount of N, P, COD and BOD in influent and effluent to the volume of treated wastewater of each WWTP, the concentration value of aforementioned parameters in influent and effluent for each WWTP was calculated in Table B2 in the Appendix B. According to the annual amount of N, P, COD and BOD in influent and effluent of WWTPs, the annual average removal rate of the aforementioned parameters for each Dutch WWTP was calculated in Table B3 in the Appendix B.

To derive the default concentration values of N, P, BOD, and COD in influent and COD in effluent, as well as removal efficiency rates for all four parameters at Dutch WWTPs, the mean method was used due to the symmetrical distribution of data. However, according to the distribution of data regarding the concentration values of N, P, and BOD in effluent, which are relatively spread with high or low values, the median method was applied to achieve the standard values. All standard (default) values are presented in Table 4 in Sub-Section 3.5. The default effluent and removal efficiency rate values were calculated to enable the future users of the Wat-IF model to evaluate the performance efficiency of the steps used and the technologies implemented at WWTPs.

3.3 The volume of influent to each Dutch WWTP

In this sub-section, the data regarding the volume of influent to each WWTP in the table in the Appendix C were collected from the WAVES database to determine the default value of volume for WWTPs. As mentioned, the size of the WWTP influences energy consumption and the costs of treatment, but this could also be affected by the implementation of the innovative scenarios and technologies. When there is no size value of a WWTP to be entered into the tool, the default value of size is used.

As the size value of Dutch WWTPs varies hugely, firstly, all Dutch WWTPs were categorized into three types of small, medium, and large (see Appendix C). Based on (Haimi et al. 2009), small-size WWTPs were considered all plants less than 30,000 P.E, while WWTPs in the range of 30,000-100,000 P.E were referred as medium-size WWTPs, and all WWTPs with more than 100,000 P.E were considered as large-size WWTPs. According to formula (3.3.1) (Association of Boards of Certification, 2017), 30,000 P.E approximately equals to the volume of influent less than 3,700,000 m^3/year, 30,000-100,000 P.E equals to the volume of influent in the range of (3,700,000-10,000,000 m^3/year), and 100,000 P.E equals to the volume of influent more than 10,000,000 m^3/year.

$$\text{Population Equivalent}=\frac{(Flow,m3/day)(BOD,mg/L)}{(1000)(0.077kgBOD/day/person)} \qquad (3.3.1)$$

WWTP Harnaschpolder located in the populated area of The Hague with the volume of 69,834,466 m^3 is the largest WWTP in the Netherlands, and Amsterdam west, Eindhoven, and Dokhaven WWTPs with the volume of 60,357,405 and 53,195,102 and 40,598,670 m^3 respectively are ranked as the largest WWTPs in the Netherlands after Harnaschpolder.

The default value of size for small-sized Dutch WWTPs was calculated as 1,208,060 m^3. For medium-sized and large-sized Dutch WWTPs default value of size was calculated respectively 5,687,850 and 17,615,999 m^3. Accordingly, corresponding energy consumption and costs of the default value of size for small Dutch WWTPs were calculated respectively 4.25 GJ/m^3 and 0.38 €/m^3, while energy consumption and costs associated with the default value of medium-sized WWTPs were calculated 4.10 GJ/m^3 and 0.34 €/m^3. Additionally, corresponding energy consumption and costs of the default value of size for large Dutch WWTPs were calculated respectively 4.00 GJ/m^3 and 0.29 €/m^3.

3.4 Total costs and energy consumption of wastewater treatment processing

Total costs and energy consumption of the wastewater treatment process of each Dutch WWTP are presented in the table in the Appendix D. Mentioned earlier, costs and energy consumption are deemed as functions of size, wastewater treatment steps, and applied technologies at Dutch WWTPs. This implies by changing these key characteristics, the costs and energy consumption are subsequently changed as well. The cost and energy consumption related to the current size, applied technologies, and commonly used wastewater treatment steps at Dutch WWTPs, per m^3 of treated wastewater for each WWTP were calculated in this respect, shown in the table Appendix E. These data are considered the default values before the implementation of any new technologies, new treatment steps or changing the size of the WWTP. This makes the Wat-IF model flexible enough at comparing the outcomes of the tool in terms of costs and energy consumption before and after any changes in key characteristics of WWTPs, hence it helps the users to make the right decision to maximize the efficiency performance of WWTP. Additionally, by calculating the cost and energy consumption per m^3 of treated wastewater for each WWTP, smaller and larger WWTPs in terms of costs and energy can be compared to determine to what extent each WWTP is efficient.

3.5 The default settings for the Wat-IF model

The standard value for each main characteristic of WWTPs in the Netherlands was calculated based on data analysis results by the method of average measuring. Following the calculated standard values are presented to be incorporated in the first block of the Wat-IF model as the default settings.

The default WWT steps are comprised of physical purification: lattice removal as a preliminary treatment step. The secondary treatment step is biological P and N removal in the main current: bypass circuit. The tertiary step is chemical P removal: dosage in activated sludge tank for phosphate removal. In terms of water quality, the calculated default concentration value in the influent and effluent for N, P, COD, and BOD, as well as standard removal rate at Dutch WWTPs are presented in Table 4. The calculated default value of size and its corresponding costs and energy consumption at Dutch WWTPs are presented in Table 5.

Table 4: Default concentration value and standard removal rate of water quality parameters at Dutch WWTPs

	Influent concentration(mg/L)	**Effluent concentration (mg/L)**	**Removal rate (%)**
N	54.88	6.24	88
P	7.30	0.75	89
COD	580.23	39.02	93
BOD	243.176	3.72	98

Table 5: Default values of size and its corresponding costs and energy consumption at small-sized Dutch WWTPs

Small-sized Dutch WWTPS	**Default value**
Size – volume of influent (Mm^3/year)	1,208,060
Costs (€/m^3)	0.38
Energy consumption (GJ/m^3)	4.25

Table 6: Default values of size and its corresponding costs and energy consumption at medium-sized Dutch WWTPs

Medium-sized Dutch WWTPS	**Default value**
Size – volume of influent (Mm^3/year)	5,687,850
Costs (€/m^3)	0.34
Energy consumption (GJ/m^3)	4.10

Table 7: Default values of size and its corresponding costs and energy consumption at large-sized Dutch WWTPs

Large-sized Dutch WWTPS	**Default value**
Size – volume of influent (Mm^3/year)	17,615,999
Costs (€/m^3)	0.29
Energy consumption (GJ/m^3)	4.00

4 INNOVATIVE TECHNOLOGIES AND SCENARIOS IN WASTEWATER TREATMENT PLANTS

Thus far, the default settings of Dutch WWTPs have been determined in Chapter 3 to be incorporated into the Decision Support Tool (Wat-IF model). So, when there is no information of WWTPs to run the model, these default settings can be used. This chapter investigate the promising technologies and scenarios to be embedded into the Wat-IF model.

The Wat-IF model is designed to accommodate a wide variety of technological innovations related to water treatment as well as water quality monitoring. The application of a single technology or a combination of various technologies at the same time is translated into a specific scenario, and multiple scenarios can easily be compared using the Wat-IF model. The focus of the initial set-up of the Wat-IF model has been on the monitoring and reduction of micropollutants such as pesticides and pharmaceuticals besides addressing macro-pollutants (nutrients, BOD and COD), but future extensions are expected to include a wider spectrum of relevant wastewater pollutants.

Daily usage of many chemical substances for different kinds of purposes (Schwarzenbach et al., 2006) has made the environment completely polluted. This is why a broad spectrum of organic micropollutants are detected in surface waters (Loos et al., 2013; Schäfer et al., 2011). There is a global concern because of the existence of these micropollutants in the environment and their possible risk (Ben et al., 2018). To prevent these micropollutants from entering the environment, WWTPs have been considered to work as a barrier over the past decades. However, WWTPs have been built to eliminate the nutrients, many studies on WWTPs demonstrated that the majority of micropollutants can be partly eliminated in wastewater treatment processes (Bueno et al., 2012; García-Galan et al., 2011). Consequently, micropollutants are released into the environment through effluent discharge of WWTPs, thus WWTPs are deemed the main input source of micropollutants in the environment (Eggen et al., 2014).

Moreover, The Dutch waterboards aim to reduce micropollutants including medicine residues from wastewater treatment plants by approximately 10 % by 2027 (Personal comment by A. Oomens of *Waterschap De Dommel*, board member of the *Schone Maaswaterketen* Initiative, November 2020). To this end, this chapter investigates:

1. innovative technologies to eliminate micropollutants in domestic wastewater treatment plants and the most promising treatment scenarios to be used in the Wat-IF model

2. the implementation of innovative monitoring concepts using sensor technologies to optimise treatment efficiency and reduce energy-consumption

First of all, some of the most innovative wastewater treatment technologies which have been recently tested in the pilot or full scale at Dutch WWTPs are identified (Section 4.1). Subsequently, based on the main characteristics and the outcome of the performance of each technology (Section 4.2), the maturity of that technology is analysed using the TRL method (Section 4.3). The TRL analysis method helps the researcher to select the best innovative technologies for WWTPs to be embedded into the Wat-IF model.

4.1 The application of innovations at WWTPs in the Netherlands

This section investigates the most promising treatment technologies and monitoring concepts at Dutch WWTPs.

4.1.1 Innovative treatment technologies for the removal of micropollutants

Since 2016, the Ministry of Infrastructure and Water Management in the Netherlands has been cooperating with a number of parties to develop technologies and special techniques to improve the effluent quality of WWTPs, more specifically micropollutant removal. This initiative coincided with increasing attempts to reduce the carbon footprint of WWTPs at socially acceptable costs (STOWA, 2019). Some innovative technologies and monitoring concepts seem to be promising, however, they have been inadequately attested to be applicable on a large scale at Dutch WWTPs. Thus, there are many uncertainties regarding their performance especially in terms of cost, carbon footprint and removal efficiency (STOWA, 2019). Moreover, the capability of new technologies and monitoring concepts to be integrated into Dutch WWTPs and their effects on operational management and the treatment process also need to be considered. In this vein, the Ministry of Infrastructure and Water Management in the Netherlands has been striving to expedite the application of innovative technologies at Dutch WWTPs by innovative programs (STOWA, 2019). This brings about a better comprehension of operating mechanisms and principles and minimizes the risks when new technologies are implemented. There are numerous technologies being developed for the treatment processes at WWTPs; nevertheless, very limited experience has been obtained regarding their implementation. In this respect, mainly new technologies which have provided results from full-scale implementation abroad could be implemented at Dutch WWTPs. According to full-scale results of the implementation of new technologies abroad, especially the results of demonstration installations, water authorities are able to choose a strategy in terms of implementation of more effective and efficient technologies. Also, these technologies that are anticipated to demonstrate a limited risk to the operation of WWTPs in the Netherlands have a proven removal efficiency of different types of pollutants with the least energy consumption and costs. This strategy can minimize the pollutants of effluent from WWTPs at reasonable costs and energy consumption. STOWA has provided a list of different treatment scenarios and techniques in an exploratory report (STOWA, 2017). However, a distinction has been made between treatment techniques that can be implemented with already available treatment practices at Dutch WWTPs, and techniques which require additional (infrastructural) modifications before implementation (STOWA, 2017). Development of innovative concepts and optimization treatment techniques with the short-term possibility to be applied have been prioritized in the innovative programs of the Ministry of Infrastructure and Water Management and STOWA in the Netherlands for the period 2019-2023 (STOWA, 2017). Importantly, all innovative technologies and concepts should have added value concerning treatment efficiency, costs, sustainability, and the reduction of the ecotoxicological risks of the WWTP's effluent discharge into the aquatic environment compared to existing treatment technologies and techniques (STOWA, 2017).

Therefore, this research investigates new technologies and treatment scenarios that can provide a substantial improvement in terms of carbon footprint, cost, and water quality, more specifically the elimination of micropollutants and mitigation of ecotoxicological risks in the discharge of WWTP effluent.

Along with the above argumentation, STOWA (2018) prepared a report on the most promising innovative technologies and techniques with the possibility of improving the CO_2 footprint, costs, removal efficiency of micropollutants of the WWTP effluent which can be prioritized for investigation. So far, some innovative technologies which have been tested in a pilot in the Netherlands are i) powdered activated carbon dosing to activated sludge systems (PACAS), ii) UV H_2O_2 oxidation, iii) ozone oxidation with sand filtration, and iv) Granular Activated Carbon filtration, (STOWA, 2019).

4.1.2 Innovative monitoring concepts for the optimization of treatment efficiency

In addition to wastewater treatment technologies, the implementation of online monitoring concepts at WWTPs has increasingly been drawing attention. Online monitoring concepts have been mainly applied at WWTPs with the objective of continuous monitoring of the effluent quality standards to comply with regulations (Thomann et al., 2002). For example, in one of the most recent studies on the application of online monitoring systems at WWTPs, Wortberg & Kurz (2019) utilized this online system to avoid undesirable discharges of organic compounds from a WWTP located in Ludwigshafen, Germany and thus protect the River Rhine and comply with specific regulations. To run the online system 24/7 at the WWTP, Wortberg & Kurz (2019) used visualization tools, special software and sensors, however, some of the software features were not commercially available and thus had to be developed.

Another monitoring concept at WWTPs is the application of advanced control of wastewater treatment processes using sensors. Advanced control of wastewater treatment processes can help to optimize the treatment processes, while other monitoring concepts mainly focus on effluent quality standards compliance. Optimization and advanced control of wastewater treatment processes with the deployment of sensors have contributed to saving energy and costs (Sensileau, 2019). Accordingly, Advanced Process Control (APC) technologies utilizing sensors have been implemented by many water companies throughout the world, the application of which is predicted to be increased considerably in the near future (Sensileau, 2019). Therefore, this research considers APC as the most promising monitoring concept at WWTPs.

4.2 Promising innovative technologies and scenarios at WWTPs

Here the innovative treatment technologies, namely PACAS, Ozone oxidation with sand filtration, GAC, UV H2O2 oxidation, and monitoring concept (APC) are investigated.

4.2.1 Powdered Activated Carbon dosing to Activated Sludge systems (PACAS)

4.2.1.1 Background

The Meuse River is a rain-fed river and source of drinking water, and in times of drought, the contribution of sewage treatment plant effluents to the total river flow is considerable (up to 30%). Drinking water utilities and water boards along the Meuse River, *Waternet*, STOWA and the Ministry of Infrastructure and Water Management in the Netherlands have decided to jointly investigate the use of powdered activated carbon (PAC) as a relatively simple technique to improve the removal of micropollutants at existing WWTPs (STOWA, 2018b). The major purpose of the application of PACAS was to determine the effectiveness and efficiency of dosing PAC to activated sludge, for the removal of micropollutants from wastewater (STOWA, 2018b).

4.2.1.2 Introduction

In the early 1970s, a chemical company called DuPont developed a Powdered Activated Carbon treatment system (Sublette et al., 1982). A pilot of the PAC treatment system was initially installed in Deepwater New Jersey (Sublette et al., 1982). The results of the implementation of the PAC treatment system demonstrated lower costs and treatment improvements compared to sequential treatment processes (Heath, 1986; Foy & Close, 2007). PAC and Granular Activated Carbon (GAC) have a large surface area for adsorption, and they have been used for a number of years to remove a variety of substances from water (Tri, 2002; Jafarinejad, 2015). Activated sludge treatment with the PAC process is similar to the conventional activated sludge process, however, PAC is added directly into the aeration tank or it is mixed with the influent of this tank. Consequently, a combination of biodegradation and adsorption improves the contaminant removal from WWTP effluent (Tri, 2002; IPIECA, 2010; Jafarinejad, 2017). A full scale of PAC has been implemented in Germany and Switzerland at more than 20 WWTPs to eliminate extensively micropollutants from the effluent of WWTPs (STOWA, 2019). The PACAS project has been focused on verifying acquired experiences in the further monitoring of the effects of PAC on the activated sludge process (STOWA, 2018b). When PAC is dosed into an aeration tank, the micropollutants which cannot be biodegraded adsorb easily to the PAC through the biological treatment system, thus toxins and the COD of effluent are significantly reduced (Meidl, 1999).

4.2.1.3 The implementation of PACAS at Papendrecht WWTP in the Netherlands

A full scale of this treatment system called PACAS was implemented and tested at the Papendrecht WWTP in the Netherlands between 2016 and 2017 (STOWA, 2019). PAC was dosed over a period of twelve months (July 2016 - June 2017) into an activated sludge system (STOWA, 2018a). The Papendrecht WWTP has two identical parallel treatment lines and it is representative of other WWTPs in the Netherlands regarding size. One of the streets is equipped with PAC dosing (the PAC street) and the other serves as a reference street. For the evaluation of the pilot, the usual macro-parameters were monitored, as well as the general functioning of the WWTP and the impact of operating a PAC dosing installation (STOWA, 2018b). In total, four dosing regimens were tested with PAC at Papendrecht WWTP: 10, 15, 20, and 25 mg PAC per litre of influent. A list of 50 substances was analyzed to determine removal efficiencies in the influent and both effluents (PAC street and reference street) (STOWA, 2018b). This list included drug residues but also compounds originating from industrial and household products such as flame retardants, dishwasher tablets, personal care products, and plant protection products (pesticides). In addition, the ecotoxicity of treated and untreated sewage treatment plant effluent from the PAC and reference streets were compared and quantitated by means of bioassays, at 15, 20, and 25 mg PAC/L (STOWA, 2018b).

4.2.1.4 Results

The results were remarkably promising: the ecotoxicity of the effluent was halved, while the micropollutant removal rate doubled (STOWA, 2019). The results also demonstrated that by adding PAC, the removal efficiency is increased. For example, the dosage of 10 mg of PAC per liter of influent resulted in a significant improvement in removal efficiency: the average removal efficiency increased from almost 40% to more than 60% (STOWA, 2019). At increasing PAC dosage, the average removal efficiency increased to 75% at 25 mg PAC/ l (STOWA, 2018b), while the quality of the effluent for macro parameters such as phosphate, nitrogen, and organic matter did not deteriorate (STOWA, 2019).

PAC is deemed a fossil product that leads to CO_2 emission (STOWA, 2019). In this project, pristine coal was used, however, developments are currently underway to enable the use of renewable raw materials for the production of PAC. These developments will take some time and, if they continue, the sustainability score of this technology will improve considerably (STOWA, 2018b). The CO_2 footprint of the implementation of the PACAS treatment system in its current form at Papendrecht WWTP was calculated at 116 g CO_2/m^3 (STOWA, 2019).

The use of PAC requires a relatively small investment, and the costs of PAC dosages are relatively low compared to other micropollutants removal technologies (STOWA, 2018b). The calculated costs of the PACAS treatment system were 0.05 €/m^3 at 25 mg/L carbon dosage (STOWA, 2019).

Another important criterion is the energy consumption of the treatment technology. According to STOWA (2018b), the Gross Energy Requirement (GRE) value of the implementation of the PACAS treatment system was calculated at 0.54 GJp/i.e or approximately 150 GJp/year.

4.2.2 Ozone oxidation with sand filtration

4.2.2.1 Background

A wide range of oxidative techniques can be applied at WWTPs to convert micropollutants into other less harmful substances. Although ozone oxidation is a good technique to eliminate micropollutants, the implementation of oxidative techniques brings about the formation of so-called transformation products, which are considered harmful compared to the parent substance present in sewage (STOWA, 2019). For instance, bromate is made of the reaction of bromide and ozone, bromate is deemed a carcinogenic substance for humans. A pilot study on the implementation of ozone oxidation with sand filtration was carried out at the De Groote Lucht WWTP in the Netherlands in 2018.

4.2.2.2 Introduction

Ozone is an oxidizing agent and it can be utilized to treat industrial wastewaters. It is impossible to generate ozone gas at water utilities, as it is very unstable under normal situation (Rice, 1996). Ozone is therefore produced and applied at its point of use (Rice, 1996). When oxygen or dry air passes over a high-voltage electric field, this gas is generated, and by the assistance of porous diffusers of baffled contactor tanks, air containing ozone is entered into the water (World Health Organization, 2011). The contactor tanks are around 5 m deep and can typically provide 10–20 minutes of contact time. Ozonation performance is dependent on acquiring the desired concentration after a given contact period (World Health Organization, 2011). Due to the ozone demand of natural background organics in untreated water, higher doses may be required. The reaction between ozone and natural organics occurs and biodegradability is increased (World Health Organization, 2011).

Ozone gas can be remained as O_3 or it is possible to be decomposed when molecular ozone O_3 dissolves in water, accordingly, a hydroxyl free radical (OH^-) is produced. (OH^-) is deemed a stronger oxidizing agent compared to molecular ozone, however, ozone decomposition is dependent on water parameters such as pH, temperature, ionic strength, etc. (Rice, 1996).

Ozone is a very powerful disinfectant and one of the best ways of inactivating pathogens. This is why ozone is increasingly used to disinfect wastewater, especially when a great degree of treatment is needed (Martinez et al., 2011).

4.2.2.3 The implementation of ozone oxidation with sand filtration at De Groote Lucht WWTP in the Netherlands

The pilot study called ‘Zoetwaterfabriek’ (‘Fresh Water Factory’) at the De Groote Lucht WWTP in the Netherlands was carried out with the objective of the degradation of various micropollutants by employing ozone oxidation with sand filtration (STOWA (RAPPORT 46), 2018). This research can make a proper prelude towards a large-scale application of ozone with sand filtration at WWTPs. It is worth noting that the implementation of additional techniques to eliminate micropollutants depends on factors such as the location of WWTP and type of influent (STOWA (RAPPORT 46), 2018). Ozonation is deemed a powerful technique with a substantially high removal efficiency, which can be implemented at WWTPs in the Netherlands (STOWA, 2018c).

This study comprised two phases:

- Phase 1: preliminary investigation,
- Phase 2: endurance test.

The preliminary investigation was carried out to determine optimal ozone dosage, optimal process configuration, and the start-up of biological activity in the downstream filters (STOWA, 2018c). In the second phase, two endurance tests with the pilot installation were carried out to determine the performance of the pilot with determined optimal process configurations and ozone dosing on Phase 1 (STOWA, 2018c).

4.2.2.4 Results

The results revealed that nitrogen and phosphorus removal by continuous sand filtration after ozonation is feasible and proven from a technological point of view, despite the higher oxygen concentration and the additional methanol dosage. The removal of nitrogen and phosphorus by continuous activated carbon filtration is not technically feasible at the necessary filtration speed (STOWA, 2018c).

To conduct the second phase, the configurations below were chosen for the endurance tests, based on the preliminary investigation:

Configuration 1: Ozone sand filtration

Configuration 2: Sand filtration - ozone - sand filtration

In Configuration 1, the removal of nitrogen and phosphorus takes place after ozonation, while in Configuration 2 nitrogen and phosphorus removal is before ozonation.

The results of tests demonstrated in both configurations that nitrogen and phosphorus removal efficiency is extensive. The total concentration of nitrogen at the end of the pilot test in Endurance Test 1 (ozone-sand filtration configuration) decreased from 9 mg N/L to 1.5 mg N/L, while this amount in Endurance Test 2 (sand filtration-ozone-sand filtration configuration) decreased from 9.5 mg N/L to 1.8 mg N/L on average (STOWA, 2018c). The total concentration of phosphorus reduced 2.5 on average to 0.35 mg P/L in Endurance Test 1, likewise in Endurance Test 2 the total concentration of phosphorus decreased from 1.7 to 0.21 mg P/L (STOWA, 2018 c).

All in all, the removal efficiency of ozone oxidation with sand filtration for nutrients was between 80 to 85 %, based on the above results.

The removal efficiency for at least 7 of the 11 guide substances including benzotriazole, diclofenac, clarithromycin, carbamazepine, metoprolol, hydrochlorothiazide, a mixture of 4- and 5-methylbenzotriazole, propranolol, sotalol, sulfamethoxazole, trimethoprim in every 24-hour or 48-hour flow rate were almost 85 %.

The costs of the ozone installation with sand filtration were calculated at approximately 0.17 €/ m^3 treated water (based on operations of the ozone plant on the full hydraulic design capacity and all year round) (STOWA, 2018c).

The Gross Energy Requirement (GRE) for the ozone installation with sand filtration was calculated at 28.59 GJp/year, and the carbon footprint of this treatment system was estimated at 119 g CO_2/m^3(STOWA, 2018c).

4.2.3 Granular Activated Carbon filtration (GAC)

4.2.3.1 Background

Unlike Powdered Activated Carbon (PAC), Granular Activated Carbon (GAC) consists of granules (STOWA, 2019). The adsorption of micro-contaminants can be ensured by the granules of GAC in a post-treatment filter in the same way as PAC. Also, GAC adsorbs bacteria which enhance the removal of macro-contaminants such as nitrogen and phosphate (STOWA (STOWA, 2019). At Horstermeer WWTP in the Netherlands, full-scale Granular Activated Carbon was used to eliminate nitrogen, phosphate, and micropollutants (1-STEP filter) (STOWA, 2019). Although the pilot study of the implementation of Granular Activated Carbon in the absence of ozone was carried out at Horstermeer WWTP, an O_3/GAC treatment system (Ozone with Granular Activated Carbon) is also briefly considered in this research, due to its promising results in terms of removal efficiency.

4.2.3.2 Introduction

It has been reported that among all technologies during ozonation, the existence of activated carbon (AC, i.e., granular activated carbon (GAC), powdered activated carbon) can enhance the function of oxidation during the transformation process of O_3 to OH^- (Faria et al., 2008; Li and Qu, 2009; Wang et al., 2009). Concerning the high surface area of this technique ranging from 500 to 1500 m^2, sorption capacity of activated carbon is high to eliminate micropollutants (Rivera-Utrilla et al., 2011).

It must be noted that the efficiency of O_3 and activated carbon treatment system relies highly on the characteristic of activated carbon and water (Sanchez-Polo et al., 2005).

The most recent study on O_3/GAC treatment systems was carried out on a pilot-scale in a water utility located in Nevada, U.S. The results revealed that the implementation of an O_3/GAC treatment system can considerably enhance the removal of micropollutants from the effluent of wastewater in comparison with the implementation of ozone-only (O_3) or GAC adsorption-only (Vatankhah et al., 2019). Vatankhah et al., (2019) analyzed the removal efficiency of micropollutants with O_3/GAC treatment systems and compared it to the removal efficiency of micropollutants with GAC in absence of O_3. The results of the research by Vatankhah et al., (2019) indicated that the highest removal efficiency of micropollutants with (GAC) adsorption-only is approximately 56%, while the removal efficiency of micropollutants with a combination of GAC and ozone can reach 87%.

Moreover, the outcomes of the research by Vatankhah et al., (2019) showed after 6 h implementation of the O_3/GAC treatment system, the Brunauer-Emmett-Teller (BET)[5] surface area of the GAC increased and micropollutant removal significantly improved. Nevertheless, the long-term implementation of the O_3/GAC treatment system proved after 20 h of O_3 exposure that the promotive effect of GAC significantly decreased due to some changes in the surface properties of GAC made by O_3 (Vatankhah et al., 2019). O_3 exposure caused fewer micropores and likely a decrease in the porosity of the GAC surface. It is also important to highlight that due to the energy

5 This theory is related to the possibility of estimating the specific surface area of activated carbon from experimental data when gas molecules are adsorbed physically on the solid surface of activated carbon (Nakayama et al., 1999).

consumption of ozone, the implementation of GAC with ozone is undoubtedly more expensive than the implementation of GAC in the absence of ozone.

4.2.3.3 The implementation of Granular Activated Carbon filtration (GAC) at Horstermeer WWTP in the Netherlands

The wastewaters of the communities of Hilversum West, Gemeente Wijdemeren, Graveland, Loosdrecht en Nederhorst den Berg and Naarden/Bussum are treated by Horstermeer WWTP (STOWA, 2013). The treated water is discharged into the De Vecht River, which is located in an area sensitive to eutrophication. The strict water quality standards of the Water Framework Directive (WFD) have been applied to this WWTP, especially regarding nitrogen and phosphate (N = 5 and P = 0.5 mg/L) (STOWA, 2013). These standards have been set according to the recovery plans for De Vecht River and targets for a better ecological condition. In addition to the nutrients within the WFD quality, standards for a selection of micropollutants, i.e. priority substances, have been determined (STOWA, 2013). In order to remove micropollutants and nutrients as well as WFD priority substances in one process, the 1-STEP® pilot research was implemented at Horstermeer WWTP (STOWA (RAPPORT 35), 2013).

4.2.3.4 The 1-STEP® filter

The 1-STEP® filter comprises high-adsorption kinetics (small coal granules with high specificity surface) and relatively large coal pellets with a small grain size distribution (STOWA, 2009). This filter is capable of achieving biological denitrification, physical/chemical removal of phosphate and micropollutants through adsorption by granulated activated carbon besides eliminating suspended solids (STOWA (RAPPORT 35), 2013).

4.2.3.5 Results

The performance of GAC regarding the removal of macro-pollutants such as N, P, suspended solids, COD and BOD was observed over the period from January till September 2013 at Horstermeer WWTP (STOWA, 2013). The average removal efficiency of N and P was respectively 67% and 71%, while the average removal efficiency for COD, suspended solids, and orthophosphate was determined at 19%, 32%, and 89% respectively (STOWA, 2013).

Regarding micropollutants, only 3 of the 45 substances on the WFD priority substances (list) were found above the limit in the effluent from Horstermeer WWTP. The substances were diuron and the metals lead and nickel (STOWA, 2013). Although the information obtained regarding the removal of priority substances by the 1-STEP® filter was very limited, no diuron was detected above the reporting limit in the filter, nickel was not removed and the removal efficiency of lead was on average 45% (STOWA (RAPPORT 35), 2013). 44 pharmaceutical micropollutants (which are not WFD priority substances) were detected above the reporting limit, of which 34 were reported more than once (STOWA (RAPPORT 35), 2013). The results of the research indicated at the start of the runtime that a large group of pharmaceutical micropollutants was removed with an average removal efficiency of 60% (STOWA, 2013). However, (with a runtime of 4.5 - 6 months at Horstermeer WWTP) the removal efficiency for most pharmaceuticals was reduced to 0% (STOWA, 2013).

4.2.4 UV H_2O_2 oxidation treatment system

4.2.4.1 Background

A subset of chemical processes employing hydrogen peroxide (H_2O_2), UV light and ozone (O_3) (National Water Research Institute (U.S.A), 2000). Hydroxyl radicals can easily react with the majority of organic compounds by abstracting hydrogen atoms, also it is possible that hydroxyl radicals react with S-, N-, and P-atoms available in the molecule (Martijn, 2015). Mostly, the processes of the production of hydroxyl radical have been illustrated such as photo Fenton (Fe^2/H_2O_2/ UV), Fenton (Fe_2+/H_2O_2), high pH O_3, peroxide process (O_3/H_2O_2), photocatalytic oxidation (UV/TiO_2 or O_3/TiO_2), when ozone is combined with ultraviolet light and hydrogen peroxide ($O_3/UV/H_2O_2$) and ultraviolet hydrogen peroxide process (UV/H_2O_2) (Martijn, 2015). For a long time, to eliminate organic micropollutants such as pharmaceuticals, algae toxins, pesticides, etc, from wastewater, attention of advanced oxidation has been given to the application of O_3/H_2O_2 (Meijers et al., 1995; Chen et al., 2006). Principally, O_3/H_2O_2 advanced oxidation can achieve complete mineralization, however, economically, this might not be feasible and some harmful by-products are formed (Martijn, 2015). Also, a non-selective degradation has been achieved by O_3/H_2O_2, however, in bromide-rich water, bromate formation may be reduced but cannot be avoided entirely. In this regard, the implementation of UV/H_2O_2 based advanced oxidation has drawn much more attention all around of world (Kruithof et al., 2007).

4.2.4.2 Introduction of UV/H_2O_2 based advanced oxidation

UV/H_2O_2 treatment is based on the interaction of UV radiation and H_2O_2 molecules, which may cause the production of hydroxyl radicals (Mierzwa et al., 2018). The UV/H_2O_2 system is comprised of the addition of hydrogen peroxide (H_2O_2) in the presence of UV light to produce hydroxyl radicals (OH^-) (Mierzwa et al., 2018). Hydrogen peroxide (H_2O_2) should be added in the presence of UV light to produce hydroxyl radicals (OH^-) at UV/H_2O_2 system. The application of UV/H_2O_2 treatment systems is very advantageous because UV radiation as a powerful disinfectant in water and wastewater. UV/H_2O_2 treatment systems inactivate microorganisms physically and break the photolysis of peroxide into highly reactive hydroxyl radical species (Mierzwa et al., 2018). Due to the quantum yield of organic compounds and molar absorption coefficient, organic compounds can be degraded by UV photolysis[6]. As an illustration, the high molar absorption coefficient and quite a high quantum yield of pesticide atrazine lead to degradation (Bolton et al., 2002). However, the solvent 1,4-dioxane cannot absorb UV light, thus UV photolysis cannot degrade this compound. Consequently, solvent 1,4-dioxane should be degraded by hydroxyl radical oxidation.

To eliminate the organic micropollutants, UV/H_2O_2-based advanced oxidation was first implemented as a non-selective barrier in one of the drinking water utilities called Andijk WWTP in the Netherlands (Martijn et al., 2007). Basically, Low Pressure (LP) lamps with a dominant emission of UV light at 254 nm and Medium Pressure (MP) mercury lamps with an emission in the 200 - 300 nm range are applied for UV/H_2O_2 treatment (Bolton, 2010). To achieve the required degradation at Andijk, the combination of electrical energy and H_2O_2 was utilized, UV of 540 mg/cm^2 (about 0.5 kWh/m^3) and 6 mg/L of H_2O_2 (Kruithof et al., 2007). According to the aforementioned conditions, dioxane, endocrine disruptors, pesticides (atrazine), microcystin, and pharmaceuticals (diclofenac, ibuprofen) can be eliminated up to 80% (Kruithof et al., 2007).

Some scientists believe some harmful by-products can be formed from organic compounds upon UV/H_2O_2 treatment, however, they are predicted not to be significantly harmful when treatment condition is well-defined (Snyder et al., 2003).

The full-scale installation of the UV/H_2O_2 treatment system has been in operation at Andijk WTP

[6] A process in which photons can be absorbed and the energy released leads to oxidation processes induced by light. According to the absorption rate of compound and quantum yield, it is feasible to estimate the photolysis rate of a compound.

since October 2004, and this system has proven to be efficient in eliminating pathogenic microorganisms and organic micropollutants by approximately 80% (Kruithof et al., 2007). Moreover, results of an investigation of some water treatment facilities which have implemented UV/H_2O_2 in North America indicate that UV-oxidation can remove unpleasant tastes and odours (T&O) in drinking water up to well over 90% (MacNab et al., 2015), whereas the treatment system with hydrogen peroxide and without UV light has shown that the treatment is negligible (MacNab et al., 2015). The performance of UV/H_2O_2 treatment has also been analyzed at North American water treatment plants in Indiana, United States. They came to the conclusion that UV in combination with H_2O_2 leads to a significantly higher level of removal efficiency of micropollutants (MacNab et al., 2015). Also, following a Life Cycle Assessment (LCA) approach and taking all individual processes for the UV/H_2O_2 treatment system into account, they calculated the GWPs (Global Warming Potentials) of the UV/H_2O_2 treatment system at 3.1 g CO_2eq/m^3.

4.2.4.3 The implementation of UV/ H_2O_2 treatment at WWTP Aarle-Rixtel in the Netherlands

The pilot test for the UV/ H_2O_2 treatment system was carried out at Aarle-Rixtel WWTP in the Netherlands in 2019. It was utilized as an additional treatment step to improve the removal efficiency of medicine residues and assess the costs and carbon footprint compared to other existing treatment techniques (Nederlof & Kras, 2019).

4.2.4.4 Results

The removal efficiency of the implementation of the UV/H_2O_2 treatment system at Aarle-Rixtel WWTP was approximately 40%, while the energy consumption was 1 kW/m^3 (Nederlof & Kras, 2019). Nederlof & Kras (2019) concluded that a pre-treatment process such as a sand filter + coagulant could improve the removal efficiency by 40 to 60 percent, however, energy consumption was still high. There is currently neither information regarding total costs and CO_2 footprint of UV/H_2O_2 treatment systems, nor details on chemical consumption at Aarle-Rixtel WWTP. However, based on the energy consumption information, a part of the CO_2 footprint and costs of the UV/H_2O_2 treatment system can be calculated, which are respectively 0.707 kg CO_2 eq/m^3 and 0.111 €/m^3.

4.2.5 Advanced Process Control

Advanced Process Control (APC) concerns the implementation of different types of (sensor) technologies and techniques within industrial process control systems. APCs are generally applied voluntarily to optimize the industrial processes.

In WWTPs, the Activated Sludge Process (ASP) is broadly implemented to minimize nutrients, biochemical oxygen demand (BOD), and other micropollutants in the effluent (Du et al., 2018). The concentration of Dissolved Oxygen (DO) is considered as a significant process control parameter with a substantial influence on the efficiency of treatment processes, operational cost and steadiness of system in an activated sludge process (Du et al., 2018). The optimization of wastewater treatment processes, specifically in the Activated Sludge Process (ASP), leads to energy savings, reduced carbon footprint and costs, and improvement in the effluent quality at WWTPs (Sensileau, 2019). The reason is more than 70% of energy is consumed in ASP at wastewater treatment works, thus this is the major contributor to carbon footprint (Sensileau, 2019). Although other treatment processes can be optimized, the Activated Sludge Process has had the most development so far (Sensileau, 2019). In this respect, the introduction of Advanced Process Control (APC), specifically optimizing Dissolved Oxygen (DO) control in ASP, can assist WWTPs in minimizing their carbon footprint and costs while enhancing the quality of effluent (Rieger & Siegrist, 2012).

Online sensors for automated process control have been used for a long time (Ingildsen, 2002; Olsson & Newell, 1999). Firstly, the focus was mostly on DO control and eliminating the biological nutrient (Ingildsen, 2002). Nevertheless, Jeppsson et al. (2002) demonstrated that the reliability of the sensors considerably improves the quality of provided data. The interruption of the signal might hinder the implementation of process control and this is why advanced process control has not been abundantly applied at WWTPs around the world.

4.2.5.1 The application of APC for ASP

Feedback is provided for the effective control of activated sludge plant aeration by conventional fixed set-point dissolved oxygen (DO), however, more sophisticated advanced process control (APC) that utilizes other sensor measurement inputs can provide further benefits such as a reduction in chemical and energy consumption (Sensileau, 2019). This leads to carbon footprint reduction and an improvement in plant stability and dynamic response (Sensileau, 2019). A reduction in the average DO concentration in aeration tanks leads to higher oxygen transfer rates. For example, DO saturation is assumed to be 10 mg/L and the aeration rate is increased by 20%, so DO average residual is decreased from 2.5 mg/L to 1.0 mg/L. This sufficient use of energy can be translated into cost savings by designing a proper DO control system (Sensileau, 2019). As DO starts to decrease, the number of filamentous microorganisms is increased, which has an adverse impact on the ability of the activated sludge to effectively remove e.g. nutrients, thus recognizing these early warning signs and modifying the level of DO before the deterioration of effluent quality is of the utmost importance (Du et al., 2018). If DO continues to decrease, even low dissolved-oxygen filamentous microorganisms will disappear from the mixed liquor, this leads to deterioration of the treatment efficiencies and the turbidity of effluent increases quickly (Du et al., 2018).

On this account, higher dissolved oxygen is a goal to assure mixing. When the DO concentration is 5 mg/l or higher, dead zones are expected to be minimal as the oxygenated mixed liquor is transported through the reactor by normal currents and mixing. However, when the concentration of DO is excessive, some problems might occur through settling of sludge because of the shearing of flocs and re-suspension of inert materials (Du et al., 2018). In addition, less efficiency in terms of the denitrification process can occur due to high DO concentration. Therefore, the stability of WWTPs performance is highly dependent on maintaining the concentration of DO within a reasonable range (Zhang et al., 2007). The microbial activities that are available in an activated sludge process has complicated nature, and small changes to the system such as a change in the temperature of the wastewater in the reactors, flow rate, or the water quality of the influent affect the concentration of DO (Du et al., 2018). To this date, various studies have been performed aimed at controlling the level of DO concentrations all around the world, and some approaches with satisfactory outcomes have been implemented. For instance, in the UK, three approaches of APC for ASP have been employed, and energy saving is the main driver for the implementation of advanced aeration control at WWTPs. However, the amount of energy that can be saved by improved DO control is dependent on the plant characteristics, plant load, and configurations as well as the level of development of instruments used (Sensileau, 2019). The implemented approaches in the UK to APC for ASP are as follows:

- combined feed-back control and conventional feed-forward incorporating a process model;
- control by utilising a predictive model of the plant which has been built based on the actual observation of the plant behaviour over a representative period;

- applying an empirical rule-based system of controlrelated to the ammonia load using a look-up table adjusts the DO setpoint (Sensileau, 2019).

In 2013, several dissolved oxygen sensors, online nitrate sensors, and ammonia sensors were used for wastewater process control in the UK (Sensileau, 2019). The outcome of the implementation of the advanced control system suggested that energy consumption decreased by 20% for systems using both a feedforward and feedback function on nitrifying plants.

From water quality discharge permits point of view, the effluent quality of WWTPs is determined by the underlying distribution of daily values. which are determined by WLA[7] (Water Quality Based Effluent Limits Procedures Manual, 1995). The underlying distribution of the effluent quality can be changed by APC. The effect is the amount of variability of effluent quality can be reduced and the mean is raised closer to the 95th percentile value (Sensileau, 2019). The 95th percentile value is an important value as it is the most used type of permitted condition limit. To protect receiving water quality, the effluent permit condition limits are the prime mechanism used (Sensileau, 2019).

4.2.5.2 The implementation of APC at Dutch WWTPs

APC has been implemented at some of Dutch WWTPs such as Westpoort, Blaricum, Ooijen, Nijverdal, de Bilt, Utrecht, and Hoogkerk (STOWA, 2012). It has been shown that APC requires a small investment and helps to reduce energy consumption, while the removal efficiency is improved at WWTPs. However, there is no referable information in the available literature regarding the costs, energy consumption, and removal efficiency of APC at Dutch WWTPs.

Importantly, the Wat-IF model is supposed to translate the results of published studies and pilot projects abroad into a utility’s own WWTP so that the expected effects can be quickly calculated. This provides more certainty about the scalability of effects observed in pilot projects because the utility’s own dimensions and circumstances are taken into account. APC implementation has of course been deployed around the world. The results of this implementation abroad might be adapted to Dutch WWTPs.

[7] WLA: Waste load allocation refers to the amount of a substance that can be discharged while maintaining instream objectives under specified conditions

4.3 TRL analysis of new innovative technologies and scenarios

Firstly, the applicability of these technologies needs to be taken into account. To this end, the Technology Readiness Level (TRL) of each technology should be considered. In this regard, the TRL level of each technology should be at least at demonstration level, i.e. 7 (see Section 2.6.4). Therefore, each of the aforementioned innovative technologies is analysed by the TRL approach to be prioritized for incorporation into the Wat-IF model.

All the aforementioned technologies have been demonstrated in an operational environment, thus due to the TRL concept in Section 2.6.4, all of them have reached TRL level 7. However, based on the outcomes of the application of PACAS, this technology has proved to be successful through operations. The results of the implementation of PACAS demonstrated that the ecotoxicity of WWTP effluent diminished by half, whereas the removal of micro-contaminants doubled. This improvement also results in a reduction in environmental risks to the water environment from WWTP effluent. Negative effects on treatment performance and operations have not been observed; there is even a light positive effect on phosphate removal and sludge processing. The costs of PAC dosages are low compared to other micropollutant removal technologies, and the use of PAC requires a relatively small investment. Additionally, although PAC is deemed a fossil product which leads to the production of carbon footprint, PAC technology has been shown to produce less carbon footprint in comparison with other mentioned technologies in this research. Therefore, it can be concluded that PACAS is a proven technology that has been considerably successful and sufficiently mature to be applied at WWTPs, thus the TRL level of this technology is 9.

So far, the combination of ozone with sand filtration has been broadly implemented in full scale throughout the world. Based on the implementation results of this technology abroad, it has proved to be qualified and successful in an operational environment. Therefore, it is also considered a proven technology with TRL level 9 (STOWA, 2019). However, the application results of this technology abroad cannot be used as a basis for Dutch WWTPs. For instance, although previous research abroad proved that this technology cannot eliminate transformation products which have formed such as bromate, it is not possible to be sure whether this finding occurs at Dutch WWTPs. However, ozone with sand filtration was implemented at the De Groote Lucht WWTP in the Netherlands but did not prove whether bromate was removed or not.

Moreover, the results of the implementation of ozone with sand filtration at De Groote Lucht WWTP demonstrated the removal of micropollutants is slightly better than PACAS, nevertheless, its energy consumption, carbon footprint and costs are higher than PACAS.

The only difference between PACAS and Granule Activated Carbon (GAC) is granules used instead of powdered activated carbon. This treatment has also been implemented abroad in full scale, at the Horstermeer WWTP in the Netherlands. The application results of GAC in the Netherlands and abroad in terms of pollutant removal efficiency was successful. Its micropollutants removal is the same as PACAS, also GAC removed macro-pollutants such as N and P successfully. However, the micropollutant removal of GAC usually decreases after a couple of months, at which point it needs to be regenerated. Consequently, GAC becomes more expensive compared to PACAS and ozone with sand filtration. That is why this technology is not widely used at WWTPs. Additionally, its carbon footprint is much higher than the aforementioned technologies. In this respect, STOWA (2019) mentioned there are some complementary technologies which might enhance the efficiency of GAC. Along with the aforementioned argumentations concerning GAC, some improvements still need to occur for this technology to be successful and mature enough to be implemented widely at WWTPs. Therefore, the TRL level of GAC is 8.

Although the UV/H_2O_2 treatment system can be applied for disinfection in both drinking water and wastewater, the UV/H_2O_2 treatment system has not been widely used for WWTPs, especially in the Netherlands. Thus, the implementation of the UV/H_2O_2 treatment system at Dutch WWTPs has not been qualified, and there are no solid results regarding the performance of this technology. However, the prototype of this system was demonstrated in an operational environment in the Netherlands although there is not sufficient information to evaluate this treatment system properly. That is why UV/H_2O_2 is considered a “non-proven technology” for WWTP effluent in the Netherlands (Nederlof & Kras, 2019), thus the TRL level of the UV/H_2O_2 treatment system for Dutch WWTPs is 7.

4.4 Interview analysis

The interviews were semi-structured and focused on the second research question “*What are the most important innovative technologies and scenarios that should be addressed by the Decision Support Tool?”*. Interviews were conducted with experts in the field of wastewater treatment technologies and scenarios. One interview was held with an expert on promising wastewater treatment technologies, and one interview with an expert on online monitoring concepts at WWTPs. The main topics during the interviews were the implementation, costs, carbon footprint and water quality of the most promising wastewater treatment technologies and scenarios. All interviews were recorded, and some notes were made by the researcher.

The first interview was held with a wastewater treatment technologies expert named Mirabella Mulder, who has her own wastewater treatment management consultancy company in the Netherlands. This interview was mainly focused on the treatment technologies with TRL 9 namely, PACAS and ozone with sand filtration. However, some questions regarding UV/H_2O_2 and GAC were asked as well. She emphasized that PACAS and ozone with sand filtration are proven technologies and deemed as reference technologies. However, if the GAC filter is implemented directly for effluent without any pre-treatment, then activated carbon is polluted by many organic pollutants instead of micropollutants. So, every three months the activated carbon needs to be changed, which is expensive and produces a huge carbon footprint. Likewise, UV/H_2O_2 requires too much energy, which leads to high carbon footprint production – this is why experts do not focus on GAC and UV/H_2O_2 technologies. Mirabella Mulder believes that PACAS is the best technology in terms of micropollutant removal so far due to its simplicity, small investment and relatively low costs. She pointed out that when PACAS is implemented at the biological treatment step, it can remove both organic pollutants and micropollutants with satisfactory efficiency. On the other hand, although the removal efficiency of ozone is slightly higher than PACAS, it might produce toxic substances, especially if the origin of wastewater is from an industrial sector. Mirabella Mulder mentioned bio-based activated carbon are being considered to replace fossil activated carbon to reduce the carbon footprint of PACAS. Mirabella Mulder confirmed that the TRL level of both PACAS and ozone with sand filtration is 9, while the TRL level of two other technologies GAC and UV/H_2O_2 is less than 9. She also confirmed the information regarding costs, carbon footprint and water quality that the researcher mentioned earlier in this research for each technology.

The second interview was held with Dr Leo Carswell who is the principal consultant at WRc in the UK. The interview was mainly focused on Advanced Process Control, which is a most promising monitoring concept at WWTPs. He confirmed that APC can optimize the treatment efficiency at WWTPs by stabilizing the treatment processes with the assistance of the application of sensors such as DO, TSS, Ammonia, Nitrate, TOC and COD. Dr Carswell emphasized that sensors with combined conventional feed-forward and feed-back control incorporating a model-based process make the treatment process more stable, thus energy savings between 10 and 30 percent can be achieved. Additionally, he stressed that when the effluent quality is stabilized by APC, the risk of water quality regulation compliance failure is reduced. Although Dr. Carswell did not have the exact information regarding costs, carbon footprint and water quality of APC implementation at WWTPs, he indicated that by reducing energy consumption, carbon footprint and costs are consequently decreased while water quality is improved. He referred the researcher to the example of APC implementation at a WWTP in the UK, which demonstrates that by reducing energy consumption by about 20%, the initial investment can be recovered after 9 months.

4.5 Conclusion

In this chapter, the research covered the most promising wastewater treatment technologies and scenarios by carrying out desk research and conducting semi-structured interviews to answer the second research question "*What are the most important innovative technologies and scenarios that should be addressed by the Decision Support Tool?*. Based on the results of secondary research and interview analysis regarding the best innovative wastewater treatment technologies, PACAS and ozone with sand filtration are so far the best treatment technologies in terms of micropollutant removal. However, the results of desk research and the interviews indicated that PACAS requires a small investment, costs, and less energy consumption than ozone with sand filtration. Additionally, both researcher and expert in the interview emphasized that ozone with sand filtration might produce toxic and carcinogenic substances, thus PACAS is considered a safer technology. Therefore, the results of secondary research and interview analysis demonstrated that PACAS is preferred over other aforementioned technologies to be embedded into the Wat-IF model.

Moreover, the results of secondary research showed that APC is the most promising monitoring concept which can be applied at WWTPs with the aim of monitoring effluent quality and simultaneously optimizing treatment processes efficiency. The APC expert also confirmed in the interview that APC can optimize the treatment process and removal efficiency by stabilizing treatment processes and reduce effluent quality regulation compliance failure. Therefore, in the initial development phase of the Wat-IF model, PACAS and APC are incorporated as the most promising innovative technology and monitoring concepts.

5 COSTS, CARBON FOOTPRINT AND WATER QUALITY

Hitherto the default settings were determined as the first block and input to run the Wat-IF model in Chapter 3. Additionally, the most promising wastewater treatment technologies and monitoring concepts were determined to be incorporated into the second block and input of the Wat-IF model in Chapter 4. Chapter 5 investigates the output of the applied default settings in the first block and the implemented technologies in the second block on costs, carbon footprint, and water quality; in other words, it elaborates on how the Decision Support Tool (Wat-IF) calculates the effect of the first and the second blocks of the model. Finally, all numerical data regarding costs, carbon footprint, and water quality of each implemented technology are presented in graphs by the Wat-IF model, which the future users of the model can consult and make a decision regarding the implementation of a specific technology and scenario.

5.1 Costs

Regarding the costs of technologies and scenarios implemented at WWTPs, the capital expenditure (CAPEX) and operational expenditure (OPEX) of the new technologies are compared to the current (default) treatment costs. Firstly, the total capital costs of installation, equipment purchasing and construction should be divided over the estimated economic lifetime of the WWTP to calculate CAPEX per year (Abu-Madi & Rashed, 2005). As the detailed costs associated with the various components of WWTPs are not available, an economic life period of 20 years is assumed for WWTPs. Also, as mentioned earlier in this research, OPEX costs are comprised of personnel costs (salaries), energy consumption and consumable materials such as chemicals. Importantly, the aforementioned costs are considered against the size (the volume of influent m^3) of the WWTPs (Abu-Madi & Rashed, 2005). Lastly, the default costs which were determined as 0.352 €/m^3 in Chapter 3 are related to the basic costs of WWTPs in the Netherlands. The sum of all the listed costs are presented in graphs which the model users can consult and subsequently compare the total costs of the implemented technologies and scenarios to make a decision on whether it is worth implementing a specific technology.

The CAPEX and OPEX costs of PACAS and APC are respectively presented in Table 8 and Table 9

Table 8: Calculated costs of the implementation of PACAS for small, medium, and large WWTPs. (source: STOWA, 2018b)

Costs (€)	**Small**	**Medium**	**large**
CAPEX	39,546	50,990	62,443
maintenance (staff)	5,000	6,100	7,200
maintenance(infra)	8,703	11,180	13,656
costs (PAC)	64,532	161,330	258,128
costs (electricity)	8.541	9,965	11,388
savings	-3,630	-9,076	-14,521
total	122,692	230,488	338,284
total/i.e	4.91	3.52	3.38
CAPEX/p.e	1.58	0.78	0.62
OPEX/p.e	3.33	2.74	2.76
CAPEX (%)	32	22	18
OPEX (%)	68	78	82

Table 9: Calculated costs of the implementation of APC for small, medium, and large WWTPs. (source: Role of Wastewater Process Control in Delivering Operating Efficiencies, (UKWIR report)

Costs (€)	**Small**	**Medium**	**large**
control system	30-40K	40-55K	50-150K
sensors	30-40K	40-60K	60-90K
mmaintenance	9K	10-17K	15-21K
CAPEX (%)	89	88	89
OPEX (%)	11	12	11

CAPEX: acquisition costs for equipment; OPEX: mainly energy consumption of monitoring, communication and data evaluation systems, and technical maintenance costs

5.2 Carbon footprint

The Wat-IF utilizes a software called The Climate Impact Forecast (CIF) to calculate the CO_2eq of implemented technologies and scenarios.

The Climate Impact Forecast (CIF)

CIF is a quick-and-easy software tool to monitor and calculate the carbon footprint production of businesses and processes, and a trusted tool to assess the accurate Life Cycle Assessment of a commercial product, process and service. Newly established companies and start-ups can use the CIF to calculate the CO2eq of their processes and products (Van der Grinten, 2017). The CIF was developed by Bram van der Grinten, a circular and climate-positive design engineer, with the objective of making companies climate-positive and circular, and of providing the insights that Life Cycle Assessments could offer to companies or start-ups by means of a tool which does not require any knowledge of LCA. CIF also uses an open-source database called Idemat [8].

Six steps need to be completed to run the CIF tool; these are described below.

Step 1: Scope

First of all, six multiple-choice questions need to be answered to define innovation, scope, scale and function of the process or product.

[8] Idemat (Industrial Design & Engineering MATerials database) is the LCI (Life Cycle Inventory) set of databases containing the calculated carbon footprint of different substances, processes, materials, etc. designed by Delft University of Technology.

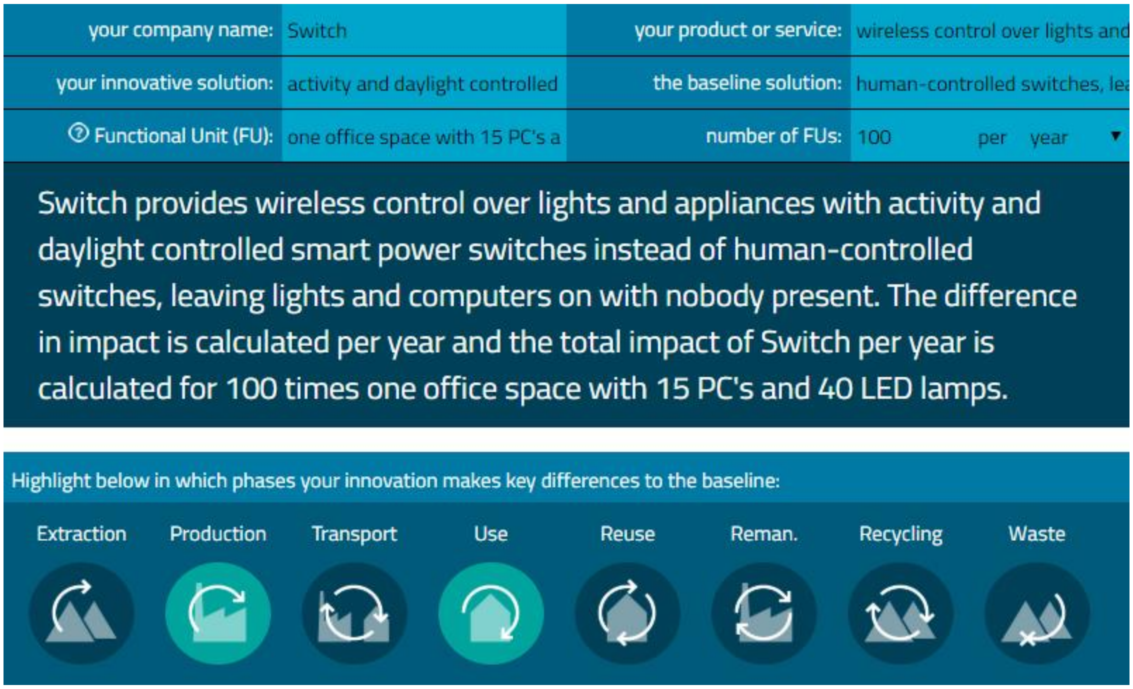

Figure 2: Example of the first step of CIF. (Source: van der Grinten, 2017)

Step 2: Differences

In this step, the CIF determines the differences between the baseline and innovation product, process, etc. utilizing drop-down menus. This indicates the life cycle indicators and corresponding carbon footprint. Four to eight differences are sufficient to describe the key source of impact.

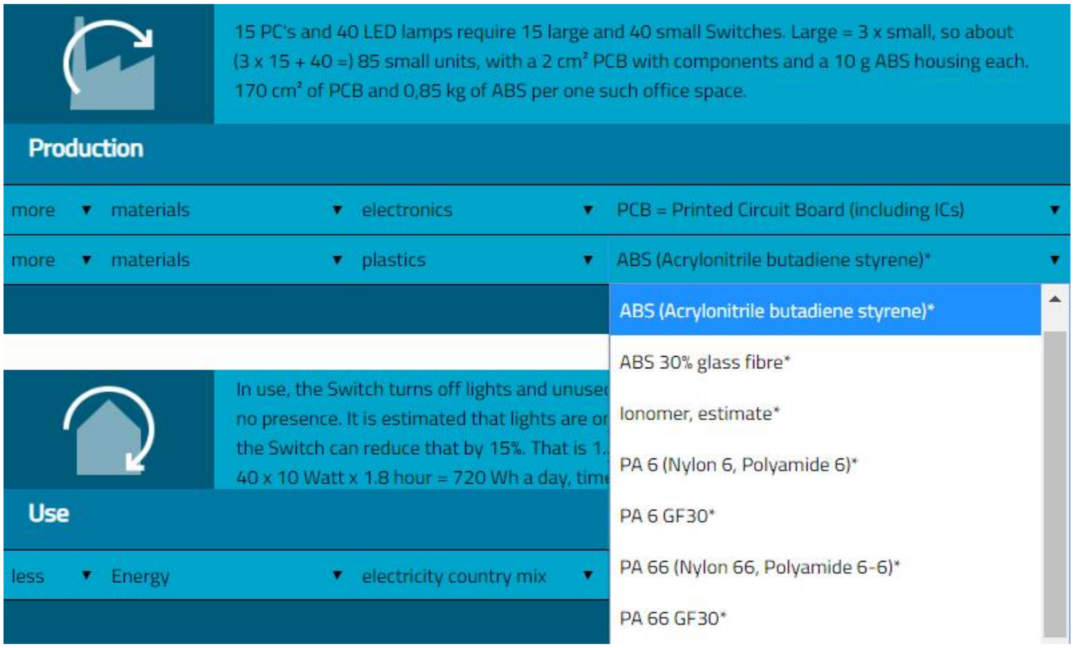

Figure 3: Example of the second step of CIF. (Source: van der Grinten, 2017)

Step 3: Differences

In Step 3, the number of kilograms, kilowatt hours or cubic meters are required to be determined for the product or process. Then, the impact of process, product or service are immediately displayed: green for positive impact; red for negative kilograms of carbon dioxide equivalents.

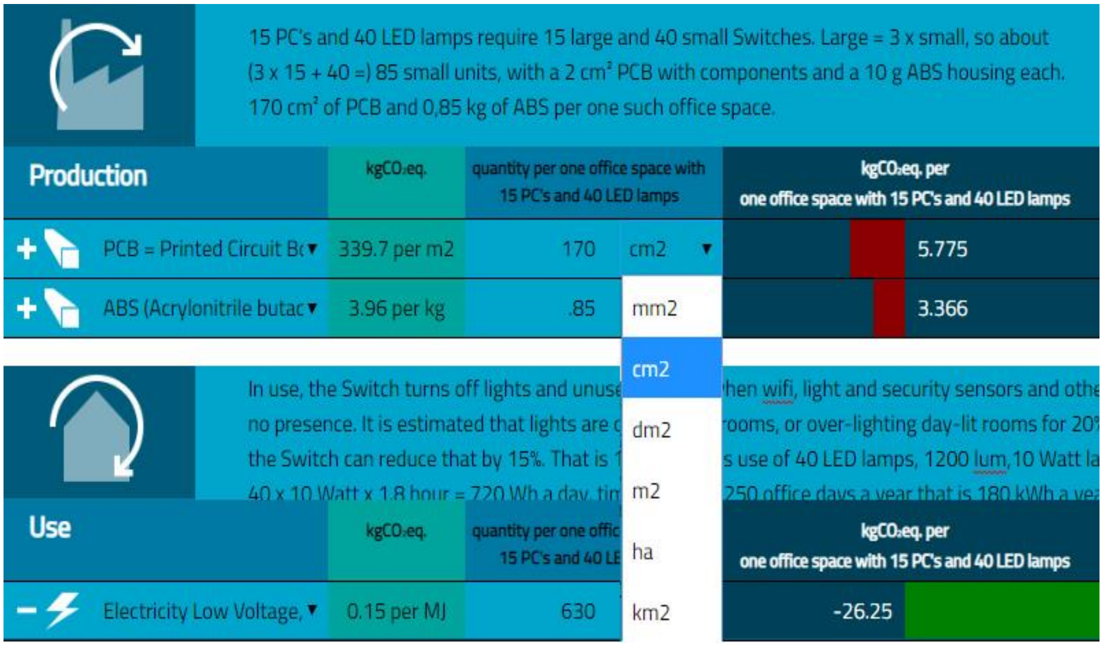

Figure 4: Example of the third step of CIF. (Source: van der Grinten, 2017)

Step 4: Prevent side-effect

An innovation to obtain a climate-friendly solution might be harmful for the environment and humans. Figure 5 shows a smart example of switching technology that has a green carbon footprint due to the reduction of energy consumption, but a red eco-toxicity footprint from the harmful production of the electronics and plastics necessary to create the product.

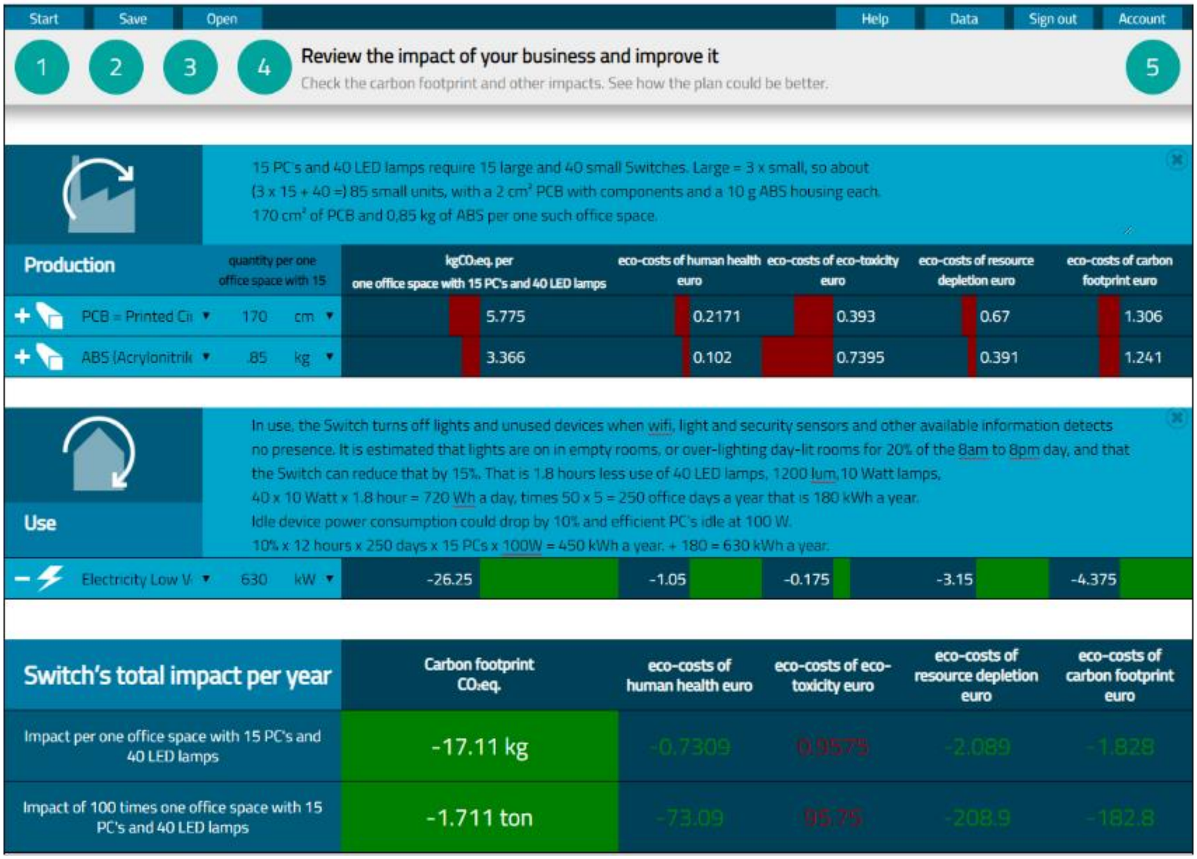

Figure 5: Example of the fourth step of CIF. (Source: van der Grinten, 2017)

Step 5: Overview

All assumptions made, information, the resulting impacts per functional unit, and in total for the business (e.g. in a given year) are displayed on an overview page. For example, as Figure 6 denotes, the total impact is positive, however, not considerable, and there is a negative eco-toxicity footprint.

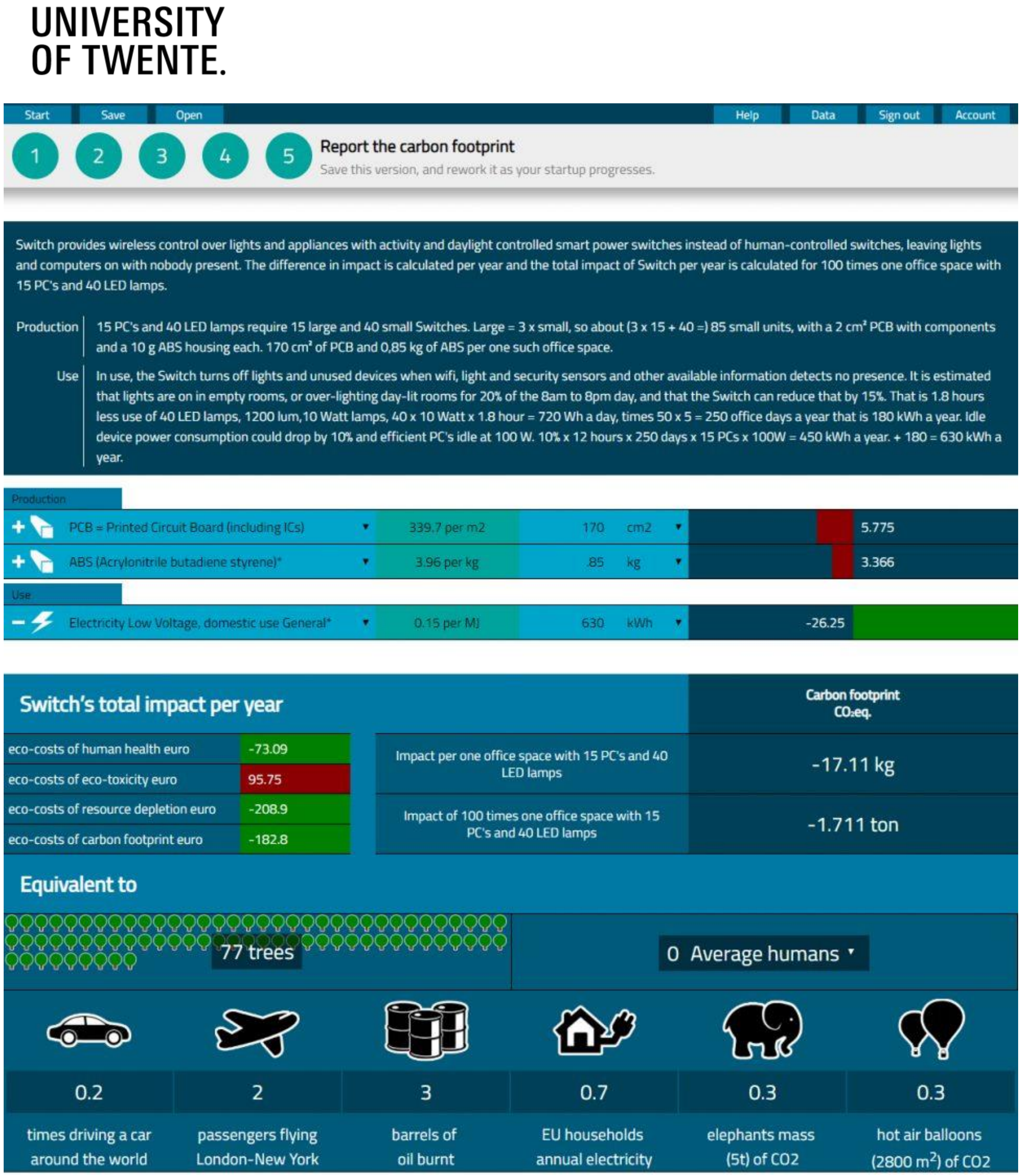

Figure 6: Overview of a CIF calculation (Source: van der Grinten, 2017)

As regards the two main scenarios under investigation in this study (PACAS treatment and APC), the literature on PACAS treatment provides enough information to calculate the impact of this technology on the overall carbon footprint of the WWTP. The PACAS concept requires 0.54 GJp/p.e., which is 36% higher than the default WWTP without additional treatment for the removal of micropollutants (0.39 GJp/p.e.; STOWA, 2018b). For APC, the CIF calculation was performed and the results are shown in Figure 7. The default settings of the Wat-IF model were used as the starting point for the calculations. The main impact reduction is caused by a 20% reduction in energy consumption, which outweighs the negative effects of the harmful production of mainly electronics necessary to produce the sensors and controllers.

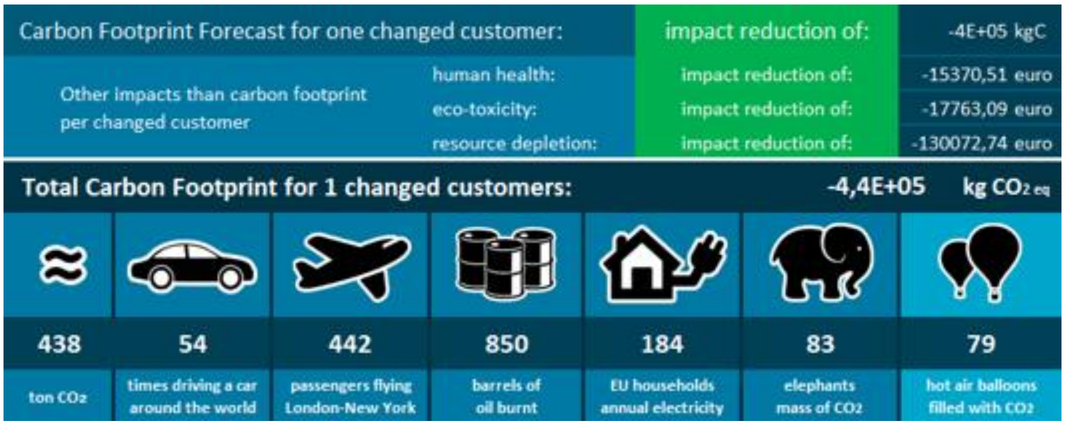

Figure 7: CIF calculation for APC

5.3 Water Quality

After the implementation of new technologies and scenarios, the Wat-IF model determines the water quality improvement of the implemented technologies and scenarios in a numerical way. This section assesses the best strategies to determine the water quality improvement numerically to be incorporated into the Wat-IF model.

One of the most important factors concerning health and safety issues is water quality correspond to aquatic life and public health. Thus, trustworthy assessment and representative data regarding water quality are deemed to be significant. The assessment of water quality is traditionally carried out according to water quality standards and objectives (Rosemond et al., 2009). However, this method could provide insufficient information and data on water quality (Kannel et al., 2007). Alternatively, mathematical modelling methods and statistics approaches seem to be a reliable approach to determine water quality, however, it requires much effort, time, money and expertise (Boyacıoglu, 2007). This is why expressing water quality in numerical way is deemed a scientific challenge. However, a solution to the quantification of water quality can be a prominent step to make a scientific background of water resources management (Ryding & Rast, 1989; Chapman, 1992; Hakanson & Peters, 1995). There are relationships between water quality and different effective factors on water quality (e.g., external nutrient loading, the intensity of water supply), accordingly water quality needs to be expressed in a measurable form. To determine water quality improvement, an important question needs to be answered; "Is the current water quality good or bad?" (Parparov et al., 2006). To determine whether the water quality is improving or deteriorating numerically, water quality indices should be considered (Parparov et al., 2006). The characteristics and uses of water resources can be considered by water quality indices t to help water to formulate an optimal management strategy in terms of water quality improvement (Parparov et al., 2006).

Basically, pollutants in wastewater are mainly classified into macropollutants and micropollutants. Macropollutants are e.g N, P, COD, BOD, TOC, (Zolfaghari et al., 2017), and micropollutants including heavy metals, pesticides, pharmaceutical and personal products (PPCPs), etc, which because of ecological risk for environment and adverse effects on humans and must be monitored (Zareitalabad et al., 2013; Liu and Wong, 2013). Additionally, anthropogenic chemicals that enter into the water bodies at a low concentration as a consequence of human activities are defined as micropollutants as well (Stamm et al., 2016). There are many sources such as industries, households, agriculture, etc, from which micropollutants may originate (Stamm et al., 2016).

As mentioned earlier, water quality indices could be helpful to aggregate monitoring data on macro- and micropollutants in wastewater. However, different water quality indices should be used because of the mentioned differences between macro- and micropollutants. Parameters such as N, P, COD, BOD, TOD, in wastewater can be measured individually, thus based on these quality parameters a Water Quality Index (WQI) can provide a single number (like a grade) that expresses overall water quality (Mitchell & Stapp, 2000). As it is virtually impossible to measure all micropollutants individually in wastewater, assessing the water quality in terms of micropollutants with target chemical analyses only is also impossible. Therefore, in this research, a complementary effect-based risk assessment is used in the bioanalyses of mixtures of bioavailable micropollutants: The Smart Integrated Monitoring (SIMONI) strategy (van der Oost et al., 2017). The Water Quality Index (WQI) and SIMONI index are further elaborated below.

5.3.1 Water Quality Index (WQI)

Complicated water quality data can be converted into the understandable information for the public by WQI. WQI calculates a grade for several water quality parameters individually to demonstrate the overall water quality status at a certain location and time (Mitchell & Stapp, 2000). In this way, a WQI is relatively similar to an air quality index that shows if it is a red or blue air quality day. However, a WQI has always been a controversial issue, as scientists believe a single number cannot sufficiently determine water quality status since there are many other parameters such as micropollutants that a WQI cannot include (Mitchell & Stapp, 2000). A WQI based on some important parameters such as P, N, COD and BOD can indicate the overall status of water quality. Accordingly, a WQI is helpful to choose and implement the appropriate treatment technology and scenario to meet the standard values (Tyagi et al., 2013). The calculation of WQI comprises three steps (Shah & Joshi, 2015):

1. Determine the measurements on individual water quality
2. Convert measurements into “sub-index” values to represent them on a common scale
3. Aggregate the individual sub-index values into an overall WQI value

A water quality index can be based on five types of WQI aggregation functions: (a) weighted arithmetic aggregation function, (b) multiplicative aggregation function, (c) geometric mean, (d) harmonic mean, and (e) minimum operator (Shah & Joshi, 2015). This research uses weighted arithmetic aggregation because of its advantages over the other methods. These advantages are (Tyagi et al., 2013):

1. Weighted arithmetic aggregation incorporates data of important water quality parameters into a mathematical equation to determine the water quality status of a water body with a number.
2. Only a low number of water quality parameters need to be incorporated compared to all water quality parameters for a particular application, such as is the case for Wat-IF.
3. It is much easier to explain the water quality status to citizens and policy makers.
4. This method indicates the impact of different water quality parameters individually.

The Water Quality Index by weighted arithmetic method is calculated by the following formulae (Oni & Fasakin, 2016):

$$WQI = \frac{\sum_{i=0}^{n} qi \times Wi}{\sum_{i=1}^{n} Wi=1} \quad (5.3.1.1)$$

Where:

q_i=quality rating (sub-index) of ith water quality parameter

w_i= unit weight of ith water quality parameter; $\sum_{i=1}^{n} Wi = 1$

n= number of sub-indices aggregated

Also, q_i is calculated as follows (Oni & Fasakin, 2016):

$$q_i = 100\left(\frac{vi-vio}{si-vio}\right) \quad (5.3.1.2)$$

Where:

v_i= estimated value of the ith parameter (in this research the concentration value of each water quality parameter in effluent is deemed v_i).

v_{io}= ideal value of the ith parameter; v_{io} for nitrogen is 2.4 mg N/L, for phosphorus is 0.14 mg P/L, and for COD is 5 mg COD/L (National Institute for Public Health and the Environment, the Netherlands, 2017). Based on Waterbase - Water Quality provided by the European Environmental Agency (EEA; 2020), the annual average concentration of BOD in European rivers was 2.2 mg O_2/L in 2018. The average removal efficiency of BOD by Dutch WWTPs is 98%, thus some of them have already reduced BOD in the effluent to 1.5 mg O_2/L. Therefore, in this research the ideal value of BOD in the effluent of Dutch WWTPs was deemed to be 1 mg O_2/L.

s_i= standard permissible value of the ith parameter; based on Council Directive 91/271/EEC concerning urban wastewater treatment, s_i for COD and BOD are 125 mg/L and 25 mg/L respectively. The s_i for P with (10,000-100,000 P.E.) in effluent is 2 mg/L and with more than 100,000 P.E. in the effluent is 1 mg/L. The s_i for N with (10,000-100,000 P.E.) in the effluent is 15 mg/L and with more than 100,000 P.E. in the effluent is 10 mg/L.

The unit weight (W_i) of each parameter is calculated proportional to K, which is the constant of proportionality and standard permissible value (Oni & Fasakin, 2016)

$$W_i = \frac{Ki}{Si} \tag{5.3.1.3}$$

$$\text{Where } K = \frac{1}{\sum_{i=1}^{n} \frac{1}{si}} \tag{5.3.1.4}$$

Additionally, based on the WQI calculation for each WWTP effluent, the status of effluent quality is classified into five descriptive ranges according to Oni & Fasakin (2016): “Excellent” (0–25), “Good” (26–50), “Poor” (51–75), “Very poor” (76–100), and “Unsuitable” above 100. The classification scheme is shown in Table 8.

Table 10: Rating of Water Quality Index. (source: Oni & Fasakin, 2016)

WQI	**Rating of Water Quality**
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very poor
Above 100	Unsuitable

The WQI of the effluent of each Dutch WWTP based on N, P, COD, and BOD parameters was calculated in this study to establish the pollution`s level of each WWTP’s effluent in the Netherlands (see Appendix F). As the tables in Appendix F denote, the calculated WQI for each WWTP’s effluent is less than 25, thus according to Table 8 the effluent quality of Dutch WWTPs in terms of macropollutants such as N, P, COD and BOD is excellent.

5.3.2 Smart Integrated Monitoring index (SIMONI)

As mentioned earlier, it is not possible to assess the effluent quality of WWTPs in terms of micropollutants by available methods such as the Water Quality Index (WQI), nor is it possible to measure individual micropollutants in the water by chemical analyses only. In order to determine to what extent the water quality has been improved or deteriorated, each parameter needs to be assigned a number, which is virtually impossible for micropollutants in water. According to the European Water Framework Directive (2000/60/EC), the concentration analysis of 45 (groups of) priority substances determines the chemical status of a water body. Thus, the water quality status is deemed good when the concentration of priority substances is below the standard values determined by WFD (European Commission, 2012). To monitor the regular chemical water quality, chemical analysis of a limited set of compounds is carried out. However, there are some restrictions to carry out chemical analyses of spot samples to assess the overall chemical status (Escher & Leusch, 2012). First, as small numbers of target substances are analyzed, it is not possible to determine the ecological risk of some unidentified substances in the aquatic environment (Escher & Leusch, 2012). Second, chemicals are mostly available in complex mixture in the aquatic environment, not as a single substance in the environment. Accordingly, the concentration of an individual chemical substance may be below the Lowest Observed Effect Concentrations (LOEC) or detection limits, but the concentration of the entire mixture can be above the allowable standards and harm the environment (Silva et al., 2002). As a result, these restrictions cause an insufficient assessment of the ecological risks of chemicals, e.g. (Van der Oost et al., 2003), thus alternative methods need to be investigated. To this end, a complementary method called effect-based risk assessment was proposed by Van der Oost et al. (2017). This method is called "Smart Integrated Monitoring (SIMONI)". The SIMONI comprises two tiers: Tier 1 identifies the bioanalytical hazard of sites, while Tier 2 is an ecological risk assessment that should be carried out when hazards are detected in Tier 1 (Van der Oost et al., 2017). According to the Tier 1 evaluation and data obtained regarding the aquatic system, Tier 2 needs to be customized.

To evaluate water quality status from chemical point of view, effect-based monitoring tools have been used for more than 30 years; they measure effects instead of substances (Van der Oost et al., 2017). Bioanalyses are carried out by means of two methods; i) exposing biomarkers in caged organisms in the field (e.g., reviews by Stegeman et al., 1992; Van der Oost et al., 2003), and ii) exposing bioassays with laboratory cell-lines or organisms to environmental samples or extracts (reviews by e.g. Castaño et al., 2003; Durand et al., 2009). Bioassays are quantitative biological assays that are utilized to observe the effect of agents on living animals (FDA, 2011). In vivo assays (using whole organisms) can measure effects on gross parameters such as mortality, feeding activity, growth and reproduction. In vitro assays (using cell lines or unicellular organisms) are able to measure specific biochemical effects of bioactive compounds, such as genotoxicity and endocrine disruption (Van der Oost et al., 2017).

These effect-based tools have been proven to be beneficial to ecological risk assessments in research (Van der Oost et al., 2003). Firstly, in vivo assays respond to a wide range of pollutants present in the water which can be transferred to the test organism. Secondly, as bioanalytical tools can detect mixture toxicity and the effects of metabolites and unknowns, they provide a more holistic assessment of biologically active chemicals present in the water (Van der Oost et al., 2003).

As mentioned above, the Tier 1 of SIMONI is a bioanalytical hazard identification of sites. To do this, firstly, some criteria need to be considered. The most important criteria are (Van der Oost et al., 2003):

1- A wide range of pollutants and their transformation products need to be identified to be monitored by effect-based monitoring strategy; to accomplish this, a good bioassay panel should be designed.

2- Due to the potential ecological health risks, different sites should be discriminated. The hazard assessment needs to be carried out by applying the Effect-Based Trigger values (EBT)[9] to prioritize the site with the highest ecological risks.

3- The panel of bioassays should be cost-effective and provide better ecological health-based information for the same budget or less.

4- Based on ISO or equivalent, the performance of bioassays must be good. Bioassays must meet certain quality standards to measure the selected toxicological endpoints. The requirements include sensitivity, speed, accuracy, robustness and high potential-throughput capacity.

5- Bioanalytical techniques should be implemented easily by routine labs. It is also important that selected bioassays can analyze environmental samples without any high-tech laboratory.

6- The sampling methods should be effective and reliable. For example, due to high variation of micropollutants concentrations, snapshot grab samples might not be reliable. Thus, time-integrated sampling with passive samplers that concentrate bioavailable micropollutants

[9] The difference between good and poor water quality in terms of organic micropollutants can be determined by Effect-Based Trigger values (EBT) (Escher et al., 2018).

on site can be used as an alternative method. This method can be a good reflection of the micropollutants that accumulate in tissues of aquatic organisms (Smedes, 2007; Li et al., 2013).

SIMONI meets all the aforementioned criteria and it was designed to make a combination of in vivo and in vitro endpoints with the objective of estimating environmental hazards by using Effect-Based Trigger values (EBT) at reasonable costs (Van der Oost et al., 2017). The SIMONI strategy uses a suitable bioanalytical monitoring battery to identify a wide range of chemical hazards. Further, derived EBT for environmental risks were applied to classify and interpret observed bioassay responses (Van der Oost et al., 2017).

Figure 8 presents the two-tiered SIMONI strategy, which is based on the combination of laboratory bioassay measurements and field-exposed passive samplers. Tier 1 is the bioanalytical hazard identification and Tier 2 is the risk assessment.

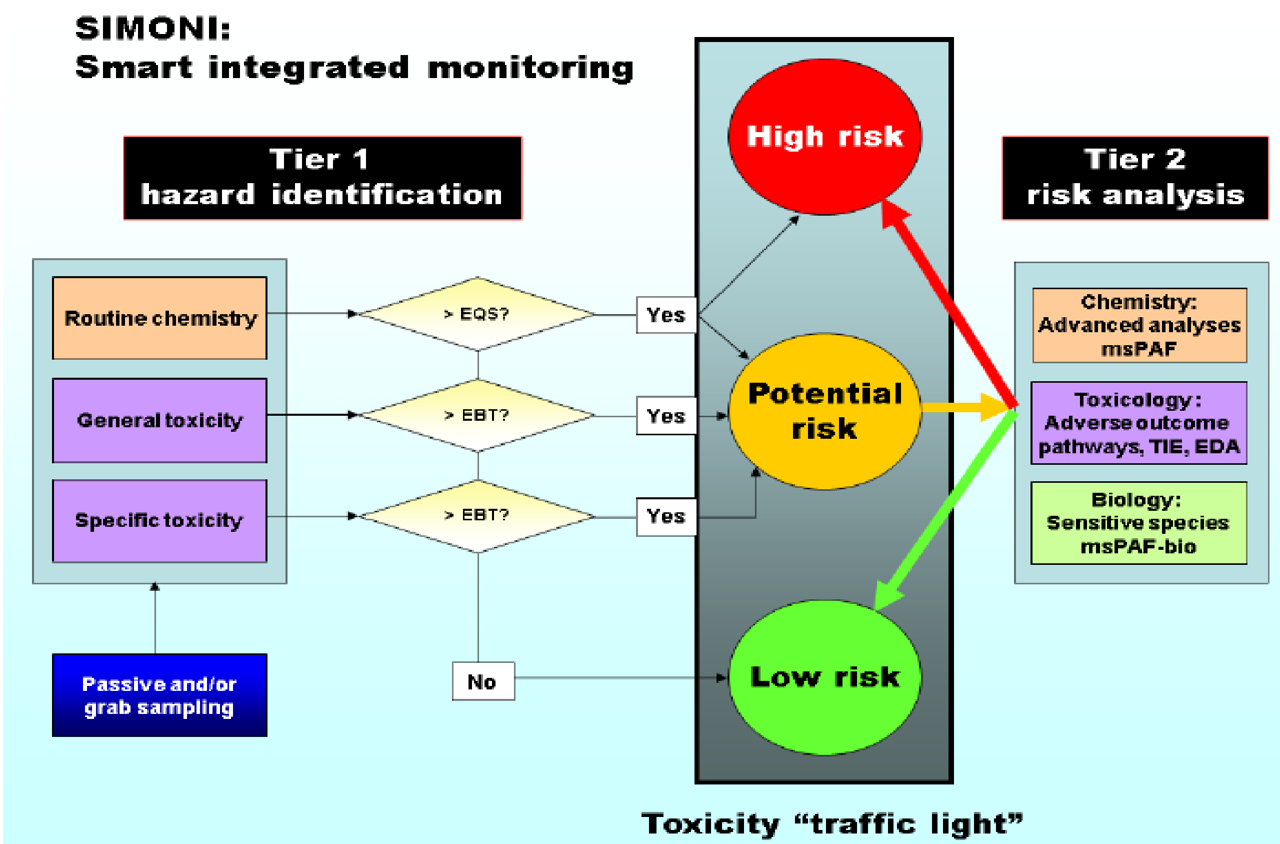

Figure 8: SIMONI (Smart Integrated Monitoring) effect-based monitoring strategy. (Source: Van der Oost et al., 2017)

EBT in Figure 8 is the Effect-Based Trigger value; EQS is Environmental Quality Standard, msPAF: multiple substances Potentially Affected Fraction of species; TIE: Toxicity Identification & Evaluation; EDA: Effect Directed Analysis. Tier 1 is used to evaluate the ecological risks of micropollutants and identify locations with high chemical water pollution. The responses of validated bioassays are evaluated through applying EBT as criteria for potential risks. By the means of evaluated bioassays responses, Tier 1 characterizes hazards of chemical micropollutants (Van der Oost et al., 2017). The results of Tier 1 determine whether Tier 2 should be carried out. Tier 2 is an expensive phase, which is carried out for the actual risk assessment for sites where bioassay responses exceed EBT, and the concentrations of inorganic substances also exceed EQS values. This demonstrates the potential ecological risks and environmental hazards (Van der Oost et al., 2017). However, when Tier 1 shows slight chemical micropollutant hazards, applying the expensive Tier 2 is not required because this does not denote a rising ecological risk.

To perform Tier 1, firstly, bioanalytical endpoints need to be selected, then, bioassays should also be selected to measure these endpoints, these selections were out by Van der Oost et al. (2017). To use bioanalytical tools with the aim of assessing the water quality, it is important to decide which bioassays need to be taken into account to denote an environmental hazard (Van der Oost et al., 2017). The selected endpoints and bioassays types are presented in Table 11. In Tier 1, from a chemical analysis point of view, only ammonium and metals are analyzed, and to carry out ecological risk assessments, the concentration of inorganic substances is compared to Environmental Quality Standard (EQS) values (Van der Oost et al., 2017).

Table 11: Selection of SIMONI endpoints and bioassays for effect-based hazard identification of micropollutants, with examples of targeted chemicals. (Source: Van der Oost et al., 2017).

Category	Endpoints	Targeted chemicals
Non-specific (in vivo)	Non-specific toxicity zooplankton, in situ	All chemicals
Non-specific (in vivo)	Non-specific toxicity zooplankton	All extracted chemicals
Non-specific (in vivo)	Non-specific toxicity phytoplankton	All extracted chemicals
Non-specific (in vivo)	Non-specific toxicity bacteria	All extracted chemicals
Non-specific (in vivo)	Non-specific toxicity Cytotoxicity	All extracted chemicals

Category	Endpoints	Targeted chemicals
Specific (in vitro)	Estrogenic activity	Natural and synthetic estrogens, pseudo-estrogens, bisphenol A, alkyl phenols, pharmaceutical, pesticides
Specific (in vitro)	Anti-androgenic activity	Various pesticides, insecticides, herbicides, brominated flame retardants, (pseudo-) androgens, anabolic steroids, antibiotics, growth promoters, estrogens, PCBs
Specific (in vitro)	Glucocorticoid activity	Wide range of pharmaceuticals, corticosteroids
Specific (in vitro)	Metabolism: Pregnane X	Pesticides, PAHs, alkyl phenols, triazin
Specific (in vitro)	receptor	pesticides, pharmaceuticals, polychloro biphenyls, cyanotoxins
Specific (in vitro)	Metabolism: Aryl hydrocarbon receptor (persistent substances)	PCDDs, PCDFs, PCBs, brominated compounds
Specific (in vitro)	Metabolism: Aryl hydrocarbon receptor (degradable substances)	PAHs, nitro-PAHs, halogenated PAHs
Specific (in vitro)	Lipid metabolism (PPAR)	Organotins, perfluorinated compounds, esters, fatty acid derivatives, retinoic acid
Specific (in vitro)	Antibiotic activity	Five classes of antibiotics (amidoglycosides, macrolides & ß-lactams, sulfonamides, tetracyclines and quinolones), biocides (triclosan)
Reactive (in vitro)	Genotoxicity	Chlorinated byproducts, aromatic amines, PAHs
Reactive (in vitro)	Adaptive stress response: Oxidative stress	General chemical stress, reactive compounds, fungicides, insecticides, phenoles, pharmaceuticals, estrogens

Secondly, EBT for applied bioassays needs to be determined. It is important to distinguish between low- and high-ecological risk for the environment and public health. To this end, Effect-Based Trigger values (EBT) for non-specific toxicity[10] and specific toxicity endpoints were determined.

[10] None-specific toxicity is associated with the toxic actions that lead to produce narcosis. On the contrary, toxic actions which do not produce narcosis but specific action at a specific target site is called specific toxicity (Rand, 1995).

Van der Oost et al. (2017) determined specific toxicity endpoints in in vitro bioassays, and Durand et al. (2009) determined non-specific toxicity endpoints in in vivo bioassays.

5.3.2.1 Effect-based trigger values for non-specific toxicity

In non-concentrated surface water, Van der Oost et al. (2017) used an in-situ Daphnia assay, this was the only bioassay used on site.

Durand et al., (2009) assumed that non-specific toxicity in a concentrated sample indicates a chronic effect in the original sample. Accordingly, they derived an EBT for apical endpoints (in vivo bioassay) by proposing an EBT of 0.05 TU (Toxic Units) for potential ecological chronic effects.

5.3.2.2 Effect-based trigger values for specific and reactive toxicity

In order to derive trigger values for in vitro bioassays, a method based upon bioanalytical equivalents (BEQs) or toxic equivalents (TEQs) of chosen substances that can trigger the bioassays is combined with a benchmark method utilizing toxicological, chemical, and biological data (Maas et al., 2003). As the observed bioassay responses at sites should be deemed as a background bioanalytical equivalent (BEQ) level of the bioassay, the benchmark method should be considered. The concentrations of BEQ are deemed as a measure to demonstrate the effect of the mixture of unknown and unidentified chemicals into a known reference compound's concentration provoking the same effect (Escher & Leusch, 2012). In the Netherlands, it is virtually impossible to find completely unpolluted sites, thus deriving an applicable trigger value with 100 % safety is not feasible. Therefore, the best option is to derive the "low-risk" Effect-Based Trigger EBT values (Van der Oost et al., 2017).

To derive EBT for all in vitro endpoints, Van der Oost et al., (2017) developed a novel three-step method. In the first step, a safe toxic equivalent (safe BEQ) needed to be determined to indicate the no-risk level of micropollutants to the ecosystem. To determine a safe BEQ, the lowest BEQ concentrations of each toxicological endpoint (NOEC, LOEC, EC50 and LC50[11]) were selected and divided by an assessment factor (AF). The Assessment Factor (AF) ranges from 1 to 100

[11] NOEC: no observed effect concentration; LOEC: lowest observed effect concentration; EC50: effect concentration where 50% of organisms show the observed effect; LC50: concentration at which 50% of test organisms die as a result of exposure.

depending on the toxicological endpoint considered. AF values were proposed by Van der Oost et al. (2017) with the consultation of Dutch water experts to estimate safe biological activities by extrapolation of five different toxicological endpoints (see Table 12).

Table 12: Assessment Factor (AFs)

Endpoint	Assessment Factor (AFs)
PNEC	1
NOEC	1
LOEC	5
EC50	10
LC50	100

The second step is HC5 BEQ which indicates "low risk" instead of no risk, this is why it is deemed a more realistic trigger value approach. This method is based upon a Species Sensitivity Distribution (SSD)[12] analysis (Posthuma et al., 2002). SSD curves can be made by placing the distribution of long-term toxicological data (usually EC50, NOEC or LC50) of some types of individual compounds (STOWA, 2016). The outcome of the SSD curves analysis (see SSD curves in Van der Oost et al., 2017, Appendix V) determines the 5th percentile hazard concentration (HC5), which depicts the concentrations that affect 5% of the species negatively (Van der Oost et al., 2017). Finally, in the third step, to determine a realistic EBT, a benchmark study with available field data is carried out. The background level of bioassays should be based on the average bioassay's responses monitored at sites with a good ecological status. When the background of a bioassay is determined, responses below the background BEQ level demonstrate low ecological risk (Van der Oost et al., 2017). Based on results of bioassay field surveys at eight Dutch WWTPs discharging into waters with a good ecological status according to WFD quality guidelines, Van der Oost et al. (2017) determined background BEQs. Safe BEQ, HC5 BEQ, and Background BEQ as derived by Van der Oost et al. (2017) are presented in Table 13.

[12] (SSDs) are a tool applied to determine safe limits on chemical concentrations in surface waters (United States Environmental Protection Agency (EPA, 2020).

Table 13: Derived EBT values corresponded with BEQs for in vitro bioassays. Source: Van der Oost et al. (2017).

Endpoints	Safe BEQ endpoint/compound	HC5 BEQ ** (95% CI range)	Background BEQ	EBT
Estrogenic activity (endpoint) ERa CALUX [ng EEQ/L](bioassay)	0.0066 LOEC/estrone	0.52 (0.019-5.4)	0.06	0.5
Anti-androgenic (endpoint) antiAR CALUX [µg FluEQ/L] (bioassay)	0.00005 LC50/endosulfan	0.13 (0.05-0.27)	4.6	25
Dioxin and dioxin-like(endpoint) DR CALUX [pg TEQ/L] (bioassay)	0.4 LOEC/2,3,7,8-TCDD	137 (15-736)	13.2	50
Glucocorticoid (endpoint) GR CALUX [ng DexEQ/L] (bioassay)	20 LOEC/dexamethasone	2145 (116-14311)	<LOD	100
PPAR. receptor(endpoint) PPAR. CALUX [ng RosEQ/L] (bioassay)	0.00014 PNEC/dibenzo [a.h] anthracene	0.3 (0.002-6.9)	4.4	10
Toxic PAHs (endpoint) PAH CALUX [ng BaPEQ/L] (bioassay)	0.04 LOEC/2,3,7,8-TCDD	41 (2.5-254)	63	150
Oxidative stress(endpoint) Nrf2 CALUX [µg CurEQ/L] (bioassay)	0.000006 NOEC/estradiol	0.034 (0.008-0.11)	4.3	10
Pregnane X receptor(endpoint)	0.000004	0.008 (0.002-0.024)	1.5	3

Endpoints	Safe BEQ endpoint/compound	HC5 BEQ ** (95% CI range)	Background BEQ	EBT
PXR CALUX [μg NicEQ/L] (bioassay)	LOEC/chlorpyrifos-ethyl			
Antibiotics:				
Aminoglycosides RIKILT [ng NeoEQ/L]	300 PNEC/neomycin	33222 (1546-219614)	<LOD	500
Macrolides & ß-lactams RIKILT [ng PenEQ/L]	1.8 EC50/tiamulin	98 (13-470)	<LOD	50
Sulphonamides RIKILT [ng SulEQ/L]	10 LOEC/sulfadiazine	67037 (24675-148222)	4.6	100
Tetracyclines RIKILT [ng OxyEQ/L]	170 PNEC/oxytetracycline	27275 (8292-68544)	<LOD	250
Quinolones RIKILT [ng FlqEQ/L]	0.53 EC50/triclosan	8759 (2197-26050)	<LOD	100

Unit of bioassays:

expressed as equivalents of the reference compounds:

EEQ = estradiol; FluEQ = flutamide; TEQ = 2378-TCDD; DexEQ = dexamethasone; RosEQ = rosiglitazone; BaPEQ = benzo[a]pyrene; CurEQ = curcumine; NicEQ = nicardipine; NeoEQ = neomycine; PenEQ = penicillin; SulEQ = sulfamethoxazole; OxyEQ = oxytetracyclin; FlqEQ = flumequine.

**: 95% confidence intervals (in parenthesis)

<LOD = all below limit of detection

According to the three-step method, EBT values for selected bioassays can be derived. If the Background BEQ value is less than HC5 BEQ, the EBT value equals the HC5 BEQ. But when the Background BEQ value is much less than the HC5 BEQ value, EBT value equals 0.2 times the safe BEQ value. If the Background BEQ value is more than the HC5 BEQ value, the EBT value equals 0.5 times the Background BEQ value, and when the Background BEQ equals the HC5 BEQ value, the EBT value is within the HC5 95% confidence interval (STOWA, 2016). The schematic presentation of the three-step approach to derive Effect-Based-Trigger values is shown in Figure 9.

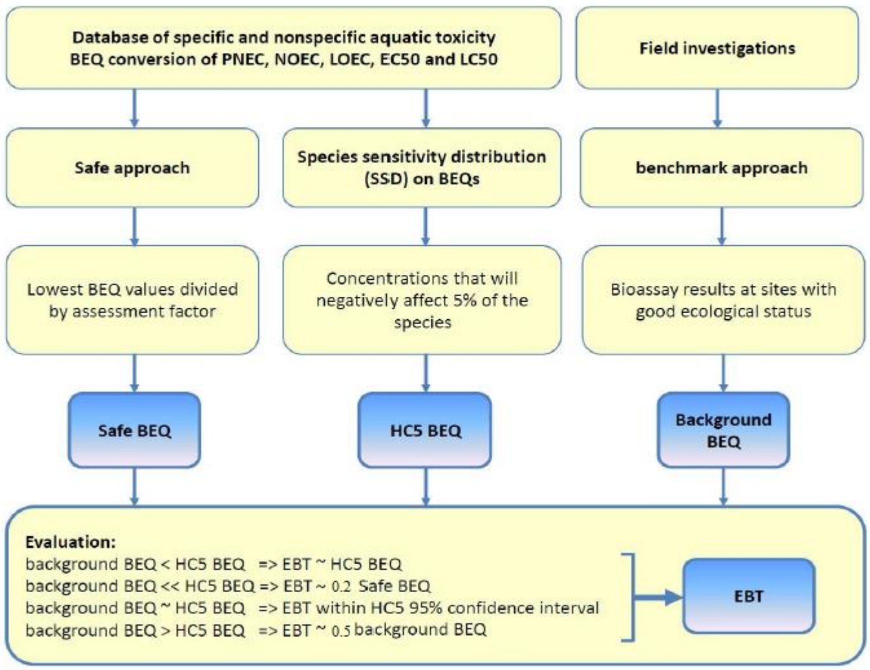

Figure 9: Schematic presentation of the three-step approach to design EBT values. Source: Van der Oost et al. (2017)

The derived EBT values for the selected in vitro bioassays based on the three-step approach Safe BEQ, HC5 BEQ, Background BEQ are presented in Table 13. It must be pointed out that the EBT values for selected bioassays and antibiotics activities which were derived by Van der Oost et al. (2017) are the same as water quality standard values and it is not necessary to re-calculate them for any other WWTP.

To calculate the SIMONI score, bioassay responses are divided by the derived EBT values and multiplied by a weight factor; the result is divided by 0.5 times the total bioassay weight. In this regard, the SIMONI score formula (5.3.2.1) demonstrates the overall risk for the aquatic system. When the calculated SIMONI score is less than one, there is a low risk (green light) and no action is required, while when the calculated SIMONI score is more than 1, it indicates that the exposure of the mixture of chemical substance or micropollutants is causing an ecological risk to the ecosystem. Therefore, actual risk analyses must be carried out (Tier 2). The SIMONI score is calculated using the following formula by Van der Oost et al. (2017):

$$\text{SIMONI score} = \frac{\sum_{i=1}^{n}\left(\frac{\text{bioassay response}_i}{\text{EBT}_i}\right) \text{x weight}_i}{0.5 \text{ x total bioassay weight}} \qquad (5.3.2.1)$$

Where:

Bioassay response_i = the effect of selected endpoints at sites

EBT_i =Effect-Based Trigger value

weight_i = A weight factor of bioassays

All individual bioassay responses are integrated using formula (5.3.2.1) with the objective of quantifying the combined ecological hazards of micropollutants. A weight factor (weight_i) was determined for all bioassays, for reactive toxicity endpoints (in vitro) weight_i was assigned a value of 1, while for apical toxicity (in vivo) weight_i was assigned 2 (Van der Oost et al., 2017). Van der Oost et al. (2017) assumed the weight of applied in vitro and in vivo bioassays must be at least 10, so the total bioassay weight is 20.

Finally, based on the information of Table 13, in order to make a decision on the implementation of Tier 2, SIMONI uses a specific formula to determine the SIMONI score (5.3.2.1).

On the whole, endpoints, bioassays, and EBT values were successfully determined by Van der Oost et al. (2017) and can be applied to determine SIMONI scores for any WWTP. However, the effect of endpoints (bioassay responses) needs to be determined for individual WWTPs.

Based on the biological effect research of the SIMONI method, it appears that the environmental risks of organic micropollutants in the effluent of the Papendrecht WWTP decrease significantly after dosing PAC in activated sludge part (PACAS) (see figure 10). The decrease in environmental risks after the implementation of PACAS (quantified by means of a SIMONI score) ranged between 36% and 65%.

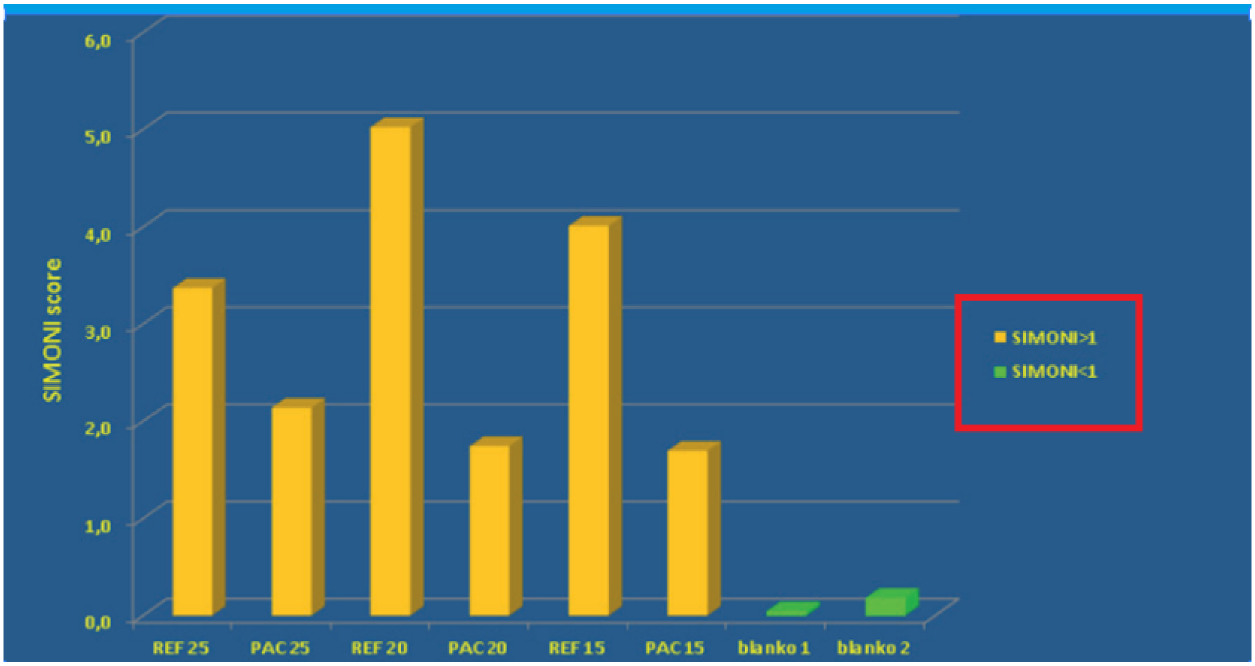

Figure 10: Results of SIMONI after the implementation of PACAS at Papendrecht WWTP. (source: STOWA, 2018 b).

5.4 SWOT analysis

This section investigates the SWOT analysis of water quality quantification methods that have been elaborated on so far to explore the strengths and weaknesses of each method. To begin with Water Quality Index (WQI)'s strengths, it is worth emphasizing that a WQI is capable of calculating every individual water quality parameter in different kinds of water. Thus, it is much easier to detect and control water quality parameters exceeding the limit values. Additionally, it is straightforward to detect changes in water quality, and even identify the source of water (Mădălina & Iuliana, 2014). WQI calculation is much easier, understandable, flexible, and less expensive compared to other water quality quantification methods such as SIMONI. A WQI is not a complicated model, thus it can communicate water quality information easily to policy-makers or legislators, and the general public (McClelland, 1974). Importantly, a WQI assesses the overall quality of the water by summing up many single water quality values quickly and logically in a numerical way (Mădălina & Iuliana, 2014), thus it is simple to monitor the trend of water quality over several years and determine whether it has improved or deteriorated. In this regard, WQI is used to apply the best treatment techniques to meet water quality standards. However, while the overall water quality index might meet the standard, some water quality parameters might be bad.

Moreover, regarding the weaknesses, it is worth noting that while WQI can calculate a wide range of water quality parameters and pollutants, a huge amount of data needs to be handled, and it is possible that these data can be easily lost. Another weakness is associated with the incompetency of WQI to deal with complex environmental issues such as micropollutants. WQI is incompetent in calculating or expressing the combined effects of mixtures of micropollutants such as pharmaceuticals and pesticides in the water. Therefore, WQI may not present sufficient information to demonstrate the real water quality situation.

Contrarily, the SIMONI index can cope with the complex issues of water quality specifically in terms of micropollutants and pesticides. SIMONI can express and estimate the effect of a broad spectrum of micropollutants existing in the water by quantifying ecological hazards, thus it can prioritize sites with a high potential of ecological risk in terms of micropollutants. Another strong point of SIMONI is that water quality experts agree that this strategy can be a promising alternative to current EU WFD monitoring such as chemical analysis of a limited number of substances. Further, Van der Oost et al. (2017) claimed that the SIMONI approach is less expensive than regular monitoring programs. For example, to analyze 45 priority substances, WFD chemical surveillance monitoring consists of 12 monthly grab samples, which costs around 3,000 € in the Netherlands, while the suggested SIMONI approach costs about 2,000 € (Van der Oost et al., 2017). A WFD chemical campaign for one water body costs around 40,000 € in the Netherlands, while a SIMONI campaign in one water body costs around €10,000 (Van der Oost et al., 2017). However, SIMONI is much more expensive compared to WQI. It is important to highlight that the weakness of SIMONI is that it is still under research and development, so many assumptions were made to derive the required components such as weight factors of the SIMONI score formula. The complexity of the SIMONI calculation compared to other water quality quantification methods such as a WQI is another weakness, which makes it more difficult to understand and communicate information for the public, water managers, and policy-makers and water quality legislators. One of the challenges of SIMONI is related to sampling: 1) Not all compounds accumulate in samplers, 2) No (sensitive) response to all pollutants can be achieved. These challenges cause more uncertainties regarding the implementation of the SIMONI approach at WWTPs. Furthermore, to calculate a SIMONI score, a wide range of information is required. Van der Oost et al. (2017) selected some specific endpoints and bioassays and EBT values were derived based upon these.

But if new endpoints or bioassays are selected to be used for SIMONI score formula, a large amount of research again needs to be carried out to provide the required components of the SIMONI score formula.

5.5 Interview analysis

For this chapter, two interviews were conducted. One interview on the SIMONI approach was held with the author and creator of SIMONI, in order to understand its precise performance and the application of this novel strategy. The second interview was a semi-structured interview which was conducted with the general manager of Brabantse Delta Water Board. The second interview focused on the third research question "*What are the main challenges of water managers at WWTPs in the Netherlands and how can these be effectively incorporated into the Decision Support Tool?*"

In the first interview, Dr Ron van der Oost (SIMONI author) was mainly asked questions regarding the function of the SIMONI approach. Firstly, he confirmed that SIMONI is a novel strategy which aims at quantifying micropollutants and ecological hazard effects in the water. He elaborated on the function of SIMONI and emphasized that there is no need to find new endpoints or bioassays to provide the required components of the SIMONI score formula. Therefore, he suggested that his selected endpoints and bioassays can be applied to any other WWTP. Also, Dr Van der Oost mentioned the derived EBT values in his research can be used to calculate the SIMONI score for different WWTPs, thus there is no need to find and calculate new Safe BEQ, HC5 BEQ, and Background BEQ, which makes the implementation and calculation of SIMONI much easier. Dr Van der Oost confirmed that the SIMONI approach is the best alternative to other chemical monitoring approaches, and it is much cheaper. Although SIMONI is capable of analysing a broad range of chemicals, other chemical analysis methods can analyze a limited number of substances. However, he mentioned there are some challenges regarding the SIMONI approach, such as the many assumptions necessary to provide the required elements to use the SIMONI score formula, which might cause some uncertainties. Moreover, Dr Van der Oost agreed that SIMONI requires too much information and it might not be easy for everyone to understand and use it.

The second interview was carried out with Dr Arthur Meuleman (Manager of the Brabantse Delta Water Board) on the main criteria for Dutch water managers to apply new technologies or monitoring concepts. Dr Meuleman mentioned that costs are significantly important. He pointed out that CAPEX and OPEX are firstly considered before any decision on the application of new technologies. The annual budget of 40 million euros is allocated and OPEX and CAPEX cost must fit within the allocated budget. Subsequently, the long-term environmental impacts of implemented technologies need to be taken into account. In this regard, energy and chemical consumption are considered to monitor the carbon footprint production and the water quality impact of implemented technologies. Dr Meuleman emphasized that micropollutant removal (such as for pharmaceuticals) and nutrient recovery (e.g. P) are the most important challenges that they currently face. Moreover, energy consumption reduction by optimizing their treatment processes is another objective for Dutch water managers. To this end, they would like to use sensors to stabilize their processes and thus reduce their energy consumption. Dr Meuleman explained that there is an elected board which makes decisions on the implementation of new technologies or monitoring concepts. Dr Meuleman and his organization team prepare all the information on the considered technology in terms of costs, carbon footprint, water quality improvement, and then supply this information to the elected board to decide whether a specific technology or monitoring concept needs to be applied or not.

The results of this interview clearly imply that the outcome of the Decision Support Tool should be associated with costs, carbon footprint and water quality improvement of any implemented technology or monitoring concept so that water managers can easily decide on the application of new technologies.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This section highlights important findings of this research to answer the main research question: "How can the Decision Support Tool build upon existing knowledge and incorporate new insights regarding the implementation of eco-innovations at WWTPs in the Netherlands?" Firstly, all sub-research questions are reviewed, and the main research question is answered based upon the answers of all sub-research questions. Accordingly, the initial schematic of the Decision Support Tool (Wat-IF) is presented.

The first sub-research question was "What is the general configuration of WWTPs in the Netherlands, and which characteristics can be used as standardized representatives ("default settings") for a Dutch WWTP in the Decision Support Tool?". To answer this question, firstly, all main characteristics of Dutch WWTPs were collected and standard values for each main characteristic were calculated by means of descriptive analysis methods (as default settings) for Dutch WWTPs to be incorporated in the first block of the Wat-IF model. The derived default settings are presented in Section 3.3.5.

The second sub-research question was "What are the most important innovative technologies and scenarios that should be addressed by the Decision Support Tool?" The results of secondary research and interview analysis demonstrated that PACAS is currently the most promising wastewater technology compared to other available treatment technologies as it requires less investment and energy. Additionally, the findings in Chapter 4 show that Advanced Process Control (APC) is one of the best monitoring concepts that can be applied at WWTPs to optimize treatment processes. APC stabilizes treatment processes, thus energy consumption is reduced, while the effluent quality of WWTPs is improved by increasing the removal efficiency. Therefore, PACAS and APC are embedded in the second block of Wat-IF model as the most important innovative technologies and scenarios.

The third question sub-research question was "What are the main challenges of water managers at WWTPs in the Netherlands and how can these be effectively incorporated into the Decision Support Tool?" The outcome of desk research and interviews with a general manager of a Dutch Water Board resulted in the main challenges for water managers at WWTPs on the implementation of new wastewater treatment technology and scenarios to be costs, carbon footprint, and water quality improvement. Accordingly, the Wat-IF model has been designed to be capable of calculating the impact of implemented technologies and scenarios on costs, carbon footprint and water quality improvement. Wat-IF can list all the costs as CAPEX and OPEX of the implementation and operation of each technology or treatment scenario so that future users can consider and compare the total costs to decide whether it is worth applying a specific technology or scenario. Also, Wat-IF can calculate the water quality improvement of implemented technologies and scenarios by the means of the water quality quantification methods WQI (for macropollutants) and SIMONI index (for micropollutants). Wat-IF uses a software called The Climate Impact Forecast (CIF) to calculate the CO_2eq of implemented technologies and scenarios, which was described Section 5.5.3.

Following the answers of the sub-research questions, it is thus possible to answer the main research question “How can the Decision Support Tool build upon existing knowledge and incorporate new insights regarding the implementation of eco-innovations at WWTPs in the Netherlands?” The necessary basic information which has been collected for Dutch WWTPs has been found to be sufficiently detailed and complete to serve as a starting point for impact assessments using the Wat-IF model. Additionally, detailed and reliable experimental data have been collected regarding additional (treatment) technologies and monitoring concepts, which allow for a thorough assessment of their impact on the costs, carbon footprint and effluent quality of a Dutch WWTP, thereby providing the possibility to calculate any deviations from the (default) starting point. Lastly, calculation tools and methodologies have been identified to quantify in a numerical way the size of the impact for the three most important assessment factors, i.e. costs, carbon footprint and effluent quality. This allows for an objective comparison of various (combinations) of implementation scenarios. Thus, it can be concluded that for all the essential parts of the Wat-IF model, sufficient, scientifically based data, methodologies and concepts are available to ensure its credibility and usability.

The initial version of Wat-IF was built by incorporating all described and assessed components, resulting in the initial schematic of Wat-IF as presented in Figure 11.

The Wat-IF tool enables decision-making on the basis of calculated effects instead of global expectations. Technology evaluations can then be carried out in relation to specific objectives and the dimensions of the utility's own WWTP and the prevailing conditions. As a result, the entire decision-making process is ultimately better substantiated and considerably accelerated. Moreover, the flexible nature of the tool makes it possible to add new scenarios as new information about possible technical applications becomes available. This benefits the dissemination of information about new techniques and their application possibilities and can significantly accelerate their implementation at other utilities as well.

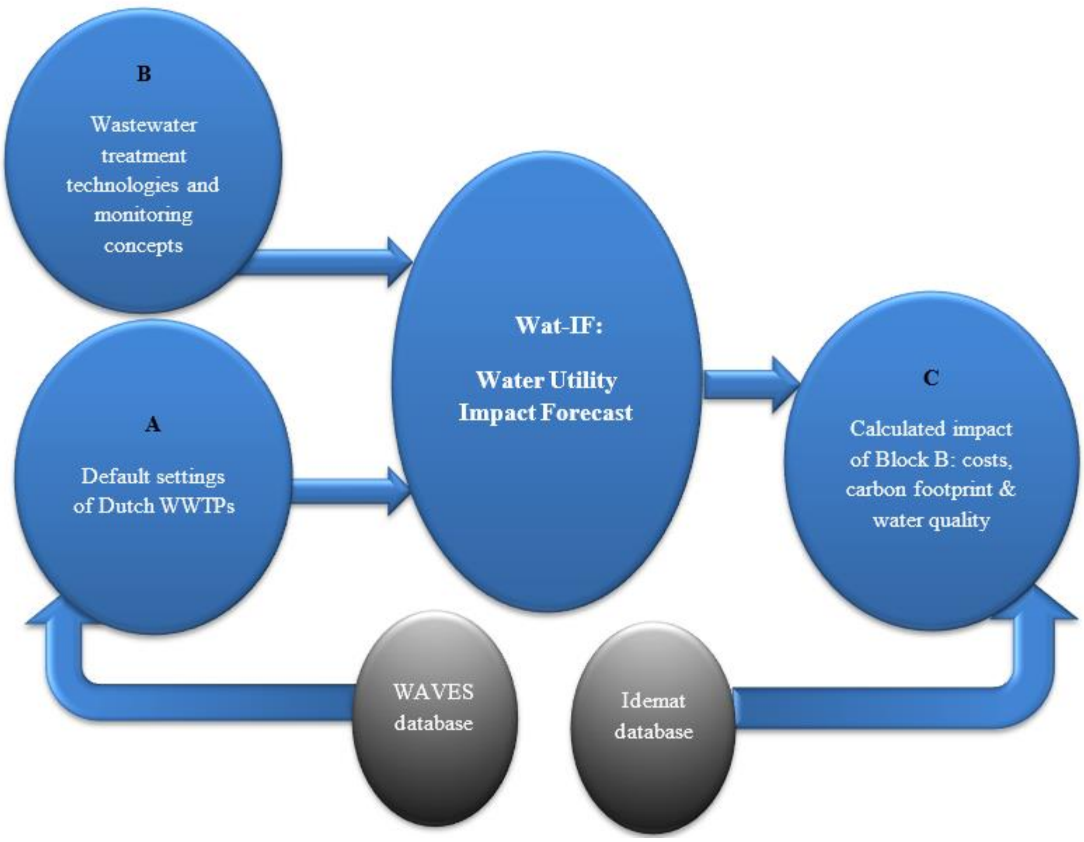

Figure 11: Initial schematic presentation of the Wat-IF model for Dutch WWTPs

6.2 Recommendations

This section presents the recommendations for future research involving the development of the Wat-IF model. Recommendations were formulated after concluding the investigations described in Chapters 3, 4 and 5, supplemented by feedback and recommendations on the future of the Wat-

IF model of the interviewees involved in this research after the presentation of the Wat-IF model schematic.

For the future development of the Wat-IF model, other methods such as PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluation) can be considered to give users the option to rank technologies and scenarios based on their preferences (Hamouda et al., 2009). For instance, if a water utility prioritizes water quality over other challenges, technologies and treatment scenarios with the highest removal efficiency can be recommended for this water utility, regardless of costs and carbon footprint.

The first interview was conducted with Judith Herschell Cole (Wastewater treatment expert at *Sensileau*, USA). Judith Herschell Cole believed that costs are the most important criterion to be considered and thus the costs should be visualized comprehensively for water managers to decide on the implementation of technologies and monitoring scenarios. Therefore, she highly recommended prioritizing costs calculations and savings over water quality and carbon footprint to convince future users to use this model. During the second interview with Dr Leo Carswell, he mainly recommended that in addition to micropollutant removal, some other technologies associated with microplastics, phosphorous removal, etc, should also be incorporated into the Wat-IF model. It makes the model more topical to deal with the current issues in wastewater treatment by means of new technologies. Another interesting recommendation was to add nutrient-recovery steps into the model. For example, at the phosphorous removal step in the current treatment scheme, phosphorous can be recovered, and thus revenue can be generated. This can mainly cover the costs and should be considered for the further development of the Wat-IF model. In terms of water quality, Dr Carswell suggested that the model could benefit from including a limit value for specific pollutants so it can indicate whether a specific technology is able to achieve specified limit values. Also, the model could offer a selection of specific technologies to remove specific parameters. In this way, technologies which do not have any influence on water quality can be distinguished easily.

The third feedback interview was held with Dr Ron van der Oost. He emphasized that ozone with sand filtration is another promising technology, with a better removal efficiency compared to PACAS. Thus, he recommended that ozone with sand filtration individually or combined with

PACAS be considered for inclusion in the Wat-IF model. However, PACAS is the cheapest and easy to implement. It is important that the nature and the characteristics of the origin of influent and receiving water are considered to be embedded in the future development of the model because it leads the users to choose the right technology to satisfy their specific expectation on water quality.

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APPENDICES

Appendix A: Commonly used WWT steps at Dutch WWTPs

	Used wastewater treatment steps by Dutch WWTPs	The number of Dutch WWTPs using treatment steps
1	Physical purification: Lattice removal	324 out of 331
2	Physical purification: Fine sieving	5 out of 331
3	Physical purification: Sand trap	167 out of 331
4	Physical purification: Pre-settling	83 out of 331
5	Physical purification: rainwater buffer tank	28 out of 331
6	Biological removal P and N in main stream-1: plug stream	70 out of 331
7	Biological removal P and N in main current-1: Bypass circuit	250 out of 331
8	Biological removal P and N in main stream-2: AB two-stage purification	5 out of 331
9	Biological removal P and N in main stream-2: Phosim system	37 out of 331
10	Biological removal P and N in main stream-2: PhoRedox system	43 out of 331
11	Biological removal P and N in main stream-2: UCT System	61 out of 331
12	Biological removal P and N in main stream-2: High flea system	11 out of 331
13	Biological removal P and N in main stream-2: grain sludge technology	5 out of 331

14	Biological removal P and N in main stream-2: MBR	Only Ommen WWTP applies this step
15	Biological removal P and N in main stream-2: Oxidation bed	96 out of 331
16	Biological removal P and N in main stream-2: Other	168 out 331
17	Chemical P removal: none	139 out of 331
18	Chemical P removal: Dosage in physical purification or phosphate removal	17 out of 331
19	Chemical P removal: dosage in activated sludge tank for phosphate removal	147 out of 331
20	Chemical P removal: Dosing in sludge line for phosphate removal	28 out of 331

UNIVERSITY OF TWENTE.

Appendix B: Influent and effluent data values of WWTPs in the Netherlands

B1: The annual amount of Nitrogen, Phosphorous COD and BOD in influent and effluent of WWTPs in the Netherlands (2018)

Dutch WWTPs	Nitrogen load in the influent (kg)	Phosphate load in the influent (kg)	COD load in the influent (kg)	BOD load in the influent (kg)	Nitrogen load in the effluent (kg)	Phosphate load in the effluent (kg)	COD load in the effluent (kg)	BOD load in the effluent (kg)
Harnaschpolder	4,044,552	514,256	39,630,826	17,434,661	552,560	41,027	2,496,542	178,180
Amsterdam West	3,859,693	481,820	36,528,397	17,360,104	461,439	51,060	2,653,421	280,392
Eindhoven	2,772,852	504,875	27,377,272	12,379,713	411,296	29,398	1,646,974	196,589
Dokhaven	1,795,800	217,540	17,810,905	7,748,585	768,325	54,020	1,690,680	297,475
Bath	1,522,062	260,129	16,722,813	7,006,014	323,388	66,059	1,814,096	124,869
Utrecht	1,483,399	237,030	15,256,412	6,887,051	181,478	12,759	688,068	80,932
Tilburg	1,389,414	193,281	14,829,594	6,671,408	184,568	10,986	930,040	73,240
Westpoort	1,353,849	198,634	13,906,993	6,116,123	168,473	15,821	996,785	116,601
Venlo	1,316,636	183,194	11,915,847	4,931,987	240,032	7,978	1,077,228	98,767
Nieuwveer	1,296,733	175,835	13,766,527	5,214,246	279,239	38,048	857,746	103,673
Houtrust	1,284,859	155,250	13,033,827	6,333,762	278,813	19,145	813,080	89,241
Nijmegen	1,272,738	163,608	14,636,404	7,110,416	249,068	33,606	772,612	112,539
Dordrecht	1,266,550	228,125	8,869,865	3,639,050	133,225	10,950	756,645	54,020
Kralingseveer	1,235,538	149,837	11,386,437	4,566,701	222,775	35,619	1,118,971	110,009
Apeldoorn	1,191,842	147,377	12,050,600	3,770,955	256,570	34,501	935,900	71,970
Aarle-Rixtel	1,138,053	165,492	15,712,166	6,432,539	145,857	16,947	1,035,285	101,847
Garmerwolde	1,082,390	145,071	12,097,600	5,348,183	244,482	9,370	1,230,179	170,050
’s-Hertogenbosch	1,058,296	175,448	12,062,266	5,391,852	198,245	14,764	723,346	82,889

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Wervershoof	1,042,005	197,847	10,594,561	4,461,806	85,093	8,789	622,969	72,703
de Groote Lucht	968,094	129,796	8,623,163	3,643,548	248,488	60,083	847,735	93,532
Almere	960,562	117,535	11,133,879	4,346,099	68,011	8,436	389,899	33,391
Amersfoort	946,454	120,103	11,518,478	4,220,579	132,689	8,740	572,631	31,909
Dinther	919,333	296,639	10,469,111	4,809,962	91,920	16,464	609,137	70,350
Enschede-West	907,604	124,575	10,852,377	4,171,445	110,163	10,169	583,032	42,451
Zutphen	905,069	126,908	9,544,261	3,930,435	21,954	2,641	347,102	18,570
Nieuwgraaf	890,017	110,733	9,899,335	3,735,027	133,149	20,649	439,143	36,437
Beverwijk	877,169	136,071	7,457,174	3,057,864	161,516	29,301	970,108	143,545
Ede	875,250	138,377	11,185,533	3,924,737	97,479	6,110	663,217	42,135
Oijen	846,400	152,591	10,233,229	4,395,860	75,325	25,612	568,233	57,794
Susteren	815,457	101,749	11,053,504	4,300,472	122,122	12,135	709,510	106,613
Haarlem Waarderpolder	812,445	110,435	9,520,439	4,175,925	102,562	25,251	604,220	75,256
Hoensbroek	805,813	88,357	8,075,729	3,224,520	114,177	7,857	687,723	88,923
Geestmerambacht	795,246	104,055	9,033,538	4,329,539	124,242	9,180	559,263	48,007
Harderwijk	728,095	96,132	10,040,790	4,064,037	101,685	6,397	515,224	35,004
Roermond	722,849	81,774	8,267,512	2,968,074	178,636	6,869	930,323	103,937
Arnhem	656,668	82,220	7,099,482	3,126,651	89,792	7,097	249,340	27,242
Hengelo	649,259	104,928	6,259,833	2,147,897	149,987	9,638	700,994	36,525
Katwijk	645,887	88,661	7,555,889	3,331,602	109,268	15,072	472,050	51,583
Leeuwarden	635,641	115,909	7,086,130	2,722,921	65,977	14,422	594,038	54,115
Zwaanshoek	626,522	78,831	6,035,255	3,205,516	68,454	16,149	492,671	50,416
Walcheren	620,397	75,938	5,896,545	2,821,537	145,380	12,680	665,593	108,917
Emmen	611,216	96,751	10,337,604	2,765,968	35,974	1,714	191,033	15,338
Zwijndrecht	604,440	86,505	5,619,540	2,246,575	45,990	8,760	371,935	38,690
Zwolle	565,716	70,593	6,791,238	2,714,112	114,554	18,352	428,011	39,791

Tollebeek	565,642	115,415	5,995,388	2,462,117	50,748	5,970	193,379	12,684
Land van Cuijk	562,232	99,071	6,600,870	2,866,219	81,442	11,038	545,413	68,145
Etten	521,811	64,715	7,379,433	2,986,151	69,001	6,761	378,644	28,906
Nieuwegein	517,300	60,811	4,870,369	2,200,638	90,602	11,253	290,307	25,865
Heerenveen	511,906	76,775	4,594,075	1,896,054	48,925	10,748	559,399	44,177
Horstermeer	508,698	62,210	4,585,450	1,998,597	30,206	1,682	239,069	19,066
Zwanenburg	506,110	69,089	5,474,608	2,323,500	46,778	4,455	291,817	39,579
Amstelveen	496,041	63,085	4,281,043	1,928,845	132,775	9,102	354,974	42,917
Dongemond	492,178	62,740	6,391,491	2,746,351	136,993	8,280	417,851	76,444
Limmel	482,821	52,002	4,913,876	1,973,734	93,015	7,257	328,011	43,792
Echten	475,933	90,950	5,431,036	2,139,383	68,019	8,337	344,175	24,190
Beemster	474,403	70,164	4,427,630	1,967,284	61,771	7,875	370,394	47,989
Leiden Zuid-West	440,827	56,784	4,033,262	1,861,288	62,433	9,245	403,705	49,963
Deventer	435,530	54,730	4,658,872	1,818,689	68,899	5,432	280,590	19,788
Zaandam Oost	432,322	48,469	4,903,072	2,355,812	82,920	3,981	382,847	41,468
Olburgen	430,302	69,666	4,480,368	1,612,396	65,925	24,957	265,457	24,982
Spijkenisse	425,590	78,110	4,917,280	1,946,545	23,360	9,125	210,240	17,520
Kortenoord	425,465	56,223	4,582,327	2,132,118	42,591	3,236	260,807	30,924
Weert	419,391	47,456	5,342,100	1,895,400	118,507	9,420	450,183	108,682
Hellevoetsluis	410,990	42,705	2,801,010	997,545	37,595	4,745	183,230	20,075
Elburg	408,300	64,438	4,938,815	1,844,001	35,963	4,300	268,819	17,925
Lelystad	405,798	48,498	4,674,202	1,777,185	24,875	1,818	215,082	17,009
Willem Annapolder	396,438	49,577	3,609,594	1,731,350	114,238	6,771	401,305	66,678
Nieuwe Waterweg	392,341	61,442	3,855,259	1,585,955	72,099	28,100	350,034	24,550
Leiden Noord	383,176	66,523	4,213,718	1,461,017	42,489	5,867	317,887	36,469

Gouda	382,617	49,572	3,861,319	1,684,918	39,782	2,549	273,704	27,600
Veenendaal	379,270	51,054	4,741,363	1,780,324	28,093	2,121	204,856	15,242
Tiel	374,535	52,284	4,647,682	1,930,191	48,029	7,177	204,087	22,859
Velsen	361,153	50,636	3,947,337	1,721,684	85,858	16,403	230,141	35,083
Drachten	359,247	43,829	3,680,405	1,556,267	49,397	3,210	321,039	24,145
Almelo-Sumpel	347,395	44,372	4,462,133	1,653,654	29,804	2,775	222,530	15,553
Sint-Oedenrode	346,245	48,081	3,614,486	1,716,985	30,457	3,013	234,273	28,149
Nijkerk	341,651	41,108	3,990,971	1,617,088	37,309	2,021	183,491	14,566
Assen	324,485	45,260	3,952,950	1,828,650	55,048	7,252	331,136	62,709
Bosscherveld	322,355	35,058	3,335,817	1,468,872	18,137	5,857	132,079	16,641
Renkum	321,011	40,616	3,338,247	1,241,839	62,188	19,946	196,466	24,886
Meppel	308,803	71,719	4,008,915	1,619,591	24,790	6,849	187,462	17,719
Winterswijk	308,753	42,297	3,365,237	1,144,984	31,269	2,230	217,845	17,276
Noordwijk	303,930	38,607	2,950,604	1,311,515	25,645	3,588	167,189	19,178
Hoogvliet	300,030	43,435	3,596,345	1,217,275	99,645	5,110	352,955	38,325
Boxtel	298,693	49,666	2,858,479	1,128,489	50,266	3,964	177,961	27,815
Zeist	297,467	36,645	3,177,881	1,348,424	43,663	1,670	103,391	9,841
Leidsche Rijn	296,373	36,126	3,109,341	1,468,763	28,550	2,123	160,312	18,597
Soest	292,256	36,288	4,526,429	1,505,362	42,018	3,079	163,296	11,838
Terneuzen	286,534	30,414	2,318,107	1,092,225	62,016	8,864	347,216	68,114
Zaltbommel	281,959	46,287	3,452,649	1,640,172	40,337	7,070	256,002	42,666
Katwoude	278,849	39,431	3,073,936	1,431,191	47,207	9,386	260,325	25,812
Ridderkerk	276,670	33,215	2,747,355	1,184,060	31,025	6,570	163,155	14,965
Venray	275,579	33,265	2,345,664	1,060,538	24,916	817	149,692	10,848
Rijen	272,719	37,406	3,492,294	1,555,265	29,606	3,901	194,319	26,362
Alkmaar	269,813	36,008	2,590,072	1,182,431	54,734	5,951	235,299	27,024
Oldenzaal	257,085	37,867	3,656,510	1,370,379	30,320	3,913	156,952	12,322
Hilversum	255,955	32,248	2,469,493	1,122,368	25,297	1,850	104,507	8,258

Houten	249,733	30,745	2,115,919	1,001,033	14,410	2,166	103,568	9,723
Haarlem Schalkwijk	249,088	30,333	2,489,744	1,129,564	21,906	6,036	208,841	20,331
Haarlo	247,883	45,880	3,197,355	1,244,309	15,215	904	117,044	7,564
Schelluinen	247,080	36,204	2,427,545	974,182	14,569	7,140	148,826	15,374
Woerden	246,917	31,665	2,513,364	1,071,141	45,300	4,526	235,610	27,706
Kampen	246,504	31,548	2,712,970	1,147,301	31,634	2,243	173,694	18,904
Nijverdal	245,340	38,937	2,962,071	1,010,436	26,522	16,904	343,693	16,334
De Bilt	239,406	30,749	2,652,038	1,293,584	28,424	1,970	137,765	11,249
Biest-Houtakker	234,613	30,326	2,195,124	952,411	37,169	2,236	194,044	19,588
Kaatsheuvel	234,269	28,798	2,378,879	1,053,742	13,934	1,891	92,151	11,487
Alphen Kerk en Zanen	234,096	31,803	2,455,602	1,080,481	14,791	1,172	138,212	14,795
Alphen Noord	230,345	27,490	2,315,350	1,069,711	10,702	732	130,281	12,435
Eelde	226,577	31,009	2,792,938	1,224,972	32,184	6,013	234,007	23,439
De Groote Zaag	226,046	29,029	1,946,367	898,631	29,260	2,319	197,362	22,009
Groenedijk	221,205	25,742	1,944,519	879,906	14,219	2,875	146,499	10,962
Almelo-Vissedijk	217,757	28,076	2,511,011	925,441	30,203	8,803	141,472	9,934
Vinkel	212,847	27,344	2,117,231	929,087	20,036	3,334	149,372	13,399
Huizen	211,807	23,767	2,136,685	1,022,727	20,599	567	90,914	7,822
Gennep	211,291	21,831	1,701,558	698,544	31,619	4,130	135,758	20,937
Dronten	211,218	26,827	3,130,608	916,432	25,147	1,881	106,634	9,922
Waalwijk	210,089	26,602	2,574,527	1,027,563	38,510	9,092	242,229	20,837
Steenwijk	209,135	28,206	2,300,631	1,003,504	15,096	1,500	112,324	9,202
Asten	208,984	30,296	2,288,283	1,025,923	16,493	2,561	142,225	14,187
Dedemsvaart	208,857	37,759	2,337,449	906,036	21,161	1,152	146,120	11,890
Hapert	203,291	25,851	1,872,462	773,619	21,584	1,160	130,559	16,015

Waddinxveen-Randenburg	203,271	24,758	2,230,093	998,070	14,514	934	165,143	15,030
Sneek	202,215	25,406	1,970,914	755,036	23,417	3,316	186,653	10,771
Heugem	198,304	20,485	1,194,219	533,834	26,760	3,236	100,075	9,646
Terwolde	194,715	21,943	1,733,599	594,517	65,640	5,235	163,794	10,971
Hattem	194,013	28,637	2,104,473	801,302	14,482	8,832	95,001	11,224
Veendam	193,085	25,915	2,620,700	1,129,310	29,501	7,802	320,807	31,675
Stolpen	190,759	24,187	1,706,038	725,504	40,624	7,644	160,124	18,286
Den Helder	190,524	23,610	2,024,462	825,458	35,844	5,450	232,003	32,626
Kaffeberg	188,746	20,509	2,332,237	987,128	11,517	865	85,031	9,147
Beilen	188,199	34,717	2,461,157	1,105,999	20,730	2,682	120,807	11,106
Culemborg	186,101	23,512	1,915,225	857,366	28,598	9,838	131,629	17,594
Uithoorn	180,408	23,724	1,611,572	690,641	30,812	1,972	127,041	11,230
Raalte	179,574	23,174	1,950,314	796,959	11,813	665	99,683	6,448
Maarssenbroek	179,505	27,233	2,205,394	1,078,892	10,334	5,014	67,146	6,633
Hardenberg	176,738	21,165	1,961,254	689,735	17,294	2,042	141,434	8,895
Barendrecht	175,930	20,805	1,677,175	773,435	21,170	1,095	101,835	13,505
Sliedrecht	175,634	22,238	1,764,073	852,706	27,227	1,200	121,958	12,810
Haaren	174,966	21,951	1,609,764	670,455	24,117	1,209	111,993	15,064
Heiloo	173,740	22,965	1,703,177	704,621	27,111	5,485	158,361	13,343
Scheemda	173,375	22,995	2,419,585	977,470	29,763	5,290	272,241	35,786
Ronde Venen	171,822	25,007	1,891,423	836,269	19,021	1,457	153,456	11,936
Bodegraven	171,802	24,495	2,524,437	1,223,120	10,936	1,051	135,436	14,079
Sleeuwijk	170,733	23,799	1,790,827	746,389	37,369	4,600	127,241	19,438
Ursem	169,755	22,540	1,635,644	733,207	24,948	1,139	123,176	13,129
Driebergen	168,221	21,485	2,511,897	685,352	13,392	1,364	92,667	10,800
Alblasserdam	167,687	24,818	1,751,949	744,164	26,355	4,577	136,109	18,263

Rhenen	167,580	20,128	1,932,561	905,023	16,770	1,317	76,481	8,957
Haaksbergen	164,867	21,510	1,992,191	745,033	11,616	1,861	93,122	7,467
Rijssen	161,925	20,406	1,682,337	596,646	12,360	1,193	83,860	5,646
Papendrecht	161,223	18,906	1,337,034	576,138	18,146	2,019	127,500	22,659
Wijlre	156,514	20,386	2,084,544	940,263	36,559	1,753	150,744	25,478
Coevorden	156,267	20,641	2,961,372	1,173,951	19,300	1,503	155,306	10,157
Rimburg	156,187	21,370	1,878,814	745,778	12,633	1,443	99,971	7,093
Bolsward	154,900	25,978	2,005,584	790,114	23,693	4,168	141,431	8,887
Panheel	152,751	19,029	1,856,722	620,001	67,613	13,808	171,641	36,051
Woudenberg	152,446	20,207	1,621,579	600,433	14,857	868	85,959	4,930
Franeker	151,502	20,109	2,173,148	1,053,101	40,337	4,667	246,506	38,599
Oud Beijerland	149,650	19,710	1,793,245	730,365	9,490	730	87,600	9,490
Goor	147,860	17,205	1,960,930	729,243	19,065	1,108	97,087	8,773
Geldermalsen	147,604	18,133	1,435,893	626,831	19,893	1,662	86,279	12,965
Gieten	147,460	21,535	1,820,985	770,515	23,864	1,681	159,164	21,315
Druten	145,335	18,766	1,479,195	617,153	24,467	6,303	117,653	22,395
Blaricum	144,916	19,837	1,487,409	678,887	11,644	1,669	93,509	9,313
De Meern	144,097	17,694	1,530,283	612,953	23,847	3,081	92,162	9,871
Burgum	141,653	17,028	1,153,037	460,121	11,479	2,490	114,951	9,970
Oosterwolde	140,841	19,503	1,754,132	743,554	12,967	1,746	109,932	9,086
Harlingen	138,676	34,419	1,362,349	579,758	9,248	4,669	84,607	3,851
Delfzijl	136,875	19,106	1,712,215	628,445	15,823	4,891	157,481	12,940
Groot-Ammers	135,275	18,373	1,436,539	606,987	26,666	5,517	89,947	8,459
Weesp	134,290	17,698	1,447,660	651,413	96,170	2,455	191,148	34,692
Stadskanaal	132,860	17,155	1,713,310	735,475	19,285	1,933	176,749	16,680
Wolvega	132,851	17,670	1,368,635	598,873	15,248	3,186	105,257	7,094
Leerdam	130,747	20,823	2,125,121	958,392	16,743	834	84,075	9,080
Foxhol	130,305	17,155	1,615,125	781,830	15,410	2,042	151,309	18,096

Lisse	130,136	18,258	1,381,371	621,532	11,858	1,623	74,362	6,319
Joure	129,915	16,275	1,506,002	597,773	8,077	474	127,323	4,481
Zeewolde	128,859	17,109	1,938,927	746,860	9,274	782	79,565	6,447
Oostvoorne	128,115	29,930	1,128,215	416,465	10,950	4,745	77,745	5,840
Vianen	127,951	21,350	1,304,784	579,770	11,048	4,045	78,871	8,211
Nieuwveen	127,919	18,410	1,426,224	638,357	7,726	748	94,566	6,355
Everstekoog	127,637	18,507	1,239,665	523,538	10,364	926	80,894	8,451
Kootstertille	126,103	17,378	1,223,817	496,434	11,234	1,776	96,959	6,081
Lichtenvoorde	125,321	14,783	1,329,504	495,437	9,236	3,448	83,259	6,128
Waarde	124,434	15,765	1,375,331	656,350	18,569	1,318	115,347	15,760
Dalfsen	124,231	16,885	1,212,387	502,596	10,747	1,016	66,810	4,166
Heemstede	124,002	15,425	1,231,699	551,941	33,273	1,430	68,247	16,464
Epe	123,877	13,277	1,355,291	553,475	7,384	237	44,640	2,673
Dokkum	123,055	15,704	1,118,611	360,338	17,384	2,824	109,712	6,752
Middelharnis	121,180	17,520	1,315,095	618,310	6,570	730	63,510	5,840
Gendt	118,616	14,825	1,425,591	519,205	23,630	4,372	128,021	18,328
Stein	117,693	12,631	1,243,709	483,826	64,149	2,391	146,242	31,714
Genemuiden	113,440	14,724	1,180,368	506,348	13,825	496	69,664	4,729
Wijk bij Duurstede	113,295	14,406	1,215,846	586,467	14,174	868	68,296	9,912
Holten	112,505	15,240	1,403,547	594,039	14,850	3,127	83,749	9,509
Sleen	109,688	14,488	1,205,482	460,702	15,481	1,323	74,348	10,498
Brummen	107,114	13,016	1,201,654	454,211	11,166	498	57,155	4,836
Dodewaard	106,403	13,348	1,639,441	781,209	28,031	2,873	88,416	19,208
Groesbeek	104,657	19,146	1,039,803	464,565	11,910	1,597	64,594	8,475
Goedereede	104,390	12,775	1,154,860	510,635	4,380	365	54,020	4,380
Breukelen	99,784	10,531	944,597	460,348	11,791	392	56,736	6,240
Dieverbrug	99,061	12,916	964,486	398,182	12,277	975	59,045	5,598
Aalten	99,037	12,791	1,002,414	384,480	8,545	1,661	51,513	5,832

Soerendonk	97,521	13,174	1,313,544	572,757	10,574	575	75,512	9,931
Hoogezand	97,455	16,060	1,407,075	631,450	7,518	1,120	100,878	9,652
Leek	96,891	19,852	1,433,559	568,727	10,159	2,702	95,295	6,414
Bunnik	95,576	13,721	1,439,300	639,738	10,798	826	54,037	6,228
Gorredijk	94,990	11,946	971,834	369,443	10,457	1,308	80,190	6,212
Birdaard	93,037	14,513	928,216	347,854	14,025	4,144	94,670	9,142
Westerschouwen	92,417	10,929	696,618	314,816	13,315	2,277	76,661	10,804
Losser	90,639	12,339	1,115,424	388,719	6,650	1,186	71,474	4,963
De Verseput	90,130	11,725	927,525	420,832	8,288	672	66,573	9,006
Olst-Wijhe	89,962	12,506	1,085,706	458,983	7,841	1,357	43,818	3,682
Grou	89,308	16,444	1,132,429	397,435	5,280	486	52,503	2,523
Nieuwe Wetering	88,422	14,526	1,081,352	477,162	7,487	611	58,073	4,563
Gorinchem	85,845	11,524	928,317	412,497	7,060	3,247	47,231	4,982
Damwoude	84,438	10,400	800,314	308,928	11,589	1,379	68,195	4,016
Heerde	83,868	11,631	964,247	343,809	8,692	1,020	49,820	3,733
Ommen	82,743	11,533	1,132,769	467,496	6,453	837	53,055	3,995
Lemmer	77,082	12,059	738,446	286,961	4,844	894	49,245	2,562
Hulst	76,128	8,665	619,759	296,957	9,947	2,973	74,396	9,298
Vroomshoop	75,198	10,061	932,634	352,189	8,353	1,117	69,708	5,610
Maarssen	74,940	9,520	780,860	349,708	9,356	563	54,044	6,311
Lopik	74,808	11,015	1,022,477	494,294	8,471	951	60,266	7,234
Varsseveld	74,655	10,064	757,961	296,151	10,221	1,005	54,851	6,465
Denekamp	72,698	12,759	1,323,362	493,438	4,519	808	45,391	3,567
Montfoort	72,404	9,439	818,697	344,223	9,656	1,361	56,112	7,728
Numansdorp	71,905	8,760	622,325	262,435	7,300	730	40,150	4,745
Bennekom	68,040	8,833	768,725	300,774	5,741	288	27,451	1,507
Baarle-Nassau	67,224	9,382	847,493	434,938	7,550	590	42,653	6,075

Sint Maartensdijk	66,447	7,677	561,176	260,408	9,183	1,059	42,572	4,967
Hardinxveld De Peulen	65,894	8,496	633,718	266,100	10,261	3,564	61,934	8,128
Oudewater	65,740	8,871	925,560	470,503	5,873	614	64,642	7,458
Sloten	65,093	8,515	591,488	249,333	7,940	821	43,023	2,827
Vriezenveen	62,732	9,087	926,425	319,696	12,991	3,112	56,832	7,303
Rozenburg	62,415	7,665	563,560	247,470	11,680	2,920	51,465	6,935
Retranchement	61,814	7,423	561,821	282,788	5,491	2,207	39,867	7,420
Ter Apel	60,955	8,030	700,435	352,225	6,363	544	58,114	7,034
Winsum	60,123	8,599	670,477	298,928	12,957	2,733	113,737	20,498
Halsteren	59,222	7,131	706,620	272,905	7,809	849	50,159	9,834
Haaften	58,713	9,122	680,343	271,664	6,927	1,328	49,316	8,387
Workum	57,499	9,290	591,551	284,531	5,451	1,465	39,849	2,596
Tubbergen	55,768	8,877	731,114	235,370	12,473	3,323	52,046	3,407
Camperland polder	55,521	6,315	420,914	193,872	5,827	709	39,998	4,904
Tholen	55,075	6,693	531,554	255,661	6,900	434	35,101	4,795
Gaarkeuken	54,942	7,657	619,513	282,696	9,619	1,404	58,718	5,838
Aalsmeer	54,650	6,552	628,408	302,915	12,403	788	44,104	6,512
Mastgat	53,029	6,508	476,002	211,540	11,933	796	49,641	8,880
Hessenpoort	52,393	7,103	562,100	206,821	5,734	626	40,247	3,895
Dinxperlo	50,678	5,980	479,998	183,021	5,192	1,009	29,299	1,848
St.Annaparochie	49,707	7,004	481,348	193,233	8,251	2,646	46,258	4,375
Ameland	49,586	6,631	470,755	183,971	3,819	1,227	39,208	2,941
Wieringermeer	49,107	6,158	411,689	159,686	10,860	2,227	41,883	7,351
Terschelling	48,809	6,871	543,837	251,364	6,143	1,249	35,832	2,809
Oostburg	48,718	6,837	435,728	220,743	15,877	5,233	76,021	21,144

Oude Pekela	47,815	5,840	508,445	223,745	4,203	528	46,461	4,194
Ootmarsum	47,655	6,917	585,874	244,456	5,886	887	29,258	2,672
Onderdendam	46,975	6,721	548,098	250,998	9,467	1,143	51,231	7,017
Aalst	46,401	7,424	423,810	163,339	9,088	2,137	35,134	3,915
Breskens	44,912	5,637	462,462	232,595	9,224	4,115	38,290	6,393
Smilde	44,895	5,611	433,100	174,033	3,817	373	29,179	2,549
Ruurlo	44,466	5,916	468,140	178,757	3,836	288	22,176	1,725
Uithuizermeeden	44,211	6,090	550,831	246,947	6,046	462	32,911	2,936
Simpelveld	44,041	4,642	393,531	162,362	7,929	389	31,247	4,413
Wijk en Aalburg	43,659	6,045	433,005	198,466	6,533	1,461	26,279	3,127
Oude Tonge	43,435	5,840	451,870	189,800	8,395	1,460	33,580	4,015
Eck en Wiel	42,644	5,519	442,000	197,387	5,821	902	26,734	3,671
Loenen	42,186	5,579	392,349	170,138	5,928	2,412	30,730	5,488
Glanerbrug	41,686	6,634	541,055	182,621	3,770	218	31,926	2,348
Valburg	41,465	6,770	430,497	172,846	6,777	2,019	29,013	5,312
Strijen	39,785	4,745	442,015	209,875	1,460	88	20,075	1,460
Wieringen	39,093	4,982	332,809	152,559	8,575	1,230	31,435	3,861
Riel	36,732	5,020	432,438	225,685	3,109	616	27,032	3,762
Waspik	36,057	7,070	579,145	222,147	3,157	417	36,611	3,022
Millingen	34,630	4,748	198,700	58,956	4,737	768	23,839	2,801
Zetten	34,580	4,518	403,473	166,566	7,415	1,848	26,985	5,393
Heenvliet	34,310	4,015	250,755	107,675	4,015	1,095	22,995	2,555
Dussen	34,016	6,279	360,130	147,960	3,735	1,085	17,697	2,138
Meijel	33,867	4,701	380,930	165,013	3,718	277	21,827	2,800
Warns	33,770	4,405	315,507	134,486	2,852	478	19,476	1,054
Beesd	33,323	4,568	342,828	134,164	2,671	556	15,990	1,858
Akkrum	32,006	4,240	266,227	102,399	2,851	659	22,370	1,039
Dreumel	31,814	4,044	316,149	136,183	3,758	868	25,618	3,603

Wehl	31,767	4,359	373,811	157,164	3,747	252	14,523	1,566
Heino	31,574	4,544	292,302	117,310	2,460	207	11,804	819
Zuidhorn 1	31,552	5,164	362,546	164,380	4,748	445	23,506	1,775
Lienden	31,411	4,370	356,046	148,728	3,815	540	19,151	2,281
Marum	30,843	4,860	463,190	224,194	6,397	711	32,952	3,613
Bergambacht	30,657	3,884	327,041	147,506	2,983	760	27,456	2,355
Lage Zwaluwe	29,901	4,025	427,019	172,348	4,168	617	29,971	4,531
Tweede Exloermond	29,565	4,015	356,605	161,695	3,887	368	36,553	5,229
Ulrum	29,362	4,294	355,156	158,445	3,596	884	26,568	2,086
Kloosterzande	29,142	3,707	242,003	107,775	5,110	494	22,661	3,729
Vriescheloo	28,470	4,015	313,170	139,795	2,876	391	26,035	2,877
Overasselt	28,351	3,880	381,430	172,104	2,197	665	12,113	1,735
Stolwijk	28,263	3,771	283,283	136,322	2,118	106	17,740	1,550
Chaam	28,255	4,014	308,987	151,406	2,498	156	14,366	2,021
Bergharen	27,615	3,599	321,448	136,914	2,746	518	17,343	2,504
Dinteloord	27,249	4,251	296,908	122,557	4,643	445	23,118	3,041
Vollenhove	27,248	3,329	271,000	106,016	2,474	305	12,775	1,010
Leimuiden	27,082	4,417	293,294	131,424	1,950	126	14,500	1,067
Ossendrecht	26,999	3,342	433,905	217,734	3,168	367	19,848	4,366
Oosthuizen	26,724	3,919	346,079	167,988	3,540	586	20,139	2,011
Asperen	26,623	3,579	282,472	97,134	2,560	692	14,225	1,596
Den Ham	24,573	3,929	270,940	97,117	2,324	690	14,458	1,019
Piershil	22,630	2,920	221,920	91,250	4,015	1,095	17,520	2,555
Scheve Klap	22,265	3,285	204,035	83,585	2,563	884	22,694	1,777
Haastrecht	22,212	2,766	228,328	105,906	1,555	570	14,060	1,274
Willemstad	20,826	3,359	233,302	80,391	2,972	926	12,548	1,611
Putte	20,417	2,277	236,468	92,219	2,525	240	18,090	2,972

Zuidhorn 2	19,463	3,158	270,465	118,078	3,511	847	20,923	2,716
Bellingwolde	19,345	2,555	204,035	90,155	2,052	226	19,276	1,631
Eethen	18,977	2,538	187,915	91,367	2,718	970	10,137	1,225
Groede	17,836	2,331	143,766	66,887	3,358	1,807	13,045	2,266
Wehe den Hoorn	17,470	2,810	220,428	96,804	4,108	731	18,845	2,534
Rijsenhout	16,683	2,247	132,672	36,058	3,376	67	7,357	671
Maasbommel	15,516	1,927	136,420	61,459	1,387	195	7,423	901
Schiermonnikoog	14,470	2,325	175,515	60,279	1,146	535	12,267	893
Vlieland	13,489	1,863	122,731	53,905	734	278	5,695	297
Ooltgensplaat	12,045	1,460	91,250	34,675	1,825	365	7,665	730
Den Bommel	12,045	1,460	101,470	41,610	2,190	365	9,125	1,825
Feerwerd	10,483	1,742	125,886	54,444	2,105	221	11,275	1,050
Berkenwoude	9,560	1,618	141,711	73,126	611	146	6,938	621
Nieuw-Vossemeer	9,441	1,127	91,699	39,891	1,348	71	6,081	871
Ammerstol	9,296	1,406	82,609	34,273	1,101	344	7,100	784
Rijnsaterwoude	3,835	807	51,952	13,264	355	13	1,341	87

B 2: The removal efficiency of N, P, COD and BOD at WWTPs in the Netherlands

Dutch WWTPs	N removal efficiency rate %	P removal efficiency rate%	COD removal efficiency rate%	BOD removal efficiency rate%
Harnaschpolder	86	92	94	99
Amsterdam West	88	89	93	98
Eindhoven	85	94	94	98
Dokhaven	57	75	91	96
Bath	79	75	89	98
Utrecht	88	95	95	99
Tilburg	87	94	94	99
Westpoort	88	92	93	98
Venlo	82	96	91	98
Nieuwveer	78	78	94	98
Houtrust	78	88	94	99
Nijmegen	80	79	95	98
Dordrecht	89	95	91	99
Kralingseveer	82	76	90	98
Apeldoorn	78	77	92	98
Aarle-Rixtel	87	90	93	98
Garmerwolde	77	94	90	97
’s-Hertogenbosch	81	92	94	98
Wervershoof	92	96	94	98
de Groote Lucht	74	54	90	97
Almere	93	93	96	99
Amersfoort	86	93	95	99
Dinther	90	94	94	99
Enschede-West	88	92	95	99
Zutphen	98	98	96	100
Nieuwgraaf	85	81	96	99
Beverwijk	82	78	87	95

Ede	89	96	94	99
Oijen	91	83	94	99
Susteren	85	88	94	98
Haarlem Waarderpolder	87	77	94	98
Hoensbroek	86	91	91	97
Geestmerambacht	84	91	94	99
Harderwijk	86	93	95	99
Roermond	75	92	89	96
Arnhem	86	91	96	99
Hengelo	77	91	89	98
Katwijk	83	83	94	98
Leeuwarden	90	88	92	98
Zwaanshoek	89	80	92	98
Walcheren	77	83	89	96
Emmen	94	98	98	99
Zwijndrecht	92	90	93	98
Zwolle	80	74	94	99
Tollebeek	91	95	97	99
Land van Cuijk	86	89	92	98
Etten	87	90	95	99
Nieuwegein	82	81	94	99
Heerenveen	90	86	88	98
Horstermeer	94	97	95	99
Zwanenburg	91	94	95	98
Amstelveen	73	86	92	98
Dongemond	72	87	93	97
Limmel	81	86	93	98
Echten	86	91	94	99
Beemster	87	89	92	98

Leiden Zuid-West	86	84	90	97
Deventer	84	90	94	99
Zaandam Oost	81	92	92	98
Olburgen	85	64	94	98
Spijkenisse	95	88	96	99
Kortenoord	90	94	94	99
Weert	72	80	92	94
Hellevoetsluis	91	89	93	98
Elburg	91	93	95	99
Lelystad	94	96	95	99
Willem Annapolder	71	86	89	96
Nieuwe Waterweg	82	54	91	98
Leiden Noord	89	91	92	98
Gouda	90	95	93	98
Veenendaal	93	96	96	99
Tiel	87	86	96	99
Velsen	76	68	94	98
Drachten	86	93	91	98
Almelo-Sumpel	91	94	95	99
Sint-Oedenrode	91	94	94	98
Nijkerk	89	95	95	99
Assen	83	84	92	97
Bosscherveld	94	83	96	99
Renkum	81	51	94	98
Meppel	92	90	95	99
Winterswijk	90	95	94	98
Noordwijk	92	91	94	99
Hoogvliet	67	88	90	97
Boxtel	83	92	94	98

Zeist	85	95	97	99
Leidsche Rijn	90	94	95	99
Soest	86	92	96	99
Terneuzen	78	71	85	94
Zaltbommel	86	85	93	97
Katwoude	83	76	92	98
Ridderkerk	89	80	94	99
Venray	91	98	94	99
Rijen	89	90	94	98
Alkmaar	80	83	91	98
Oldenzaal	88	90	96	99
Hilversum	90	94	96	99
Houten	94	93	95	99
Haarlem Schalkwijk	91	80	92	98
Haarlo	94	98	96	99
Schelluinen	94	80	94	98
Woerden	82	86	91	97
Kampen	87	93	94	98
Nijverdal	89	57	88	98
De Bilt	88	94	95	99
Biest-Houtakker	84	93	91	98
Kaatsheuvel	94	93	96	99
Alphen Kerk en Zanen	94	96	94	99
Alphen Noord	95	97	94	99
Eelde	86	81	92	98
De Groote Zaag	87	92	90	98
Groenedijk	94	89	92	99
Almelo-Vissedijk	86	69	94	99
Vinkel	91	88	93	99

Huizen	90	98	96	99
Gennep	85	81	92	97
Dronten	88	93	97	99
Waalwijk	82	66	91	98
Steenwijk	93	95	95	99
Asten	92	92	94	99
Dedemsvaart	90	97	94	99
Hapert	89	96	93	98
Waddinxveen-Randenburg	93	96	93	98
Sneek	88	87	91	99
Heugem	87	84	92	98
Terwolde	66	76	91	98
Hattem	93	69	95	99
Veendam	85	70	88	97
Stolpen	79	68	91	97
Den Helder	81	77	89	96
Kaffeberg	94	96	96	99
Beilen	89	92	95	99
Culemborg	85	58	93	98
Uithoorn	83	92	92	98
Raalte	93	97	95	99
Maarssenbroek	94	82	97	99
Hardenberg	90	90	93	99
Barendrecht	88	95	94	98
Sliedrecht	84	95	93	98
Haaren	86	94	93	98
Heiloo	84	76	91	98
Scheemda	83	77	89	96
Ronde Venen	89	94	92	99

Bodegraven	94	96	95	99
Sleeuwijk	78	81	93	97
Ursem	85	95	92	98
Driebergen	92	94	96	98
Alblasserdam	84	82	92	98
Rhenen	90	93	96	99
Haaksbergen	93	91	95	99
Rijssen	92	94	95	99
Papendrecht	89	89	90	96
Wijlre	77	91	93	97
Coevorden	88	93	95	99
Rimburg	92	93	95	99
Bolsward	85	84	93	99
Panheel	56	27	91	94
Woudenberg	90	96	95	99
Franeker	73	77	89	96
Oud Beijerland	94	96	95	99
Goor	87	94	95	99
Geldermalsen	87	91	94	98
Gieten	84	92	91	97
Druten	83	66	92	96
Blaricum	92	92	94	99
De Meern	83	83	94	98
Burgum	92	85	90	98
Oosterwolde	91	91	94	99
Harlingen	93	86	94	99
Delfzijl	88	74	91	98
Groot-Ammers	80	70	94	99
Weesp	28	86	87	95

Stadskanaal	85	89	90	98
Wolvega	89	82	92	99
Leerdam	87	96	96	99
Foxhol	88	88	91	98
Lisse	91	91	95	99
Joure	94	97	92	99
Zeewolde	93	95	96	99
Oostvoorne	91	84	93	99
Vianen	91	81	94	99
Nieuwveen	94	96	93	99
Everstekoog	92	95	93	98
Kootstertille	91	90	92	99
Lichtenvoorde	93	77	94	99
Waarde	85	92	92	98
Dalfsen	91	94	94	99
Heemstede	73	91	94	97
Epe	94	98	97	100
Dokkum	86	82	90	98
Middelharnis	95	96	95	99
Gendt	80	71	91	96
Stein	45	81	88	93
Genemuiden	88	97	94	99
Wijk bij Duurstede	87	94	94	98
Holten	87	79	94	98
Sleen	86	91	94	98
Brummen	90	96	95	99
Dodewaard	74	78	95	98
Groesbeek	89	92	94	98
Goedereede	96	97	95	99

Breukelen	88	96	94	99
Dieverbrug	88	92	94	99
Aalten	91	87	95	98
Soerendonk	89	96	94	98
Hoogezand	92	93	93	98
Leek	90	86	93	99
Bunnik	89	94	96	99
Gorredijk	89	89	92	98
Birdaard	85	71	90	97
Westerschouwen	86	79	89	97
Losser	93	90	94	99
De Verseput	91	94	93	98
Olst-Wijhe	91	89	96	99
Grou	94	97	95	99
Nieuwe Wetering	92	96	95	99
Gorinchem	92	72	95	99
Damwoude	86	87	91	99
Heerde	90	91	95	99
Ommen	92	93	95	99
Lemmer	94	93	93	99
Hulst	87	66	88	97
Vroomshoop	89	89	93	98
Maarssen	88	94	93	98
Lopik	89	91	94	99
Varsseveld	86	90	93	98
Denekamp	94	94	97	99
Montfoort	87	86	93	98
Numansdorp	90	92	94	98
Bennekom	92	97	96	99

Baarle-Nassau	89	94	95	99
Sint Maartensdijk	86	86	92	98
Hardinxveld De Peulen	84	58	90	97
Oudewater	91	93	93	98
Sloten	88	90	93	99
Vriezenveen	79	66	94	98
Rozenburg	81	62	91	97
Retranchement	91	70	93	97
Ter Apel	90	93	92	98
Winsum	78	68	83	93
Halsteren	87	88	93	96
Haaften	88	85	93	97
Workum	91	84	93	99
Tubbergen	78	63	93	99
Camperlandpolder	90	89	90	97
Tholen	87	94	93	98
Gaarkeuken	82	82	91	98
Aalsmeer	77	88	93	98
Mastgat	77	88	90	96
Hessenpoort	89	91	93	98
Dinxperlo	90	83	94	99
St.Annaparochie	83	62	90	98
Ameland	92	81	92	98
Wieringermeer	78	64	90	95
Terschelling	87	82	93	99
Oostburg	67	23	83	90
Oude Pekela	91	91	91	98
Ootmarsum	88	87	95	99
Onderdendam	80	83	91	97

Aalst	80	71	92	98
Breskens	79	27	92	97
Smilde	91	93	93	99
Ruurlo	91	95	95	99
Uithuizermeeden	86	92	94	99
Simpelveld	82	92	92	97
Wijk en Aalburg	85	76	94	98
Oude Tonge	81	75	93	98
Eck en Wiel	86	84	94	98
Loenen	86	57	92	97
Glanerbrug	91	97	94	99
Valburg	84	70	93	97
Strijen	96	98	95	99
Wieringen	78	75	91	97
Riel	92	88	94	98
Waspik	91	94	94	99
Millingen	86	84	88	95
Zetten	79	59	93	97
Heenvliet	88	73	91	98
Dussen	89	83	95	99
Meijel	89	94	94	98
Warns	92	89	94	99
Beesd	92	88	95	99
Akkrum	91	84	92	99
Dreumel	88	79	92	97
Wehl	88	94	96	99
Heino	92	95	96	99
Zuidhorn 1	85	91	94	99
Lienden	88	88	95	98

Marum	79	85	93	98
Bergambacht	90	80	92	98
Lage Zwaluwe	86	85	93	97
Tweede Exloermond	87	91	90	97
Ulrum	88	79	93	99
Kloosterzande	82	87	91	97
Vriescheloo	90	90	92	98
Overasselt	92	83	97	99
Stolwijk	93	97	94	99
Chaam	91	96	95	99
Bergharen	90	86	95	98
Dinteloord	83	90	92	98
Vollenhove	91	91	95	99
Leimuiden	93	97	95	99
Ossendrecht	88	89	95	98
Oosthuizen	87	85	94	99
Asperen	90	81	95	98
Den Ham	91	82	95	99
Piershil	82	63	92	97
Scheve Klap	88	73	89	98
Haastrecht	93	79	94	99
Willemstad	86	72	95	98
Putte	88	89	92	97
Zuidhorn 2	82	73	92	98
Bellingwolde	89	91	91	98
Eethen	86	62	95	99
Groede	81	22	91	97
Wehe den Hoorn	76	74	91	97
Rijsenhout	80	97	94	98

Maasbommel	91	90	95	99
Schiermonnikoog	92	77	93	99
Vlieland	95	85	95	99
Ooltgensplaat	85	75	92	98
Den Bommel	82	75	91	96
Feerwerd	80	87	91	98
Berkenwoude	94	91	95	99
Nieuw-Vossemeer	86	94	93	98
Ammerstol	88	76	91	98
Rijnsaterwoude	91	98	97	99

Appendix C: Size of Dutch WWTPs

Dutch WWTP	**Total amount of waste water supplied [m3] [2018]**	**Scale**	**Cost €/m^3**	**Energy consumption GJ/m^3**
Berkenwoude	150,875	small	1.24	6.81
Rijnsaterwoude	179,620	small	0.56	1.6
Vlieland	180,004	small	1.71	11.38
Rijsenhout	211,282	small	4.41	4.5
Nieuw-Vossemeer	227,133	small	0.87	5.63
Maasbommel	242,774	small	0.95	10.96
Ammerstol	247,387	small	0.40	3.07
Schiermonnikoog	297,786	small	0.93	6.24
Eethen	299,792	small	0.46	7.89
Den Bommel	308,236	small	1.78	4.53
Ooltgensplaat	308,703	small	0.93	4.03
Groede	317,926	small	0.44	4.58
Feerwerd	331,079	small	0.22	3.43

Putte	364,531	small	0.91	5.65
Haastrecht	382,695	small	0.30	3.48
Oosthuizen	393,561	small	0.42	4.48
Willemstad	406,418	small	0.41	3.96
Bellingwolde	437,004	small	1.03	5.83
Bergharen	444,658	small	0.30	4.81
Overasselt	463,831	small	0.34	4.37
Vollenhove	472,796	small	0.64	8.15
Chaam	484,246	small	0.77	5.52
Zuidhorn 2	485,885	small	0.31	0
Wehe den Hoorn	488,483	small	0.14	4.34
Meijel	500,544	small	0.64	3.91
Leimuiden	512,208	small	0.43	4.59
Wehl	514,365	small	6.54	6.35
Asperen	517,552	small	0.22	3.2
Stolwijk	523,516	small	0.75	4.78
Piershil	531,387	small	0.58	4.73
Zetten	542,200	small	0.28	4.56
Heino	551,503	small	0.59	6.14
Ossendrecht	559,934	small	0.77	4.26
Akkrum	567,058	small	0.66	4.49
Vriescheloo	582,218	small	0.81	4.08
Riel	600,255	small	0.73	5.023
Lienden	600,975	small	0.33	5.11
Dreumel	612,887	small	0.28	4.17
Ulrum	622,386	small	0.47	5.6
Warns	625,522	small	0.43	4.07
Dussen	631,852	small	0.04	3.27
Lage Zwaluwe	632,949	small	0.29	4.79

Tweede Exloermond	634,632	small	0.90	4.05
Zuidhorn 1	636,840	small	0.36	4.03
Beesd	642,778	small	0.154	3.81
Ruurlo	660,413	small	0.69	6.9
Scheve Klap	720,081	small	0.33	2.74
Marum	733,624	small	0.17	3.74
Terschelling	736,710	small	0.71	7.43
Ameland	741,096	small	0.68	6.39
Loenen	743,720	small	0.35	3.9
Dinteloord	748,617	small	0.42	4.04
Wijk en Aalburg	751,082	small	0.06	4.45
Valburg	775,928	small	0.25	3.59
Millingen	795,884	small	0.23	4.62
Smilde	796,838	small	0.63	5.21
Bergambacht	806,328	small	0.38	2.84
Wieringen	808,380	small	0.28	4.23
Heenvliet	809,244	small	0.24	3.92
Kloosterzande	849,764	small	0.25	2.92
Eck en Wiel	891,262	small	0.20	4.26
Baarle-Nassau	935,477	small	0.51	4.77
Wieringermeer	944,052	small	0.56	3.91
Strijen	975,150	small	0.84	3.87
Aalsmeer	976,425	small	0.48	3.55
Halsteren	1,002,408	small	0.63	3.37
Breskens	1,016,654	small	0.43	5.23
Tholen	1,028,562	small	0.26	3.52
Waspik	1,034,746	small	0.34	2.99
Oude Tonge	1,036,848	small	0.43	4.14
Oude Pekela	1,062,647	small	0.52	3.01

Bennekom	1,078,656	small	0.45	4.93
Aalst	1,093,891	small	0.09	4.29
Sloten	1,109,505	small	0.48	5.29
Maarssen	1,129,862	small	1.12	7.45
Uithuizermeeden	1,131,581	small	0.59	4.6
Oudewater	1,136,356	small	0.52	3.62
Hessenpoort	1,137,788	small	0.43	3.26
Oostburg	1,148,840	small	0.28	5.09
St.Annaparochie	1,1751,22	small	0.21	3.07
Dinxperlo	1,176,930	small	0.80	4.09
Vriezenveen	1,183,738	small	0.81	4.08
Ter Apel	1,203,049	small	0.56	3.33
Haaften	1,203,127	small	0.20	4.99
Montfoort	1,208,060	small	0.38	4.51
Mastgat	1,219,135	small	0.18	3.29
Retranchement	1,228,812	small	0.48	4.04
Varsseveld	1,242,918	small	0.66	5.11
Lemmer	1,284,791	small	0.37	4.08
Onderdendam	1,315,742	small	0.11	3.74
Camperlandpolder	1,359,783	small	0.43	3.27
Hardinxveld De Peulen	1,378,090	small	0.35	4.97
Heerde	1,392,756	small	0.53	5.92
Gaarkeuken	1,412,120	small	0.09	3.05
Olst-Wijhe	1,435,688	small	0.34	6.52
Grou	1,518,447	small	0.34	4.18
Aalten	1,531,966	small	0.39	4.43
Winsum	1,560,663	small	0.11	3.37
Holten	1,564,996	small	0.73	9.29
Lopik	1,633,434	small	0.39	4.6

Nieuwe Wetering	1,638,209	small	0.18	3.3
Gorinchem	1,640,741	small	0.25	4.4
Workum	1,654,061	small	0.17	3.23
Sint Maartensdijk	1,665,601	small	0.35	3.57
Zeewolde	1,695,056	small	0.56	5.62
Numansdorp	1,711,172	small	0.59	3.93
Groesbeek	1,734,273	small	0.35	5.04
Breukelen	1,756,812	small	0.43	5.23
Dieverbrug	1,760,214	small	0.37	5.54
Sleen	1,761,675	small	0.33	2.34
Lichtenvoorde	1,810,570	small	0.46	5.14
Everstekoog	1,840,288	small	0.72	5.43
Brummen	1,846,022	small	0.47	5.63
Epe	1,851,725	small	0.82	6.3
De Verseput	1,853,452	small	0.58	4.73
Wijk bij Duurstede	1862484	small	0.46	5.19
Rozenburg	1,897,018	small	0.15	1.64
Bunnik	1,937,639	small	0.44	3.06
Dodewaard	1,950,844	small	0.14	3.41
Hulst	2,018,924	small	0.26	3.18
Gorredijk	2,034,771	small	0.37	4.47
Westerschouwen	2080575	small	0.33	3.29
Nieuwveen	2,088,730	small	0.54	4.76
Damwoude	2,089,645	small	0.28	4.61
Genemuiden	2,125,831	small	0.25	5.7
Lisse	2,133,110	small	0.69	4.07
Goedereede	2,175,826	small	0.44	4.58
Joure	2,178,182	small	0.27	3.73
Leek	2,205,035	small	0.35	2.97

Heemstede	2,244,240	small	0.41	3.43
Dalfsen	2,284,151	small	0.34	4.33
Birdaard	2,288,260	small	0.23	3.45
Oostvoorne	2,310,001	small	0.26	3.5
Gendt	2,340,608	small	0.21	4.13
Driebergen	2,485,340	small	0.38	4.99
Hoogezand	2,486,908	small	0.27	3.14
Panheel	2,511,219	small	0.29	3.66
Soerendonk	2,564,606	small	0.74	3.34
Oosterwolde	2,617,668	small	0.44	4.13
Stein	2,635,153	small	0.28	4.57
Vianen	2,644,012	small	0.28	5.34
Middelharnis	2,681,918	small	0.49	4.88
Terwolde	2,690,856	small	0.42	4.78
Geldermalsen	2,777,612	small	0.43	4.31
Gieten	2,802,489	small	0.32	4.22
Blaricum	2,832,024	small	0.31	3.15
Raalte	2,864,610	small	0.43	4.69
Groot-Ammers	2,874,165	small	0.20	4.02
Waarde	2,875,539	small	0.23	3.54
Woudenberg	2,930,354	small	0.31	4.42
Weesp	2,966,567	small	0.26	2.65
Burgum	3,007,271	small	0.30	4.84
Ursem	3,028,874	small	0.29	4.69
De Meern	3,033,418	small	0.17	3.32
Druten	3,056,868	small	0.23	3.51
Rimburg	3,099,837	small	0.31	4.08
Foxhol	3,172,473	small	0.30	3.25
Stadskanaal	3,192,966	small	0.29	3.3

Bolsward	3,193,993	small	0.24	3.17
Uithoorn	3,320,980	small	0.51	4.09
Stolpen	3,345,803	small	0.33	4.73
Dokkum	3,454,455	small	0.23	3.21
Harlingen	3,488,984	small	0.23	5.1
Den Helder	3,504,610	small	0.86	7.58
Kootstertille	3,521,064	small	0.23	4.04
Alblasserdam	3,544,302	small	0.34	2.86
Ronde Venen	3,584,283	small	0.80	4.77
Barendrecht	3,624,589	small	0.25	2.74
	1,208,060		0.38	4.25
Culemborg	3,793,099	medium	0.19	2.83
Franeker	3,805,230	medium	0.37	4.51
Kaffeberg	3,829,829	medium	0.30	4.59
Haarlo	3,837,220	medium	0.30	3.47
Kaatsheuvel	3,864,044	medium	0.25	4.71
Hilversum	3,941,892	medium	0.58	2.98
Houten	3,989,476	medium	0.20	4.8
Vinkel	3,996,659	medium	0.39	3.59
Almelo-Vissedijk	4,058,109	medium	6.73	2.76
Wijlre	4,102,473	medium	0.48	4.57
Alphen Kerk en Zanen	4,126,469	medium	0.21	3.99
Winterswijk	4,161,344	medium	0.35	4.5
Leidsche Rijn	4,163,132	medium	0.46	4.62
Waddinxveen-Randenburg	4,226,918	medium	0.33	3.37
Katwoude	4,236,901	medium	0.35	6.65
Biest-Houtakker	4,240,799	medium	0.43	3.48
Zeist	4,342,744	medium	0.34	3.8

Waalwijk	4,362,914	medium	0.25	3.67
Haarlem Schalkwijk	4,370,436	medium	0.16	3.97
Noordwijk	4,447,086	medium	0.70	4.15
Asten	4,615,388	medium	0.33	5.53
Scheemda	4,658,311	medium	0.34	4.46
Lelystad	4,700,188	medium	0.49	5.03
Rijen	4,754,400	medium	0.33	4.05
Veendam	4,878,184	medium	0.34	3.44
Bosscherveld	4,981,955	medium	0.39	4.6
Kampen	4,984,794	medium	0.30	3.18
Schelluinen	5,018,205	medium	0.62	4.55
Woerden	5,112,435	medium	0.34	3.36
Alkmaar	5,112,510	medium	0.39	6.1
Boxtel	5,244,853	medium	0.35	5.73
Groenedijk	5,303,230	medium	0.16	3.4
Venray	5,353,363	medium	0.46	4.15
Renkum	5,457,508	medium	0.30	4.77
Meppel	5,479,731	medium	0.47	4.52
De Groote Zaag	5,574,200	medium	0.22	2.41
Nijkerk	5,687,850	medium	0.36	3.71
Eelde	5,732,084	medium	0.10	3.67
Velsen	5,868,798	medium	0.72	4.44
Almelo-Sumpel	5,906,664	medium	6.73	2.76
Soest	5,936,400	medium	0.41	4.76
Zaltbommel	5,956,470	medium	0.25	5.15
Sint-Oedenrode	6,071,229	medium	0.29	3.68
Ridderkerk	6,273,243	medium	0.19	3.24
Tollebeek	6,382,235	medium	0.40	6.38
Zaandam Oost	6,417,996	medium	0.42	5.79

Elburg	6,480,012	medium	0.33	5.08
Terneuzen	6,686,920	medium	0.35	3.92
Tiel	6,878,234	medium	0.49	4.8
Hellevoetsluis	7,118,555	medium	0.42	3.32
Heerenveen	7,229,205	medium	0.53	2.86
Gouda	7,385,997	medium	0.32	3.11
Hoogvliet	7,450,260	medium	0.24	2.54
Zwolle	7,460,648	medium	0.55	6.47
Kortenoord	7,467,879	medium	0.29	5.6
Weert	7,556,016	medium	0.27	2.65
Spijkenisse	7,661,153	medium	0.19	4.05
Veenendaal	7,898,342	medium	0.30	3.89
Drachten	7,912,972	medium	0.29	3.16
Deventer	8,024,270	medium	0.45	5.9
Beemster	8,040,349	medium	0.33	5.039
Horstermeer	8,493,739	medium	0.56	4.84
Willem Annapolder	8,777,307	medium	0.23	3.42
Olburgen	8,809,852	medium	0.30	4.01
Nieuwegein	8,866,857	medium	0.37	4.58
Leiden Zuid-West	8,911,250	medium	0.52	4.2
Amstelveen	8,937,349	medium	0.43	2.91
Leiden Noord	8,960,568	medium	0.33	5.11
Nieuwe Waterweg	9,051,872	medium	0.18	3.3
Zwanenburg	9,119,716	medium	0.12	4
Echten	9,314,239	medium	0.46	7.89
Etten	9,646,884	medium	0.30	6.57
	5,687,850		0.34	4.10
Arnhem	10,270,281	large	0.55	4.5
Limmel	10,287,446	large	0.36	4.77

Zwaanshoek	10,696,800	large	0.49	2.69
Katwijk	11,015,580	large	0.32	3.24
Land van Cuijk	11,619,935	large	0.37	4.49
Almere	11,699,576	large	0.26	4.22
Zutphen	11,853,219	large	0.28	3.67
Harderwijk	11,922,689	large	0.35	4.97
Roermond	13,388,464	large	0.35	4.75
Walcheren	13,771,700	large	0.24	2.87
Ede	13,793,002	large	0.44	5.51
Leeuwarden	13,881,148	large	0.17	3.84
Amersfoort	14,213,950	large	0.57	6.62
Geestmerambacht	14,847,650	large	0.23	6.07
Wervershoof	15,407,583	large	0.22	5.01
Beverwijk	15,885,245	large	0.37	8.62
Dinther	16,377,324	large	0.29	3.48
Haarlem Waarderpolder	17,225,442	large	0.15	3.97
Nieuwgraaf	17,375,800	large	0.26	6.12
Dordrecht	17,577,512	large	0.26	2.12
Susteren	17,654,486	large	0.35	5.12
’s-Hertogenbosch	18,655,410	large	0.47	3.92
Oijen	18,975,085	large	0.22	3.64
Westpoort	21,145,467	large	0.26	2.79
Utrecht	21,218,920	large	0.44	6.61
Houtrust	22,253,675	large	0.43	6.62
Tilburg	22,573,898	large	0.47	5.67
Hoensbroek	22,796,429	large	0.20	3.74
Venlo	22,971,970	large	0.22	5.79
Aarle-Rixtel	23,018,262	large	0.26	2.44
Apeldoorn	24,022,192	large	0.36	3.26

Nijmegen	24,430,508	large	0.25	2.95
de Groote Lucht	24,622,330	large	0.19	3.59
Nieuwveer	25,464,500	large	0.31	5.7
Kralingseveer	30,395,355	large	0.19	2.41
Bath	36,334,830	large	0.27	4.23
Dokhaven	40,598,670	large	0.29	4.6
Eindhoven	53,195,102	large	0.15	2.49
Amsterdam West	60,357,405	large	0.54	4.11
Harnaschpolder	69,834,466	large	0.29	4.06
	17,615,999		0.29	4.00

Appendix D: Total costs and energy consumption of processing wastewater treatment

Dutch Wastewater Treatment Plant	**Total direct costs of processing wastewater [euro]2018**	**Energy consumption of wastewater treatment process per 1000 i.e removed [GJprim/1000 i.e. verwijderd]**
’s-Hertogenbosch	8,903,648	257.2
Aarle-Rixtel	6,154,573	158.4
Asten	1,526,830	460.6
Dinther	4,753,113	226.6
Land van Cuijk	4,332,416	340.9
Oijen	4,315,191	285.8
Vinkel	1,565,105	274.9
Amstelveen	3,885,977	240.5
Amsterdam West	32,948,783	270.2
Blaricum	894,317	242.5
Hilversum	2,296,350	184.8
Horstermeer	4,768,130	341.9
Huizen	1,610,746	321.4
Loenen	267,394	297.1

Maarssen	1,274,826	455.1
Ronde Venen	2,876,783	378.8
Uithoorn	1,684,239	328.5
Weesp	790,450	256.1
Westpoort	5,603,005	172.3
Baarle-Nassau	485,452	221.7
Bath	9,971,262	396.5
Chaam	374,649	352.9
Dinteloord	320,692	423
Dongemond	4,373,321	298.3
Halsteren	636,246	207.2
Kaatsheuvel	965,812	302.2
Lage Zwaluwe	188,361	313.4
Nieuwveer	8,099,191	432.1
Nieuw-Vossemeer	197,980	559.2
Ossendrecht	431,298	247.1
Putte	330,042	363.1
Riel	442,551	296.3
Rijen	1,573,627	237.1
Waalwijk	1,085,776	274.7
Waspik	352,485	243.7
Willemstad	169,699	284.4
de Groote Lucht	4,733,147	409.8
Harnaschpolder	34,812,769	298.4
Houtrust	9,736,662	456.4
Nieuwe Waterweg	1,674,533	320.8
Biest-Houtakker	1,816,500	271.3
Boxtel	1,843,300	416.7
Eindhoven	8,345,400	193.6

Haaren	1,077,700	375.3
Hapert	1,472,700	395.9
Sint-Oedenrode	1,735,800	251.8
Soerendonk	1,910,200	283.5
Tilburg	10,698,600	356.5
Akkrum	377,064	365
Ameland	509,454	401.2
Birdaard	535,304	357.2
Bolsward	765,614	224.4
Burgum	910,490	484
Damwoude	605,039	484.2
Dokkum	805,795	397.7
Drachten	2,264,909	279.5
Franeker	1,390,821	380.7
Gorredijk	760,288	385.1
Grou	518,191	236.7
Harlingen	795,203	516.2
Heerenveen	3,856,786	182.8
Joure	609,000	229.4
Kootstertille	820,823	464.8
Leeuwarden	2,368,115	318.2
Lemmer	476,878	279.4
Oosterwolde	1,165,203	264.2
Schiermonnikoog	276,102	450.9
Sloten	539,859	385.6
Sneek	1,012,909	279
St.Annaparochie	257,797	312.1
Terschelling	524,002	420.1
Vlieland	307,863	635.6

Warns	274,936	315.5
Wolvega	965,909	305.5
Workum	281,835	366.5
Dalfsen	791,566	320.8
Deventer	3,595,161	415.5
Genemuiden	539,324	410.1
Heino	327,607	441.2
Hessenpoort	493,084	272.3
Kampen	1,499,451	243.4
Olst-Wijhe	497,816	357.3
Raalte	1,257,833	246.6
Zwolle	4,103,668	308
Alkmaar	2,014,882	486.1
Beemster	2,654,796	367
Beverwijk	5,935,074	768.4
Den Helder	3,024,862	637.3
Everstekoog	1,339,123	320.9
Geestmerambacht	3,494,685	419.5
Heiloo	1,925,997	326.5
Katwoude	1,498,554	395.8
Oosthuizen	166,220	217.4
Stolpen	1,090,598	386.5
Ursem	871,023	352.3
Wervershoof	3,542,618	294.5
Wieringen	231,918	422.2
Wieringermeer	532,698	368
Zaandam Oost	272,1909	325.2
Barendrecht	916,327	233.3
Den Bommel	547,591	542.5

Dokhaven	12,065,814	448.9
Dordrecht	4,715,087	150.8
Goedereede	961,028	349.6
Heenvliet	197,636	462.4
Hellevoetsluis	2,964,787	315.2
Hoogvliet	1,753,422	244.4
Middelharnis	1,329,961	401.6
Numansdorp	1,018,780	412.1
Ooltgensplaat	285,821	507.2
Oostvoorne	614,593	276.3
Oud Beijerland	1,607,886	373.8
Oude Tonge	452,496	394
Piershil	312,188	462.4
Ridderkerk	1,171,642	297.5
Rozenburg	288,352	224.3
Spijkenisse	1,481,240	258.4
Strijen	823,248	345.4
Zwijndrecht	3,442,555	251.5
Assen	3,417,819	300.8
Bellingwolde	453,143	516
Foxhol	943,858	279.9
Gieten	906,368	286.6
Hoogezand	683,293	248.1
Oude Pekela	561,843	263.5
Scheemda	1,576,931	399.1
Scheve Klap	243,429	395.1
Stadskanaal	941,786	278.2
Ter Apel	678,314	244.6
Tweede Exloermond	575,145	319.2

Veendam	1,659,485	299.5
Vriescheloo	476,763	318
Delfzijl	736,530	333.5
Eelde	581,495	332.3
Feerwerd	73,886	401.9
Gaarkeuken	135,435	297.6
Garmerwolde	10,314,075	338.9
Leek	791,724	203.9
Marum	127,489	277
Onderdendam	155,434	390.6
Uithuizermeeden	674,479	403.6
Ulrum	294,123	419.8
Wehe den Hoorn	70,560	434.2
Winsum	183,197	363.4
Zuidhorn 1	229,610	301.3
Beilen	1583,310	333.5
Dieverbrug	655,618	399
Echten	4,320,539	562.6
Meppel	2,583,619	262.6
Smilde	507,141	379.1
Steenwijk	2,005,296	227.4
Vollenhove	307,213	556.5
Aalten	609,745	271.2
Dinxperlo	943,241	393.5
Etten	2,884,705	382.2
Haarlo	1,140,302	174.4
Holten	1,147,043	443.1
Lichtenvoorde	843,029	294.4
Nieuwgraaf	4,601,804	441

Olburgen	2,686,871	333.5
Ruurlo	459,225	390.6
Varsseveld	822,138	344.3
Wehl	335,683	361.7
Winterswijk	1,466,353	231.2
Zutphen	3,364,422	182
Aalsmeer	475,881	98
Alphen Kerk en Zanen	849,121	269.8
Alphen Noord	1,805,351	310.1
Bodegraven	635,003	282
Gouda	2,358,811	240.6
Haarlem Schalkwijk	683,247	284.5
Haarlem Waarderpolder	5,142,938	310
Heemstede	937,179	252.6
Hoogmade	22,932	
Katwijk	3,532,576	202.4
Leiden Noord	4,546,470	468
Leiden Zuid-West	4,644,289	376.7
Leimuiden	222,366	325.5
Lisse	1,481,945	254.8
Nieuwe Wetering	670,548	266.5
Nieuwveen	1,132,016	288.9
Noordwijk	3,123,150	248
Rijnsaterwoude	100,492	80.1
Rijsenhout	931,907	65.1
Velsen	4,234,759	274.2
Waddinxveen-Randenburg	**1,393,792**	264.8

Zwaanshoek	**5,246,546**	164.9
Zwanenburg	**1,100,027**	272.7
Aalst	**107,575**	444.8
Alblasserdam	**1,211,620**	242.8
Arnhem	**5,697,190**	267.4
Asperen	**118,463**	222.4
Beesd	**99,204**	270.5
Bergharen	**135,316**	249.4
Groesbeek	**611,667**	286.3
Culemborg	**703,229**	233.2
Dodewaard	**273,188**	215.1
Dreumel	**171,870**	276
Druten	**691,689**	301.9
Dussen	**30,784**	228.7
Eck en Wiel	**185,414**	354
Eethen	**25,988**	320.7
Geldermalsen	**1,216,371**	304.7
Gendt	**502,693**	304.4
Gorinchem	**418,328**	318.1
Groot-Ammers	**582,524**	334
Haaften	**249,828**	374.8
Hardinxveld De Peulen	**159,878**	209
Leerdam	**551,792**	156.9
Lienden	**200,385**	359.7
Maasbommel	**231,762**	633.1
Millingen	**183,698**	627.3
Nijmegen	**6,309,816**	206.2
Overasselt	**160,337**	248.8
Papendrecht	**956,485**	447

Schelluinen	**3,090,850**	375.2
Sleeuwijk	**2,038,949**	333.5
Sliedrecht	**347,453**	219.9
Tiel	**3,341,473**	302
Valburg	**196,031**	268.7
Vianen	**742,667**	436.8
Wijk en Aalburg	**49,760**	273.8
Zaltbommel	**1,494,246**	387.5
Zetten	**156,293**	280.9
Ammerstol	99,208	363.4
Bergambacht	306,742	292.5
Berkenwoude	187,171	319.3
De Groote Zaag	1,204,673	274.3
Groenedijk	837,409	358.1
Haastrecht	114,272	234.7
Kortenoord	2,169,079	375.6
Kralingseveer	5,883,205	265.9
Stolwijk	394,760	354.2
Breukelen	765,050	385.5
Bunnik	862,265	183
De Bilt	1,700,635	314.2
De Meern	502,664	270.9
Driebergen	961,278	217.8
Houten	806,030	339.3
Leidsche Rijn	1,907,962	247.9
Lopik	646,442	320.4
Maarssenbroek	357,908	219.1
Montfoort	471,080	279.2
Nieuwegein	3,307,730	332.2

Oudewater	599,938	195
Rhenen	846,830	303.9
Utrecht	9,468,221	363.4
Wijk bij Duurstede	868,333	325.9
Woerden	1,714,702	286.7
Zeist	1,460,970	207.8
Breskens	670,271	593
Camperlandpolder	587,590	393
De Verseput	1,087,853	386.6
Groede	105,832	427.5
Hulst	528,841	404.8
Kloosterzande	213,150	399.4
Mastgat	220,093	352.5
Oostburg	322,346	619.3
Retranchement	596,638	347.1
Sint Maartensdijk	595,213	404.6
Terneuzen	2,366,259	462.7
Tholen	269,713	270.9
Waarde	689,654	314.6
Walcheren	3,436,446	283.6
Westerschouwen	691,652	371.8
Willem Annapolder	2,036,065	351.3
Bosscherveld	1,960,384	272.8
Gennep	1,014,204	322.4
Heugem	1,062,736	488.8
Hoensbroek	4,644,767	440.2
Kaffeberg	1,144,071	314.1
Limmel	3,755,656	408.5

Meijel	324,898	212.5
Panheel	731,702	223.3
Rimburg	960,134	282.6
Roermond	4,812,811	347.8
Simpelveld	1,677,897	709.5
Stein	749,229	439.5
Susteren	6,230,084	363
Venlo	5,265,369	451.8
Venray	2,440,552	358.2
Weert	2,000,754	291.7
Wijlre	1,971,049	398
Almere	3,092,566	180.4
Dronten	2,910,335	290.6
Lelystad	2,310,415	206.6
Tollebeek	2,521,918	288.3
Zeewolde	966,170	217
Almelo-Vissedijk	27,307,278	187.8
Enschede-West	3,490,626	299.5
Hengelo	153,171	735.3
Amersfoort	8,182,158	343.4
Apeldoorn	8,650,057	267.7
Bennekom	4,951,69	280.4
Brummen	873,404	356.6
Ede	6,111,877	292.2
Elburg	2,113,194	281.4
Epe	1,523,074	342.8
Harderwijk	4,173,216	259.5
Hattem	738,980	315.3
Heerde	741,868	353.9

Nijkerk	2,038,385	219.3
Renkum	1,643,251	316.1
Soest	2,429,849	276
Terwolde	1,142,263	310.6
Veenendaal	2,357,472	271.8
Woudenberg	924,696	322.1

Appendix E: The cost and energy consumption per m^3 of treated wastewater

DutchWastewater Treatment Plant	Costs (euros per m^3)	Energy consumption (GJ per m^3)
’s-Hertogenbosch	0.477269	3.92
Aarle-Rixtel	0.267378	2.44
Asten	0.330813	5.53
Dinther	0.290225	3.48
Land van Cuijk	0.372843	4.49
Oijen	0.227414	3.64
Vinkel	0.391603	3.59
Amstelveen	0.434802	2.91
Amsterdam West	0.545895	4.11
Blaricum	0.315787	3.15
Hilversum	0.58255	2.98
Horstermeer	0.56137	4.84
Huizen	0.552476	5.96
Loenen	0.359536	3.90
Maarssen	1.128302	7.45
Ronde Venen	0.80261	4.77
Uithoorn	0.507151	4.09
Weesp	0.266453	2.65
Westpoort	0.264974	2.79
Baarle-Nassau	0.518935	4.77
Bath	0.274427	4.23
Chaam	0.773675	5.52
Dinteloord	0.428379	4.04
Dongemond	0.447828	4.44
Halsteren	0.634718	3.37
Kaatsheuvel	0.249948	4.71

Lage Zwaluwe	0.297593	4.79
Nieuwveer	0.318058	5.70
Nieuw-Vossemeer	0.871648	5.63
Ossendrecht	0.770266	4.26
Putte	0.905388	5.65
Riel	0.737272	5.023
Rijen	0.330983	4.05
Waalwijk	0.248865	3.67
Waspik	0.340649	2.99
Willemstad	0.417548	3.96
de Groote Lucht	0.19223	3.59
Harnaschpolder	0.498504	4.25
Houtrust	0.437531	6.62
Nieuwe Waterweg	0.184993	3.30
Biest-Houtakker	0.428339	3.48
Boxtel	0.351449	5.73
Eindhoven	0.156883	2.49
Haaren	0.296584	4.22
Hapert	0.349688	4.50
Sint-Oedenrode	0.285906	3.68
Soerendonk	0.744832	3.34
Tilburg	0.473937	5.67
Akkrum	0.664948	4.49
Ameland	0.687433	6.39
Birdaard	0.233935	3.45
Bolsward	0.239704	3.17
Burgum	0.302763	4.84
Damwoude	0.289542	4.61
Dokkum	0.233263	3.21

Drachten	0.286227	3.16
Franeker	0.365502	4.51
Gorredijk	0.373648	4.47
Grou	0.341264	4.18
Harlingen	0.227918	5.10
Heerenveen	0.533501	2.86
Joure	0.279591	3.73
Kootstertille	0.233118	4.04
Leeuwarden	0.170599	3.84
Lemmer	0.371172	4.08
Oosterwolde	0.44513	4.13
Schiermonnikoog	0.927183	6.24
Sloten	0.486576	5.29
Sneek	0.226361	3.01
St.Annaparochie	0.219379	3.07
Terschelling	0.711273	7.43
Vlieland	1.710312	11.38
Warns	0.439531	4.07
Wolvega	#DIV/0!	4.11
Workum	0.17039	3.23
Dalfsen	0.346547	4.33
Deventer	0.448036	5.90
Genemuiden	0.2537	5.70
Heino	0.594026	6.14
Hessenpoort	0.433371	3.26
Kampen	0.300805	3.18
Olst-Wijhe	0.346744	6.52
Raalte	0.439094	4.69
Zwolle	0.550042	6.47

Alkmaar	0.394108	6.10
Beemster	0.330184	5.039
Beverwijk	0.373622	8.62
Den Helder	0.863109	7.58
Everstekoog	0.72767	5.43
Geestmerambacht	0.23537	6.07
Heiloo	0.502304	3.50
Katwoude	0.353691	6.65
Oosthuizen	0.422349	4.48
Stolpen	0.32596	4.73
Ursem	0.287573	4.69
Wervershoof	0.229927	5.01
Wieringen	0.286892	4.23
Wieringermeer	0.564268	3.91
Zaandam Oost	0.424106	5.79
Barendrecht	0.252809	2.74
Den Bommel	1.776532	4.53
Dokhaven	0.297197	4.60
Dordrecht	0.268245	2.12
Goedereede	0.441684	4.58
Heenvliet	0.244223	3.92
Hellevoetsluis	0.416487	3.32
Hoogvliet	0.23535	2.54
Middelharnis	0.495899	4.88
Numansdorp	0.59537	3.93
Ooltgensplaat	0.925877	4.03
Oostvoorne	0.266057	3.50
Oud Beijerland	0.391709	3.92
Oude Tonge	0.436415	4.14

Piershil	0.587496	4.73
Ridderkerk	0.186768	3.24
Rozenburg	0.152003	1.64
Spijkenisse	0.193344	4.05
Strijen	0.844227	3.87
Zwijndrecht	0.253739	2.65
Assen	0.54605	4.31
Bellingwolde	1.036931	5.83
Foxhol	0.297515	3.25
Gieten	0.323415	4.22
Hoogezand	0.274756	3.14
Oude Pekela	0.52872	3.01
Scheemda	0.33852	4.46
Scheve Klap	0.338058	2.74
Stadskanaal	0.294956	3.30
Ter Apel	0.563829	3.33
Tweede Exloermond	0.906265	4.05
Veendam	0.340185	3.44
Vriescheloo	0.818874	4.08
Delfzijl	0.177688	3.12
Eelde	0.101446	3.67
Feerwerd	0.223167	3.43
Gaarkeuken	0.095909	3.05
Garmerwolde	0.387657	3.80
Leek	0.359053	2.97
Marum	0.17378	3.74
Onderdendam	0.118134	3.74
Uithuizermeeden	0.59605	4.60
Ulrum	0.472573	5.60

Wehe den Hoorn	0.144447	4.34
Winsum	0.117384	3.37
Zuidhorn 1	0.360546	4.03
Zuidhorn 2	0.315035	0
Beilen	0.464588	5.60
Dieverbrug	0.372465	5.54
Echten	0.463864	7.89
Meppel	0.471486	4.52
Smilde	0.636442	5.21
Steenwijk	0.6704	4.31
Vollenhove	0.649779	8.15
Aalten	0.398015	4.43
Dinxperlo	0.801442	4.09
Etten	0.29903	6.57
Haarlo	0.297169	3.47
Holten	0.732937	9.29
Lichtenvoorde	0.465615	5.14
Nieuwgraaf	0.26484	6.12
Olburgen	0.304985	4.01
Ruurlo	0.69536	6.90
Varsseveld	0.661458	5.11
Wehl	6.540923	6.35
Winterswijk	0.352375	4.50
Zutphen	0.28384	3.67
Aalsmeer	0.487371	3.55
Alphen Kerk en Zanen	0.205774	3.99
Alphen Noord	0.558043	5.61
Bodegraven	0.182391	4.63
Gouda	0.319363	3.11

Haarlem Schalkwijk	0.156334	3.97
Haarlem Waarderpolder	0.298566	4.06
Heemstede	0.417593	3.43
Katwijk	0.320689	3.24
Leiden Noord	0.507386	5.25
Leiden Zuid-West	0.521171	4.20
Leimuiden	0.434132	4.59
Lisse	0.694734	4.07
Nieuwe Wetering	0.409318	4.16
Nieuwveen	0.541964	4.76
Noordwijk	0.702291	4.15
Rijnsaterwoude	0.55947	1.60
Rijsenhout	4.410726	4.50
Velsen	0.721572	4.44
Waddinxveen-Randenburg	0.329742	3.37
Zwaanshoek	0.490478	2.69
Zwanenburg	0.120621	4.00
Aalst	0.098342	4.29
Alblasserdam	0.34185	2.86
Arnhem	0.554726	4.50
Asperen	0.228891	3.20
Beesd	0.154336	3.81
Bergharen	0.304315	4.81
Groesbeek	0.352694	5.04
Culemborg	0.185397	2.83
Dodewaard	0.140036	3.41
Dreumel	0.280427	4.17
Druten	0.226274	3.51

Dussen	0.04872	3.27
Eck en Wiel	0.208035	4.26
Eethen	0.086687	5.03
Geldermalsen	0.43792	4.31
Gendt	0.21477	4.13
Gorinchem	0.254963	4.40
Groot-Ammers	0.202676	4.02
Haaften	0.207649	4.99
Hardinxveld De Peulen	0.116014	2.31
Leerdam	0.241746	3.05
Lienden	0.333433	5.11
Maasbommel	0.954641	10.96
Millingen	0.23081	4.62
Nijmegen	0.258276	2.95
Overasselt	0.34568	4.37
Papendrecht	0.233545	3.76
Schelluinen	0.615927	4.55
Sleeuwijk	0.332692	2.34
Sliedrecht	0.09682	2.67
Tiel	0.485804	4.80
Valburg	0.252641	3.59
Vianen	0.280886	5.34
Wijk en Aalburg	0.066251	4.45
Zaltbommel	0.250861	5.15
Zetten	0.288257	4.56
Ammerstol	0.401023	3.07
Bergambacht	0.380418	2.84
Berkenwoude	1.24057	6.81
De Groote Zaag	0.216116	2.41

Groenedijk	0.157905	3.40
Haastrecht	0.298598	3.48
Kortenoord	0.290454	5.60
Kralingseveer	0.193556	2.41
Stolwijk	0.754055	4.78
Breukelen	0.435476	5.23
Bunnik	0.445008	3.06
De Bilt	0.366331	4.32
De Meern	0.165709	3.32
Driebergen	0.386779	4.99
Houten	0.202039	4.80
Leidsche Rijn	0.4583	4.62
Lopik	0.395756	4.600
Maarssenbroek	0.125731	4.13
Montfoort	0.389948	4.51
Nieuwegein	0.373044	4.58
Oudewater	0.527949	3.62
Rhenen	0.331094	5.51
Utrecht	0.446216	6.61
Wijk bij Duurstede	0.466223	5.19
Woerden	0.335398	3.36
Zeist	0.336416	3.80
Camperlandpolder	0.43212	3.27
De Verseput	0.586933	4.73
Groede	0.332882	4.97
Hulst	0.261942	3.18
Kloosterzande	0.250834	2.92
Mastgat	0.180532	3.29
Oostburg	0.280584	5.09

Retranchement	0.485541	4.04
Sint Maartensdijk	0.357356	3.57
Terneuzen	0.353864	3.92
Tholen	0.262223	3.52
Waarde	0.239835	3.54
Walcheren	0.24953	2.87
Westerschouwen	0.332433	3.29
Willem Annapolder	0.231969	3.42
Bosscherveld	0.393497	4.60
Gennep	0.258239	3.65
Heugem	0.213098	3.33
Hoensbroek	0.20375	3.74
Kaffeberg	0.298726	4.59
Limmel	0.365072	4.77
Meijel	0.64909	3.91
Panheel	0.291373	3.66
Rimburg	0.309737	4.08
Roermond	0.359474	4.75
Simpelveld	1.451571	6.03
Stein	0.284321	4.57
Susteren	0.35289	5.12
Venlo	0.229208	5.79
Venray	0.455891	4.15
Weert	0.26479	4.60
Wijlre	0.480454	4.57
Almere	0.264331	4.22
Dronten	1.060802	6.07
Lelystad	0.491558	5.03
Tollebeek	0.395147	6.38

Zeewolde	0.569993	5.62
Almelo-Vissedijk	6.729065	2.76
Hengelo	0.012384	8.82
Amersfoort	0.575643	6.62
Apeldoorn	0.360086	3.26
Bennekom	0.459061	4.93
Brummen	0.473128	5.63
Ede	0.443114	5.51
Elburg	0.32611	5.08
Epe	0.822516	6.30
Harderwijk	0.350023	4.97
Hattem	0.206566	4.57
Heerde	0.532662	5.92
Nijkerk	0.358375	3.71
Renkum	0.301099	4.77
Soest	0.409314	4.76
Terwolde	0.424498	4.78
Veenendaal	0.298477	3.89
Woudenberg	0.315558	4.42

Appendix F: The WQI calculation

Calculation of N parameter

WWTPs	Si (N)	Ki	Wi=Ki/Si	Vi= mg N/lit	qi	N (qi × Wi)
’s-Hertogenbosch	10	0.04	0.004	10.63	108.29	0.43
Aalsmeer	15	0.04	0.003	12.7	81.75	0.22
Aalst	15	0.04	0.003	8.31	46.90	0.13
Aalten	15	0.04	0.003	5.58	25.24	0.07
Aarle-Rixtel	10	0.04	0.004	6.34	51.84	0.21
Akkrum	15	0.04	0.003	5.03	20.87	0.06
Alblasserdam	15	0.04	0.003	7.44	40.00	0.11
Alkmaar	15	0.04	0.003	10.71	65.95	0.18
Almelo-Sumpel	10	0.04	0.004	5.05	34.87	0.14
Almelo-Vissedijk	15	0.04	0.003	7.44	40.00	0.11
Almere	10	0.04	0.004	5.81	44.87	0.18
Alphen Kerk en Zanen	15	0.04	0.003	3.58	9.37	0.02
Alphen Noord	15	0.04	0.003	3.31	7.22	0.02
Ameland	15	0.04	0.003	5.15	21.83	0.06
Amersfoort	10	0.04	0.004	9.34	91.32	0.37
Ammerstol	15	0.04	0.003	4.45	16.27	0.04
Amstelveen	10	0.04	0.004	14.86	163.95	0.66
Amsterdam West	10	0.04	0.004	7.65	69.08	0.28
Apeldoorn	10	0.04	0.004	10.68	108.95	0.44
Arnhem	10	0.04	0.004	8.74	83.42	0.33
Asperen	15	0.04	0.003	4.95	20.24	0.05
Assen	15	0.04	0.003	8.79	50.71	0.14
Asten	15	0.04	0.003	3.57	9.29	0.02
Baarle-Nassau	15	0.04	0.003	8.07	45.00	0.12
Barendrecht	15	0.04	0.003	5.84	27.30	0.07

Bath	10	0.04	0.004	8.9	85.53	0.34
Beemster	10	0.04	0.004	7.68	69.47	0.28
Beesd	15	0.04	0.003	4.16	13.97	0.04
Beilen	15	0.04	0.003	6.08	29.21	0.08
Bellingwolde	15	0.04	0.003	4.7	18.25	0.05
Bennekom	15	0.04	0.003	5.32	23.17	0.06
Bergambacht	15	0.04	0.003	3.7	10.32	0.03
Bergharen	15	0.04	0.003	6.18	30.00	0.08
Berkenwoude	15	0.04	0.003	4.05	13.10	0.03
Beverwijk	10	0.04	0.004	10.17	102.24	0.41
Biest-Houtakker	15	0.04	0.003	8.76	50.48	0.13
Birdaard	15	0.04	0.003	6.13	29.60	0.08
Blaricum	15	0.04	0.003	4.11	13.57	0.04
Bodegraven	15	0.04	0.003	3.14	5.87	0.02
Bolsward	15	0.04	0.003	7.42	39.84	0.11
Bosscherveld	15	0.04	0.003	3.64	9.84	0.03
Boxtel	15	0.04	0.003	9.58	56.98	0.15
Breskens	15	0.04	0.003	9.07	52.94	0.14
Breukelen	15	0.04	0.003	6.71	34.21	0.09
Brummen	15	0.04	0.003	6.05	28.97	0.08
Bunnik	15	0.04	0.003	5.57	25.16	0.07
Burgum	15	0.04	0.003	3.82	11.27	0.03
Camperlandpolder	15	0.04	0.003	4.29	15.00	0.04
Chaam	15	0.04	0.003	5.16	21.90	0.06
Coevorden	15	0.04	0.003	6.65	33.73	0.09
Culemborg	15	0.04	0.003	7.54	40.79	0.11
Dalfsen	15	0.04	0.003	4.71	18.33	0.05
Damwoude	15	0.04	0.003	5.55	25.00	0.07
De Bilt	15	0.04	0.003	6.12	29.52	0.08

de Groote Lucht	10	0.04	0.004	10.09	101.18	0.40
De Groote Zaag	15	0.04	0.003	5.25	22.62	0.06
De Meern	15	0.04	0.003	7.86	43.33	0.12
De Verseput	15	0.04	0.003	4.47	16.43	0.04
Den Bommel	15	0.04	0.003	7.1	37.30	0.03
Den Ham	15	0.04	0.003	4.95	20.24	0.10
Den Helder	15	0.04	0.003	10.23	62.14	0.05
Denekamp	15	0.04	0.003	3.51	8.81	0.17
Deventer	10	0.04	0.004	8.59	81.45	0.02
Dieverbrug	15	0.04	0.003	6.97	36.27	0.33
Dinteloord	15	0.04	0.003	6.2	30.16	0.10
Dinther	10	0.04	0.004	5.61	42.24	0.08
Dinxperlo	15	0.04	0.003	4.41	15.95	0.17
Dodewaard	15	0.04	0.003	14.37	95.00	0.04
Dokhaven	10	0.04	0.004	18.92	217.37	0.25
Dokkum	15	0.04	0.003	5.03	20.87	0.87
Dongemond	10	0.04	0.004	14.03	153.03	0.06
Dordrecht	10	0.04	0.004	7.58	68.16	0.61
Drachten	15	0.04	0.003	6.24	30.48	0.27
Dreumel	15	0.04	0.003	6.13	29.60	0.08
Driebergen	15	0.04	0.003	5.39	23.73	0.08
Dronten	15	0.04	0.003	9.17	53.73	0.06
Druten	15	0.04	0.003	8	44.44	0.14
Dussen	15	0.04	0.003	5.91	27.86	0.12
Echten	10	0.04	0.004	7.3	64.47	0.07
Eck en Wiel	15	0.04	0.003	6.53	32.78	0.26
Ede	10	0.04	0.004	7.07	61.45	0.09
Eelde	15	0.04	0.003	5.61	25.48	0.25
Eethen	15	0.04	0.003	9.07	52.94	0.07

Eindhoven	10	0.04	0.004	7.73	70.13	0.14
Elburg	10	0.04	0.004	5.55	41.45	0.28
Emmen	10	0.04	0.004	3.53	14.87	0.17
Enschede-West	10	0.04	0.004	7.08	61.58	0.06
Epe	15	0.04	0.003	3.99	12.62	0.25
Etten	10	0.04	0.004	7.15	62.50	0.03
Everstekoog	15	0.04	0.003	5.63	25.63	0.25
Feerwerd	15	0.04	0.003	6.36	31.43	0.07
Foxhol	15	0.04	0.003	4.86	19.52	0.08
Franeker	15	0.04	0.003	10.6	65.08	0.05
Gaarkeuken	15	0.04	0.003	6.81	35.00	0.17
Garmerwolde	10	0.04	0.004	9.19	89.34	0.09
Geestmerambacht	10	0.04	0.004	8.37	78.55	0.36
Geldermalsen	15	0.04	0.003	7.16	37.78	0.31
Gendt	15	0.04	0.003	10.1	61.11	0.10
Genemuiden	15	0.04	0.003	6.5	32.54	0.16
Gennep	15	0.04	0.003	8.05	44.84	0.09
Gieten	15	0.04	0.003	8.52	48.57	0.12
Glanerbrug	15	0.04	0.003	4.4	15.87	0.13
Gorinchem	15	0.04	0.003	4.3	15.08	0.14
Gorredijk	15	0.04	0.003	5.14	21.75	0.04
Gouda	15	0.04	0.003	5.39	23.73	0.06
Groede	15	0.04	0.003	10.56	64.76	0.06
Groenedijk	15	0.04	0.003	2.68	2.22	0.17
Groesbeek	15	0.04	0.003	6.87	35.48	0.01
Groot-Ammers	15	0.04	0.003	9.28	54.60	0.09
Grou	15	0.04	0.003	3.48	8.57	0.15
Haaften	15	0.04	0.003	5.76	26.67	0.02
Haaksbergen	15	0.04	0.003	3.85	11.51	0.07

Haaren	15	0.04	0.003	6.64	33.65	0.03
Haarlem Schalkwijk	15	0.04	0.003	5.01	20.71	0.09
Haarlem Waarderpolder	10	0.04	0.004	5.95	46.71	0.06
Haarlo	15	0.04	0.003	3.97	12.46	0.19
Haastrecht	15	0.04	0.003	4.06	13.17	0.03
Halsteren	15	0.04	0.003	7.79	42.78	0.04
Hapert	15	0.04	0.003	5.13	21.67	0.11
Hardenberg	15	0.04	0.003	6.37	31.51	0.06
Harderwijk	10	0.04	0.004	8.53	80.66	0.08
Hardinxveld De Peulen	15	0.04	0.003	7.45	40.08	0.32
Harlingen	15	0.04	0.003	2.65	1.98	0.11
Harnaschpolder	10	0.04	0.004	7.91	72.50	0.01
Hattem	15	0.04	0.003	4.05	13.10	0.29
Heemstede	15	0.04	0.003	14.83	98.65	0.03
Heenvliet	15	0.04	0.003	4.96	20.32	0.26
Heerde	15	0.04	0.003	6.24	30.48	0.05
Heerenveen	10	0.04	0.004	6.77	57.50	0.08
Heiloo	15	0.04	0.003	7.07	37.06	0.23
Heino	15	0.04	0.003	4.46	16.35	0.10
Hellevoetsluis	15	0.04	0.003	5.28	22.86	0.04
Hengelo	10	0.04	0.004	12.13	128.03	0.06
Hessenpoort	15	0.04	0.003	5.04	20.95	0.51
Heugem	15	0.04	0.003	5.37	23.57	0.06
Hilversum	15	0.04	0.003	6.42	31.90	0.06
Hoensbroek	10	0.04	0.004	5.01	34.34	0.09
Holten	15	0.04	0.003	9.49	56.27	0.14
Hoogezand	15	0.04	0.003	3.02	4.92	0.15
Hoogvliet	15	0.04	0.003	13.37	87.06	0.01

Horstermeer	10	0.04	0.004	3.56	15.26	0.23
Houten	15	0.04	0.003	3.61	9.60	0.06
Houtrust	10	0.04	0.004	12.53	133.29	0.03
Huizen	15	0.04	0.003	7.07	37.06	0.53
Hulst	15	0.04	0.003	4.93	20.08	0.10
Joure	15	0.04	0.003	3.71	10.40	0.05
Kaatsheuvel	15	0.04	0.003	3.61	9.60	0.03
Kaffeberg	15	0.04	0.003	3.01	4.84	0.03
Kampen	15	0.04	0.003	6.35	31.35	0.01
Katwijk	10	0.04	0.004	9.92	98.95	0.08
Katwoude	15	0.04	0.003	11.14	69.37	0.40
Kloosterzande	15	0.04	0.003	6.01	28.65	0.18
Kootstertille	15	0.04	0.003	3.19	6.27	0.08
Kortenoord	10	0.04	0.004	5.7	43.42	0.02
Kralingseveer	10	0.04	0.004	7.33	64.87	0.17
Lage Zwaluwe	15	0.04	0.003	6.59	33.25	0.26
Land van Cuijk	10	0.04	0.004	7.01	60.66	0.09
Leek	15	0.04	0.003	4.61	17.54	0.24
Leerdam	15	0.04	0.003	7.34	39.21	0.05
Leeuwarden	10	0.04	0.004	4.75	30.92	0.10
Leiden Noord	10	0.04	0.004	4.74	30.79	0.12
Leiden Zuid-West	15	0.04	0.003	7.01	36.59	0.12
Leidsche Rijn	15	0.04	0.003	6.86	35.40	0.10
Leimuiden	15	0.04	0.003	3.81	11.19	0.09
Lelystad	10	0.04	0.004	5.29	38.03	0.03
Lemmer	15	0.04	0.003	3.77	10.87	0.15
Lichtenvoorde	15	0.04	0.003	5.1	21.43	0.03
Lienden	15	0.04	0.003	6.35	31.35	0.06
Limmel	10	0.04	0.004	9.04	87.37	0.08

Lisse	15	0.04	0.003	5.56	25.08	0.35
Loenen	15	0.04	0.003	7.97	44.21	0.07
Lopik	15	0.04	0.003	5.19	22.14	0.12
Losser	15	0.04	0.003	3.21	6.43	0.06
Maarssen	15	0.04	0.003	8.28	46.67	0.02
Maarssenbroek	15	0.04	0.003	3.63	9.76	0.12
Maasbommel	15	0.04	0.003	5.71	26.27	0.03
Marum	15	0.04	0.003	8.72	50.16	0.07
Mastgat	15	0.04	0.003	9.79	58.65	0.13
Meijel	15	0.04	0.003	7.43	39.92	0.16
Meppel	15	0.04	0.003	4.52	16.83	0.11
Middelharnis	15	0.04	0.003	2.45	0.40	0.04
Millingen	15	0.04	0.003	5.95	28.17	0.00
Montfoort	15	0.04	0.003	7.99	44.37	0.08
Nieuwe Waterweg	15	0.04	0.003	7.97	44.21	0.12
Nieuwe Wetering	15	0.04	0.003	4.57	17.22	0.12
Nieuwegein	10	0.04	0.004	10.22	102.89	0.05
Nieuwgraaf	10	0.04	0.004	7.66	69.21	0.41
Nieuwveen	15	0.04	0.003	3.7	10.32	0.28
Nieuwveer	10	0.04	0.004	10.97	112.76	0.03
Nieuw-Vossemeer	15	0.04	0.003	5.93	28.02	0.45
Nijkerk	15	0.04	0.003	6.56	33.02	0.07
Nijmegen	10	0.04	0.004	10.19	102.50	0.09
Nijverdal	15	0.04	0.003	6.48	32.38	0.41
Noordwijk	15	0.04	0.003	5.77	26.75	0.09
Numansdorp	15	0.04	0.003	4.27	14.84	0.07
Oijen	10	0.04	0.004	3.97	20.66	0.04
Olburgen	10	0.04	0.004	7.48	66.84	0.08
Oldenzaal	15	0.04	0.003	6.73	34.37	0.27

Olst-Wijhe	15	0.04	0.003	5.46	24.29	0.09
Ommen	15	0.04	0.003	5.34	23.33	0.06
Onderdendam	15	0.04	0.003	7.2	38.10	0.06
Ooltgensplaat	15	0.04	0.003	5.91	27.86	0.10
Oostburg	15	0.04	0.003	13.82	90.63	0.07
Oosterwolde	15	0.04	0.003	4.95	20.24	0.24
Oosthuizen	15	0.04	0.003	8.99	52.30	0.05
Oostvoorne	15	0.04	0.003	4.74	18.57	0.14
Ootmarsum	15	0.04	0.003	5.09	21.35	0.05
Ossendrecht	15	0.04	0.003	5.66	25.87	0.06
Oude Tonge	15	0.04	0.003	8.1	45.24	0.03
Oudewater	15	0.04	0.003	5.17	21.98	0.12
Overasselt	15	0.04	0.003	4.74	18.57	0.06
Panheel	15	0.04	0.003	26.92	194.60	0.05
Papendrecht	15	0.04	0.003	4.43	16.11	0.52
Piershil	15	0.04	0.003	7.56	40.95	0.04
Putte	15	0.04	0.003	6.93	35.95	0.11
Raalte	15	0.04	0.003	4.12	13.65	0.10
Renkum	15	0.04	0.003	11.39	71.35	0.04
Retranchement	15	0.04	0.003	4.47	16.43	0.19
Rhenen	15	0.04	0.003	6.56	33.02	0.04
Ridderkerk	15	0.04	0.003	4.95	20.24	0.09
Riel	15	0.04	0.003	5.18	22.06	0.05
Rijen	15	0.04	0.003	6.23	30.40	0.06
Rijssen	15	0.04	0.003	4.2	14.29	0.29
Rimburg	15	0.04	0.003	4.08	13.33	0.04
Roermond	10	0.04	0.004	13.34	143.95	0.04
Ronde Venen	15	0.04	0.003	5.31	23.10	0.58
Rozenburg	15	0.04	0.003	6.16	29.84	0.06

Ruurlo	15	0.04	0.003	5.81	27.06	0.08
Scheemda	15	0.04	0.003	6.39	31.67	0.07
Schelluinen	15	0.04	0.003	2.9	3.97	0.08
Scheve Klap	15	0.04	0.003	3.56	9.21	0.01
Schiermonnikoog	15	0.04	0.003	3.85	11.51	0.02
Simpelveld	15	0.04	0.003	6.86	35.40	0.03
Sint Maartensdijk	15	0.04	0.003	5.51	24.68	0.09
Sint-Oedenrode	15	0.04	0.003	5.02	20.79	0.07
Sleen	15	0.04	0.003	8.79	50.71	0.06
Sleeuwijk	15	0.04	0.003	6.1	29.37	0.14
Sliedrecht	15	0.04	0.003	7.59	41.19	0.08
Sloten	15	0.04	0.003	7.16	37.78	0.11
Smilde	15	0.04	0.003	4.79	18.97	0.10
Sneek	15	0.04	0.003	5.23	22.46	0.05
Soerendonk	15	0.04	0.003	4.12	13.65	0.06
Soest	10	0.04	0.004	7.08	61.58	0.04
Spijkenisse	10	0.04	0.004	3.05	8.55	0.25
Stadskanaal	15	0.04	0.003	6.04	28.89	0.03
Stein	15	0.04	0.003	24.34	174.13	0.08
Stolpen	15	0.04	0.003	12.14	77.30	0.06
Stolwijk	15	0.04	0.003	4.05	13.10	0.46
Susteren	10	0.04	0.004	6.92	59.47	0.03
Terneuzen	15	0.04	0.003	9.27	54.52	0.24
Terschelling	15	0.04	0.003	8.34	47.14	0.06
Terwolde	15	0.04	0.003	24.39	174.52	0.15
Tholen	15	0.04	0.003	6.71	34.21	0.13
Tiel	10	0.04	0.004	6.98	60.26	0.47
Tilburg	10	0.04	0.004	8.18	76.05	0.09
Tollebeek	10	0.04	0.004	7.95	73.03	0.24

Tubbergen	15	0.04	0.003	12.83	82.78	0.30
Tweede Exloermond	15	0.04	0.003	6.12	29.52	0.29
Uithoorn	15	0.04	0.003	9.28	54.60	0.22
Uithuizermeeden	15	0.04	0.003	5.34	23.33	0.08
Ulrum	15	0.04	0.003	5.78	26.83	0.15
Ursem	15	0.04	0.003	8.24	46.35	0.06
Utrecht	10	0.04	0.004	8.55	80.92	0.07
Valburg	15	0.04	0.003	8.73	50.24	0.12
Varsseveld	15	0.04	0.003	8.22	46.19	0.32
Veendam	15	0.04	0.003	6.05	28.97	0.13
Veenendaal	10	0.04	0.004	3.56	15.26	0.12
Velsen	15	0.04	0.003	14.63	97.06	0.08
Venlo	10	0.04	0.004	10.45	105.92	0.06
Venray	15	0.04	0.003	4.65	17.86	0.26
Vianen	15	0.04	0.003	4.18	14.13	0.42
Vinkel	15	0.04	0.003	5.01	20.71	0.05
Vlieland	15	0.04	0.003	4.08	13.33	0.04
Vollenhove	15	0.04	0.003	5.23	22.46	0.06
Vriescheloo	15	0.04	0.003	4.94	20.16	0.04
Vroomshoop	15	0.04	0.003	5.45	24.21	0.06
Waalwijk	15	0.04	0.003	8.83	51.03	0.05
Waddinxveen-Randenburg	15	0.04	0.003	3.43	8.17	0.06
Walcheren	10	0.04	0.004	10.56	107.37	0.14
Warns	15	0.04	0.003	4.56	17.14	0.09
Waspik	15	0.04	0.003	3.05	5.16	0.02
Weert	10	0.04	0.004	15.68	174.74	0.43
Weesp	15	0.04	0.003	32.42	238.25	0.05
Wehe den Hoorn	15	0.04	0.003	8.41	47.70	0.01

Wehl	15	0.04	0.003	7.28	38.73	0.70
Wervershoof	10	0.04	0.004	5.52	41.05	0.64
Westerschouwen	15	0.04	0.003	6.4	31.75	0.13
Westpoort	10	0.04	0.004	7.97	73.29	0.10
Wieringen	15	0.04	0.003	10.61	65.16	0.16
Wieringermeer	15	0.04	0.003	11.5	72.22	0.08
Wijk bij Duurstede	15	0.04	0.003	7.61	41.35	0.29
Wijk en Aalburg	15	0.04	0.003	8.7	50.00	0.17
Wijlre	15	0.04	0.003	8.91	51.67	0.19
Willem Annapolder	15	0.04	0.003	13.02	84.29	0.11
Willemstad	15	0.04	0.003	7.31	38.97	0.13
Winsum	15	0.04	0.003	8.3	46.83	0.14
Winterswijk	15	0.04	0.003	7.51	40.56	0.22
Woerden	15	0.04	0.003	8.86	51.27	0.10
Wolvega	15	0.04	0.003	6.16	29.84	0.12
Workum	15	0.04	0.003	3.3	7.14	0.11
Woudenberg	15	0.04	0.003	5.07	21.19	0.14
Zaandam Oost	10	0.04	0.004	12.92	138.42	0.08
Zaltbommel	15	0.04	0.003	6.77	34.68	0.02
Zeewolde	15	0.04	0.003	5.47	24.37	0.06
Zeist	15	0.04	0.003	10.05	60.71	0.55
Zetten	15	0.04	0.003	13.68	89.52	0.09
Zuidhorn 1	15	0.04	0.003	7.46	40.16	0.06
Zuidhorn 2	15	0.04	0.003	7.23	38.33	0.16
Zwaanshoek	10	0.04	0.004	6.4	52.63	0.11
Zwanenburg	10	0.04	0.004	5.13	35.92	0.10
Zwolle	10	0.04	0.004	15.35	170.39	0.21

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Calculation of P parameter

WWTPs	Si(P)	Ki	Wi=Ki/Si	Vi= mg N/lit	qi	P (qi × Wi)
’s-Hertogenbosch	1	0.005	0.005	0.791	75.70	0.38
Aalsmeer	2	0.005	0.003	0.807	35.86	0.09
Aalst	2	0.005	0.003	1.954	97.53	0.24
Aalten	2	0.005	0.003	1.084	50.75	0.13
Aarle-Rixtel	1	0.005	0.005	0.736	69.30	0.35
Akkrum	2	0.005	0.003	1.162	54.95	0.14
Alblasserdam	2	0.005	0.003	1.291	61.88	0.15
Alkmaar	2	0.005	0.003	1.164	55.05	0.14
Almelo-Sumpel	1	0.005	0.005	0.47	38.37	0.19
Almelo-Vissedijk	2	0.005	0.003	2.169	109.09	0.27
Almere	1	0.005	0.005	0.721	67.56	0.34
Alphen Kerk en Zanen	2	0.005	0.003	0.284	7.74	0.02
Alphen Noord	2	0.005	0.003	0.226	4.62	0.01
Ameland	2	0.005	0.003	1.656	81.51	0.20
Amersfoort	1	0.005	0.005	0.615	55.23	0.28
Ammerstol	2	0.005	0.003	1.391	67.26	0.17
Amstelveen	1	0.005	0.005	1.018	102.09	0.51
Amsterdam West	1	0.005	0.005	0.846	82.09	0.41
Apeldoorn	1	0.005	0.005	1.436	150.70	0.75
Arnhem	1	0.005	0.005	0.691	64.07	0.32
Asperen	2	0.005	0.003	1.337	64.35	0.16
Assen	2	0.005	0.003	1.159	54.78	0.14
Asten	2	0.005	0.003	0.555	22.31	0.06
Baarle-Nassau	2	0.005	0.003	0.631	26.40	0.07
Barendrecht	2	0.005	0.003	0.302	8.71	0.02
Bath	1	0.005	0.005	1.818	195.12	0.98
Beemster	1	0.005	0.005	0.979	97.56	0.49

Beesd	2	0.005	0.003	0.865	38.98	0.10
Beilen	2	0.005	0.003	0.787	34.78	0.09
Bellingwolde	2	0.005	0.003	0.517	20.27	0.05
Bennekom	2	0.005	0.003	0.267	6.83	0.02
Bergambacht	2	0.005	0.003	0.943	43.17	0.11
Bergharen	2	0.005	0.003	1.165	55.11	0.14
Berkenwoude	2	0.005	0.003	0.968	44.52	0.11
Beverwijk	1	0.005	0.005	1.845	198.26	0.99
Biest-Houtakker	2	0.005	0.003	0.527	20.81	0.05
Birdaard	2	0.005	0.003	1.811	89.84	0.22
Blaricum	2	0.005	0.003	0.589	24.14	0.06
Bodegraven	2	0.005	0.003	0.302	8.71	0.02
Bolsward	2	0.005	0.003	1.305	62.63	0.16
Bosscherveld	2	0.005	0.003	1.176	55.70	0.14
Boxtel	2	0.005	0.003	0.756	33.12	0.08
Breskens	2	0.005	0.003	4.048	210.11	0.53
Breukelen	2	0.005	0.003	0.223	4.46	0.01
Brummen	2	0.005	0.003	0.27	6.99	0.02
Bunnik	2	0.005	0.003	0.426	15.38	0.04
Burgum	2	0.005	0.003	0.828	36.99	0.09
Camperlandpolder	2	0.005	0.003	0.521	20.48	0.05
Chaam	2	0.005	0.003	0.322	9.78	0.02
Coevorden	2	0.005	0.003	0.518	20.32	0.05
Culemborg	2	0.005	0.003	2.594	131.94	0.33
Dalfsen	2	0.005	0.003	0.445	16.40	0.04
Damwoude	2	0.005	0.003	0.66	27.96	0.07
De Bilt	2	0.005	0.003	0.424	15.27	0.04
de Groote Lucht	1	0.005	0.005	2.44	267.44	1.34
De Groote Zaag	2	0.005	0.003	0.416	14.84	0.04

De Meern	2	0.005	0.003	1.016	47.10	0.12
De Verseput	2	0.005	0.003	0.363	11.99	0.03
Delfzijl	2	0.005	0.003	1.18	55.91	0.14
Den Bommel	2	0.005	0.003	1.184	56.13	0.14
Den Ham	2	0.005	0.003	1.469	71.45	0.18
Den Helder	2	0.005	0.003	1.555	76.08	0.19
Denekamp	2	0.005	0.003	0.628	26.24	0.07
Deventer	1	0.005	0.005	0.677	62.44	0.31
Dieverbrug	2	0.005	0.003	0.554	22.26	0.06
Dinteloord	2	0.005	0.003	0.594	24.41	0.06
Dinther	1	0.005	0.005	1.005	100.58	0.50
Dinxperlo	2	0.005	0.003	0.857	38.55	0.10
Dodewaard	2	0.005	0.003	1.473	71.67	0.18
Dokhaven	1	0.005	0.005	1.331	138.49	0.69
Dokkum	2	0.005	0.003	0.817	36.40	0.09
Dongemond	1	0.005	0.005	0.848	82.33	0.41
Dordrecht	1	0.005	0.005	0.623	56.16	0.28
Drachten	2	0.005	0.003	0.406	14.30	0.04
Dreumel	2	0.005	0.003	1.416	68.60	0.17
Driebergen	2	0.005	0.003	0.549	21.99	0.05
Dronten	2	0.005	0.003	0.686	29.35	0.07
Druten	2	0.005	0.003	2.062	103.33	0.26
Dussen	2	0.005	0.003	1.717	84.78	0.21
Echten	1	0.005	0.005	0.895	87.79	0.44
Eck en Wiel	2	0.005	0.003	1.012	46.88	0.12
Ede	1	0.005	0.005	0.443	35.23	0.18
Eelde	2	0.005	0.003	1.049	48.87	0.12
Eethen	2	0.005	0.003	3.236	166.45	0.42
Eindhoven	1	0.005	0.005	0.553	48.02	0.24

Elburg	1	0.005	0.005	0.664	60.93	0.30
Emmen	1	0.005	0.005	0.168	3.26	0.02
Enschede-West	1	0.005	0.005	0.653	59.65	0.30
Epe	2	0.005	0.003	0.128	-0.65	0.00
Etten	1	0.005	0.005	0.701	65.23	0.33
Everstekoog	2	0.005	0.003	0.503	19.52	0.05
Feerwerd	2	0.005	0.003	0.668	28.39	0.07
Foxhol	2	0.005	0.003	0.644	27.10	0.07
Franeker	2	0.005	0.003	1.226	58.39	0.15
Gaarkeuken	2	0.005	0.003	0.994	45.91	0.11
Garmerwolde	1	0.005	0.005	0.352	24.65	0.12
Geestmerambacht	1	0.005	0.005	0.618	55.58	0.28
Geldermalsen	2	0.005	0.003	0.598	24.62	0.06
Gendt	2	0.005	0.003	1.868	92.90	0.23
Genemuiden	2	0.005	0.003	0.233	5.00	0.01
Gennep	2	0.005	0.003	1.052	49.03	0.12
Gieten	2	0.005	0.003	0.6	24.73	0.06
Glanerbrug	2	0.005	0.003	0.254	6.13	0.02
Goedereede	2	0.005	0.003	0.168	1.51	0.00
Goor	2	0.005	0.003	0.517	20.27	0.05
Gorinchem	2	0.005	0.003	1.979	98.87	0.25
Gorredijk	2	0.005	0.003	0.643	27.04	0.07
Gouda	2	0.005	0.003	0.345	11.02	0.03
Groede	2	0.005	0.003	5.684	298.06	0.75
Groenedijk	2	0.005	0.003	0.542	21.61	0.05
Groesbeek	2	0.005	0.003	0.921	41.99	0.10
Groot-Ammers	2	0.005	0.003	1.92	95.70	0.24
Grou	2	0.005	0.003	0.32	9.68	0.02
Haaften	2	0.005	0.003	1.104	51.83	0.13

Haaksbergen	2	0.005	0.003	0.617	25.65	0.06
Haaren	2	0.005	0.003	0.333	10.38	0.03
Haarlem Schalkwijk	2	0.005	0.003	1.381	66.72	0.17
Haarlem Waarderpolder	1	0.005	0.005	1.466	154.19	0.77
Haarlo	2	0.005	0.003	0.236	5.16	0.01
Haastrecht	2	0.005	0.003	1.489	72.53	0.18
Halsteren	2	0.005	0.003	0.847	38.01	0.10
Hapert	2	0.005	0.003	0.275	7.26	0.02
Hardenberg	2	0.005	0.003	0.752	32.90	0.08
Harderwijk	1	0.005	0.005	0.537	46.16	0.23
Hardinxveld De Peulen	2	0.005	0.003	2.586	131.51	0.33
Harlingen	2	0.005	0.003	1.338	64.41	0.16
Harnaschpolder	1	0.005	0.005	0.587	51.98	0.26
Hattem	2	0.005	0.003	2.469	125.22	0.31
Heemstede	2	0.005	0.003	0.637	26.72	0.07
Heenvliet	2	0.005	0.003	1.353	65.22	0.16
Heerde	2	0.005	0.003	0.732	31.83	0.08
Heerenveen	1	0.005	0.005	1.487	156.63	0.78
Heiloo	2	0.005	0.003	1.43	69.35	0.17
Heino	2	0.005	0.003	0.375	12.63	0.03
Hellevoetsluis	2	0.005	0.003	0.667	28.33	0.07
Hengelo	1	0.005	0.005	0.779	74.30	0.37
Hessenpoort	2	0.005	0.003	0.55	22.04	0.06
Heugem	2	0.005	0.003	0.649	27.37	0.07
Hilversum	2	0.005	0.003	0.469	17.69	0.04
Hoensbroek	1	0.005	0.005	0.345	23.84	0.12
Holten	2	0.005	0.003	1.998	99.89	0.25
Hoogezand	2	0.005	0.003	0.45	16.67	0.04

Hoogvliet	2	0.005	0.003	0.686	29.35	0.07
Horstermeer	1	0.005	0.005	0.198	6.74	0.03
Houten	2	0.005	0.003	0.543	21.67	0.05
Houtrust	1	0.005	0.005	0.86	83.72	0.42
Huizen	2	0.005	0.003	0.194	2.90	0.01
Hulst	2	0.005	0.003	1.473	71.67	0.18
Joure	2	0.005	0.003	0.218	4.19	0.01
Kaatsheuvel	2	0.005	0.003	0.489	18.76	0.05
Kaffeberg	2	0.005	0.003	0.226	4.62	0.01
Kampen	2	0.005	0.003	0.45	16.67	0.04
Katwijk	1	0.005	0.005	1.368	142.79	0.71
Katwoude	2	0.005	0.003	2.215	111.56	0.28
Kloosterzande	2	0.005	0.003	0.581	23.71	0.06
Kootstertille	2	0.005	0.003	0.504	19.57	0.05
Kortenoord	1	0.005	0.005	0.433	34.07	0.17
Kralingseveer	1	0.005	0.005	1.172	120.00	0.60
Lage Zwaluwe	2	0.005	0.003	0.975	44.89	0.11
Land van Cuijk	1	0.005	0.005	0.95	94.19	0.47
Leek	2	0.005	0.003	1.225	58.33	0.15
Leerdam	2	0.005	0.003	0.365	12.10	0.03
Leeuwarden	1	0.005	0.005	1.039	104.53	0.52
Leiden Noord	1	0.005	0.005	0.655	59.88	0.30
Leiden Zuid-West	2	0.005	0.003	1.037	48.23	0.12
Leidsche Rijn	2	0.005	0.003	0.51	19.89	0.05
Leimuiden	2	0.005	0.003	0.246	5.70	0.01
Lelystad	1	0.005	0.005	0.387	28.72	0.14
Lemmer	2	0.005	0.003	0.696	29.89	0.07
Lichtenvoorde	2	0.005	0.003	1.904	94.84	0.24
Lienden	2	0.005	0.003	0.899	40.81	0.10

Limmel	1	0.005	0.005	0.705	65.70	0.33
Lisse	2	0.005	0.003	0.761	33.39	0.08
Loenen	2	0.005	0.003	3.243	166.83	0.42
Lopik	2	0.005	0.003	0.582	23.76	0.06
Losser	2	0.005	0.003	0.573	23.28	0.06
Maarssen	2	0.005	0.003	0.498	19.25	0.05
Maarssenbroek	2	0.005	0.003	1.761	87.15	0.22
Maasbommel	2	0.005	0.003	0.803	35.65	0.09
Marum	2	0.005	0.003	0.969	44.57	0.11
Mastgat	2	0.005	0.003	0.653	27.58	0.07
Meijel	2	0.005	0.003	0.553	22.20	0.06
Meppel	2	0.005	0.003	1.25	59.68	0.15
Middelharnis	2	0.005	0.003	0.272	7.10	0.02
Millingen	2	0.005	0.003	0.965	44.35	0.11
Montfoort	2	0.005	0.003	1.127	53.06	0.13
Nieuwe Waterweg	2	0.005	0.003	3.104	159.35	0.40
Nieuwe Wetering	2	0.005	0.003	0.373	12.53	0.03
Nieuwegein	1	0.005	0.005	1.269	131.28	0.66
Nieuwgraaf	1	0.005	0.005	1.188	121.86	0.61
Nieuwveen	2	0.005	0.003	0.358	11.72	0.03
Nieuwveer	1	0.005	0.005	1.494	157.44	0.79
Nieuw-Vossemeer	2	0.005	0.003	0.313	9.30	0.02
Nijkerk	2	0.005	0.003	0.355	11.56	0.03
Nijmegen	1	0.005	0.005	1.376	143.72	0.72
Nijverdal	2	0.005	0.003	4.132	214.62	0.54
Noordwijk	2	0.005	0.003	0.807	35.86	0.09
Numansdorp	2	0.005	0.003	0.427	15.43	0.04
Oijen	1	0.005	0.005	1.35	140.70	0.70
Olburgen	1	0.005	0.005	2.833	313.14	1.57

Oldenzaal	2	0.005	0.003	0.868	39.14	0.10
Olst-Wijhe	2	0.005	0.003	0.945	43.28	0.11
Ommen	2	0.005	0.003	0.693	29.73	0.07
Onderdendam	2	0.005	0.003	0.869	39.19	0.10
Ooltgensplaat	2	0.005	0.003	1.182	56.02	0.14
Oostburg	2	0.005	0.003	4.555	237.37	0.59
Oosterwolde	2	0.005	0.003	0.667	28.33	0.07
Oosthuizen	2	0.005	0.003	1.489	72.53	0.18
Oostvoorne	2	0.005	0.003	2.054	102.90	0.26
Ootmarsum	2	0.005	0.003	0.766	33.66	0.08
Ossendrecht	2	0.005	0.003	0.655	27.69	0.07
Oud Beijerland	2	0.005	0.003	0.178	2.04	0.01
Oude Pekela	2	0.005	0.003	0.497	19.19	0.05
Oude Tonge	2	0.005	0.003	1.408	68.17	0.17
Oudewater	2	0.005	0.003	0.54	21.51	0.05
Overasselt	2	0.005	0.003	1.434	69.57	0.17
Panheel	2	0.005	0.003	5.499	288.12	0.72
Papendrecht	2	0.005	0.003	0.493	18.98	0.05
Piershil	2	0.005	0.003	2.061	103.28	0.26
Putte	2	0.005	0.003	0.658	27.85	0.07
Raalte	2	0.005	0.003	0.232	4.95	0.01
Renkum	2	0.005	0.003	3.655	188.98	0.47
Retranchement	2	0.005	0.003	1.796	89.03	0.22
Rhenen	2	0.005	0.003	0.515	20.16	0.05
Ridderkerk	2	0.005	0.003	1.047	48.76	0.12
Riel	2	0.005	0.003	1.026	47.63	0.12
Rijen	2	0.005	0.003	0.821	36.61	0.09
Rijsenhout	2	0.005	0.003	0.317	9.52	0.02
Rijssen	2	0.005	0.003	0.405	14.25	0.04

Rimburg	2	0.005	0.003	0.466	17.53	0.04
Roermond	1	0.005	0.005	0.513	43.37	0.22
Ronde Venen	2	0.005	0.003	0.406	14.30	0.04
Rozenburg	2	0.005	0.003	1.539	75.22	0.19
Ruurlo	2	0.005	0.003	0.436	15.91	0.04
Scheemda	2	0.005	0.003	1.136	53.55	0.13
Schelluinen	2	0.005	0.003	1.423	68.98	0.17
Scheve Klap	2	0.005	0.003	1.228	58.49	0.15
Schiermonnikoog	2	0.005	0.003	1.797	89.09	0.22
Simpelveld	2	0.005	0.003	0.337	10.59	0.03
Sint Maartensdijk	2	0.005	0.003	0.636	26.67	0.07
Sint-Oedenrode	2	0.005	0.003	0.496	19.14	0.05
Sleen	2	0.005	0.003	0.751	32.85	0.08
Sleeuwijk	2	0.005	0.003	0.751	32.85	0.08
Sliedrecht	2	0.005	0.003	0.334	10.43	0.03
Sloten	2	0.005	0.003	0.74	32.26	0.08
Smilde	2	0.005	0.003	0.468	17.63	0.04
Sneek	2	0.005	0.003	0.741	32.31	0.08
Soerendonk	2	0.005	0.003	0.224	4.52	0.01
Soest	1	0.005	0.005	0.519	44.07	0.22
Spijkenisse	1	0.005	0.005	1.191	122.21	0.61
Stadskanaal	2	0.005	0.003	0.605	25.00	0.06
Steenwijk	2	0.005	0.003	0.501	19.41	0.05
Stein	2	0.005	0.003	0.907	41.24	0.10
Stolpen	2	0.005	0.003	2.285	115.32	0.29
Stolwijk	2	0.005	0.003	0.202	3.33	0.01
Susteren	1	0.005	0.005	0.687	63.60	0.32
Ter Apel	2	0.005	0.003	0.452	16.77	0.04
Terneuzen	2	0.005	0.003	1.326	63.76	0.16

Terschelling	2	0.005	0.003	1.695	83.60	0.21
Terwolde	2	0.005	0.003	1.945	97.04	0.24
Tholen	2	0.005	0.003	0.422	15.16	0.04
Tiel	1	0.005	0.005	1.043	105.00	0.53
Tilburg	1	0.005	0.005	0.487	40.35	0.20
Tollebeek	1	0.005	0.005	0.935	92.44	0.46
Tubbergen	2	0.005	0.003	3.417	176.18	0.44
Tweede Exloermond	2	0.005	0.003	0.58	23.66	0.06
Uithoorn	2	0.005	0.003	0.594	24.41	0.06
Uithuizermeeden	2	0.005	0.003	0.408	14.41	0.04
Ulrum	2	0.005	0.003	1.42	68.82	0.17
Ursem	2	0.005	0.003	0.376	12.69	0.03
Utrecht	1	0.005	0.005	0.601	53.60	0.27
Valburg	2	0.005	0.003	2.602	132.37	0.33
Varsseveld	2	0.005	0.003	0.809	35.97	0.09
Veendam	2	0.005	0.003	1.599	78.44	0.20
Veenendaal	1	0.005	0.005	0.269	15.00	0.08
Velsen	2	0.005	0.003	2.795	142.74	0.36
Venlo	1	0.005	0.005	0.347	24.07	0.12
Venray	2	0.005	0.003	0.153	0.70	0.00
Vianen	2	0.005	0.003	1.53	74.73	0.19
Vinkel	2	0.005	0.003	0.834	37.31	0.09
Vlieland	2	0.005	0.003	1.544	75.48	0.19
Vollenhove	2	0.005	0.003	0.645	27.15	0.07
Vriescheloo	2	0.005	0.003	0.672	28.60	0.07
Vroomshoop	2	0.005	0.003	0.729	31.67	0.08
Waalwijk	2	0.005	0.003	2.084	104.52	0.26
Waarde	2	0.005	0.003	0.458	17.10	0.04

Waddinxveen-Randenburg	2	0.005	0.003	0.221	4.35	0.01
Walcheren	1	0.005	0.005	0.921	90.81	0.45
Warns	2	0.005	0.003	0.764	33.55	0.08
Waspik	2	0.005	0.003	0.403	14.14	0.04
Weert	1	0.005	0.005	1.247	128.72	0.64
Weesp	2	0.005	0.003	0.828	36.99	0.09
Wehe den Hoorn	2	0.005	0.003	1.496	72.90	0.18
Wehl	2	0.005	0.003	0.49	18.82	0.05
Wervershoof	1	0.005	0.005	0.57	50.00	0.25
Westerschouwen	2	0.005	0.003	1.094	51.29	0.13
Westpoort	1	0.005	0.005	0.748	70.70	0.35
Wieringen	2	0.005	0.003	1.522	74.30	0.19
Wieringermeer	2	0.005	0.003	2.359	119.30	0.30
Wijk bij Duurstede	2	0.005	0.003	0.466	17.53	0.04
Wijk en Aalburg	2	0.005	0.003	1.945	97.04	0.24
Wijlre	2	0.005	0.003	0.427	15.43	0.04
Willem Annapolder	2	0.005	0.003	0.771	33.92	0.08
Willemstad	2	0.005	0.003	2.278	114.95	0.29
Winsum	2	0.005	0.003	1.751	86.61	0.22
Winterswijk	2	0.005	0.003	0.536	21.29	0.05
Woerden	2	0.005	0.003	0.885	40.05	0.10
Wolvega	2	0.005	0.003	1.286	61.61	0.15
Workum	2	0.005	0.003	0.886	40.11	0.10
Woudenberg	2	0.005	0.003	0.296	8.39	0.02
Zaandam Oost	1	0.005	0.005	0.62	55.81	0.28
Zaltbommel	2	0.005	0.003	1.187	56.29	0.14
Zeewolde	2	0.005	0.003	0.461	17.26	0.04
Zeist	2	0.005	0.003	0.385	13.17	0.03

Zetten	2	0.005	0.003	3.408	175.70	0.44
Zuidhorn 1	2	0.005	0.003	0.699	30.05	0.08
Zuidhorn 2	2	0.005	0.003	1.743	86.18	0.22
Zutphen	1	0.005	0.005	0.223	9.65	0.05
Zwaanshoek	1	0.005	0.005	1.51	159.30	0.80
Zwanenburg	1	0.005	0.005	0.489	40.58	0.20
Zwijndrecht	1	0.005	0.005	0.646	58.84	0.29
Zwolle	1	0.005	0.005	2.46	269.77	1.35

The calculation of COD parameter

WWTPs	**si**	**Ki**	**Wi=ki/si**	**vi=mg COD/lit**	**qi**	**COD (qi × Wi)**
’s-Hertogenbosch	125	0.38	0.003	38.77	28.14	0.084
Aalsmeer	125	0.38	0.003	45.17	33.48	0.100
Aalst	125	0.38	0.003	32.12	22.60	0.068
Aalten	125	0.38	0.003	33.63	23.86	0.072
Aarle-Rixtel	125	0.38	0.003	44.98	33.32	0.100
Akkrum	125	0.38	0.003	39.45	28.71	0.086
Alblasserdam	125	0.38	0.003	38.4	27.83	0.084
Alkmaar	125	0.38	0.003	46.02	34.18	0.103
Almelo-Sumpel	125	0.38	0.003	37.67	27.23	0.082
Almelo-Vissedijk	125	0.38	0.003	34.86	24.88	0.075
Almere	125	0.38	0.003	33.33	23.61	0.071
Alphen Kerk en Zanen	125	0.38	0.003	33.49	23.74	0.071
Alphen Noord	125	0.38	0.003	40.27	29.39	0.088
Ameland	125	0.38	0.003	52.91	39.93	0.120
Amersfoort	125	0.38	0.003	40.29	29.41	0.088
Ammerstol	125	0.38	0.003	28.7	19.75	0.059
Amstelveen	125	0.38	0.003	39.72	28.93	0.087

Amsterdam West	125	0.38	0.003	43.96	32.47	0.097
Apeldoorn	125	0.38	0.003	38.96	28.30	0.085
Arnhem	125	0.38	0.003	24.28	16.07	0.048
Asperen	125	0.38	0.003	27.49	18.74	0.056
Assen	125	0.38	0.003	52.9	39.92	0.120
Asten	125	0.38	0.003	30.82	21.52	0.065
Baarle-Nassau	125	0.38	0.003	45.59	33.83	0.101
Barendrecht	125	0.38	0.003	28.1	19.25	0.058
Bath	125	0.38	0.003	49.93	37.44	0.112
Beemster	125	0.38	0.003	46.07	34.23	0.103
Beesd	125	0.38	0.003	24.88	16.57	0.050
Beilen	125	0.38	0.003	35.45	25.38	0.076
Bellingwolde	125	0.38	0.003	44.11	32.59	0.098
Bennekom	125	0.38	0.003	25.45	17.04	0.051
Bergambacht	125	0.38	0.003	34.05	24.21	0.073
Bergharen	125	0.38	0.003	39	28.33	0.085
Berkenwoude	125	0.38	0.003	45.99	34.16	0.102
Beverwijk	125	0.38	0.003	61.07	46.73	0.140
Biest-Houtakker	125	0.38	0.003	45.76	33.97	0.102
Birdaard	125	0.38	0.003	41.37	30.31	0.091
Blaricum	125	0.38	0.003	33.02	23.35	0.070
Bodegraven	125	0.38	0.003	38.9	28.25	0.085
Bolsward	125	0.38	0.003	44.28	32.73	0.098
Bosscherveld	125	0.38	0.003	26.51	17.93	0.054
Boxtel	125	0.38	0.003	33.93	24.11	0.072
Breskens	125	0.38	0.003	37.66	27.22	0.082
Breukelen	125	0.38	0.003	32.29	22.74	0.068
Brummen	125	0.38	0.003	30.96	21.63	0.065
Bunnik	125	0.38	0.003	27.89	19.08	0.057

Burgum	125	0.38	0.003	38.22	27.68	0.083
Camperlandpolder	125	0.38	0.003	29.41	20.34	0.061
Chaam	125	0.38	0.003	29.67	20.56	0.062
Coevorden	125	0.38	0.003	53.55	40.46	0.121
Culemborg	125	0.38	0.003	34.7	24.75	0.074
Dalfsen	125	0.38	0.003	29.25	20.21	0.061
Damwoude	125	0.38	0.003	32.63	23.03	0.069
De Bilt	125	0.38	0.003	29.68	20.57	0.062
de Groote Lucht	125	0.38	0.003	34.43	24.53	0.074
De Groote Zaag	125	0.38	0.003	35.41	25.34	0.076
De Meern	125	0.38	0.003	30.38	21.15	0.063
De Verseput	125	0.38	0.003	35.92	25.77	0.077
Delfzijl	125	0.38	0.003	37.99	27.49	0.082
Den Bommel	125	0.38	0.003	29.6	20.50	0.062
Den Ham	125	0.38	0.003	30.78	21.48	0.064
Den Helder	125	0.38	0.003	66.2	51.00	0.153
Denekamp	125	0.38	0.003	35.26	25.22	0.076
Deventer	125	0.38	0.003	34.97	24.98	0.075
Dieverbrug	125	0.38	0.003	33.54	23.78	0.071
Dinteloord	125	0.38	0.003	30.88	21.57	0.065
Dinther	125	0.38	0.003	37.19	26.83	0.080
Dinxperlo	125	0.38	0.003	24.89	16.58	0.050
Dodewaard	125	0.38	0.003	45.32	33.60	0.101
Dokhaven	125	0.38	0.003	41.64	30.53	0.092
Dokkum	125	0.38	0.003	31.76	22.30	0.067
Dongemond	125	0.38	0.003	42.79	31.49	0.094
Dordrecht	125	0.38	0.003	43.05	31.71	0.095
Drachten	125	0.38	0.003	40.57	29.64	0.089
Dreumel	125	0.38	0.003	41.8	30.67	0.092

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Driebergen	125	0.38	0.003	37.29	26.91	0.081
Dronten	125	0.38	0.003	38.87	28.23	0.085
Druten	125	0.38	0.003	38.49	27.91	0.084
Dussen	125	0.38	0.003	28.01	19.18	0.058
Echten	125	0.38	0.003	36.95	26.63	0.080
Eck en Wiel	125	0.38	0.003	30	20.83	0.063
Ede	125	0.38	0.003	48.08	35.90	0.108
Eelde	125	0.38	0.003	40.82	29.85	0.090
Eethen	125	0.38	0.003	33.81	24.01	0.072
Eindhoven	125	0.38	0.003	30.96	21.63	0.065
Elburg	125	0.38	0.003	41.48	30.40	0.091
Emmen	125	0.38	0.003	18.74	11.45	0.034
Enschede-West	125	0.38	0.003	37.46	27.05	0.081
Epe	125	0.38	0.003	24.11	15.93	0.048
Etten	125	0.38	0.003	39.25	28.54	0.086
Everstekoog	125	0.38	0.003	43.96	32.47	0.097
Feerwerd	125	0.38	0.003	34.06	24.22	0.073
Foxhol	125	0.38	0.003	47.69	35.58	0.107
Franeker	125	0.38	0.003	64.78	49.82	0.149
Gaarkeuken	125	0.38	0.003	41.58	30.48	0.091
Garmerwolde	125	0.38	0.003	46.24	34.37	0.103
Geestmerambacht	125	0.38	0.003	37.67	27.23	0.082
Geldermalsen	125	0.38	0.003	31.06	21.72	0.065
Gendt	125	0.38	0.003	54.7	41.42	0.124
Genemuiden	125	0.38	0.003	32.77	23.14	0.069
Gennep	125	0.38	0.003	34.57	24.64	0.074
Gieten	125	0.38	0.003	56.79	43.16	0.129
Glanerbrug	125	0.38	0.003	37.24	26.87	0.081
Goedereede	125	0.38	0.003	24.83	16.53	0.050

Goor	125	0.38	0.003	45.32	33.60	0.101
Gorinchem	125	0.38	0.003	28.79	19.83	0.059
Gorredijk	125	0.38	0.003	39.41	28.68	0.086
Gouda	125	0.38	0.003	37.06	26.72	0.080
Groede	125	0.38	0.003	41.03	30.03	0.090
Groenedijk	125	0.38	0.003	27.62	18.85	0.057
Groesbeek	125	0.38	0.003	37.25	26.88	0.081
Groot-Ammers	125	0.38	0.003	31.3	21.92	0.066
Grou	125	0.38	0.003	34.58	24.65	0.074
Haaften	125	0.38	0.003	40.99	29.99	0.090
Haaksbergen	125	0.38	0.003	30.86	21.55	0.065
Haaren	125	0.38	0.003	30.82	21.52	0.065
Haarlem Schalkwijk	125	0.38	0.003	47.78	35.65	0.107
Haarlem Waarderpolder	125	0.38	0.003	35.08	25.07	0.075
Haarlo	125	0.38	0.003	30.5	21.25	0.064
Haastrecht	125	0.38	0.003	36.74	26.45	0.079
Halsteren	125	0.38	0.003	50.04	37.53	0.113
Hapert	125	0.38	0.003	31	21.67	0.065
Hardenberg	125	0.38	0.003	52.06	39.22	0.118
Harderwijk	125	0.38	0.003	43.21	31.84	0.096
Hardinxveld De Peulen	125	0.38	0.003	44.94	33.28	0.100
Harlingen	125	0.38	0.003	24.25	16.04	0.048
Harnaschpolder	125	0.38	0.003	35.75	25.63	0.077
Hattem	125	0.38	0.003	26.56	17.97	0.054
Heemstede	125	0.38	0.003	30.41	21.18	0.064
Heenvliet	125	0.38	0.003	28.42	19.52	0.059
Heerde	125	0.38	0.003	35.77	25.64	0.077
Heerenveen	125	0.38	0.003	77.38	60.32	0.181

Heiloo	125	0.38	0.003	41.3	30.25	0.091
Heino	125	0.38	0.003	21.4	13.67	0.041
Hellevoetsluis	125	0.38	0.003	25.74	17.28	0.052
Hengelo	125	0.38	0.003	56.68	43.07	0.129
Hessenpoort	125	0.38	0.003	35.37	25.31	0.076
Heugem	125	0.38	0.003	20.07	12.56	0.038
Hilversum	125	0.38	0.003	26.51	17.93	0.054
Hoensbroek	125	0.38	0.003	30.17	20.98	0.063
Holten	125	0.38	0.003	53.51	40.43	0.121
Hoogezand	125	0.38	0.003	40.56	29.63	0.089
Hoogvliet	125	0.38	0.003	47.37	35.31	0.106
Horstermeer	125	0.38	0.003	28.15	19.29	0.058
Houten	125	0.38	0.003	25.96	17.47	0.052
Houtrust	125	0.38	0.003	36.54	26.28	0.079
Huizen	125	0.38	0.003	31.18	21.82	0.065
Hulst	125	0.38	0.003	36.85	26.54	0.080
Joure	125	0.38	0.003	58.45	44.54	0.134
Kaatsheuvel	125	0.38	0.003	23.85	15.71	0.047
Kaffeberg	125	0.38	0.003	22.2	14.33	0.043
Kampen	125	0.38	0.003	34.84	24.87	0.075
Katwijk	125	0.38	0.003	42.85	31.54	0.095
Katwoude	125	0.38	0.003	61.44	47.03	0.141
Kloosterzande	125	0.38	0.003	26.67	18.06	0.054
Kootstertille	125	0.38	0.003	27.54	18.78	0.056
Kortenoord	125	0.38	0.003	34.92	24.93	0.075
Kralingseveer	125	0.38	0.003	36.81	26.51	0.080
Lage Zwaluwe	125	0.38	0.003	47.35	35.29	0.106
Land van Cuijk	125	0.38	0.003	46.94	34.95	0.105
Leek	125	0.38	0.003	43.22	31.85	0.096

Leerdam	125	0.38	0.003	36.83	26.53	0.080
Leeuwarden	125	0.38	0.003	42.79	31.49	0.094
Leiden Noord	125	0.38	0.003	35.48	25.40	0.076
Leiden Zuid-West	125	0.38	0.003	45.3	33.58	0.101
Leidsche Rijn	125	0.38	0.003	38.51	27.93	0.084
Leimuiden	125	0.38	0.003	28.31	19.43	0.058
Lelystad	125	0.38	0.003	45.76	33.97	0.102
Lemmer	125	0.38	0.003	38.33	27.78	0.083
Lichtenvoorde	125	0.38	0.003	45.98	34.15	0.102
Lienden	125	0.38	0.003	31.87	22.39	0.067
Limmel	125	0.38	0.003	31.88	22.40	0.067
Lisse	125	0.38	0.003	34.86	24.88	0.075
Loenen	125	0.38	0.003	41.32	30.27	0.091
Lopik	125	0.38	0.003	36.9	26.58	0.080
Losser	125	0.38	0.003	34.51	24.59	0.074
Maarssen	125	0.38	0.003	47.83	35.69	0.107
Maarssenbroek	125	0.38	0.003	23.59	15.49	0.046
Maasbommel	125	0.38	0.003	30.58	21.32	0.064
Marum	125	0.38	0.003	44.92	33.27	0.100
Mastgat	125	0.38	0.003	40.72	29.77	0.089
Meijel	125	0.38	0.003	43.61	32.18	0.097
Meppel	125	0.38	0.003	34.21	24.34	0.073
Middelharnis	125	0.38	0.003	23.68	15.57	0.047
Millingen	125	0.38	0.003	29.95	20.79	0.062
Montfoort	125	0.38	0.003	46.45	34.54	0.104
Nieuwe Waterweg	125	0.38	0.003	38.67	28.06	0.084
Nieuwe Wetering	125	0.38	0.003	35.45	25.38	0.076
Nieuwegein	125	0.38	0.003	32.74	23.12	0.069
Nieuwgraaf	125	0.38	0.003	25.27	16.89	0.051

Nieuwveen	125	0.38	0.003	45.27	33.56	0.101
Nieuwveer	125	0.38	0.003	33.68	23.90	0.072
Nieuw-Vossemeer	125	0.38	0.003	26.77	18.14	0.054
Nijkerk	125	0.38	0.003	32.26	22.72	0.068
Nijmegen	125	0.38	0.003	31.62	22.18	0.067
Nijverdal	125	0.38	0.003	84.01	65.84	0.198
Noordwijk	125	0.38	0.003	37.6	27.17	0.082
Numansdorp	125	0.38	0.003	23.46	15.38	0.046
Oijen	125	0.38	0.003	29.95	20.79	0.062
Olburgen	125	0.38	0.003	30.13	20.94	0.063
Oldenzaal	125	0.38	0.003	34.82	24.85	0.075
Olst-Wijhe	125	0.38	0.003	30.52	21.27	0.064
Ommen	125	0.38	0.003	43.9	32.42	0.097
Onderdendam	125	0.38	0.003	38.94	28.28	0.085
Ooltgensplaat	125	0.38	0.003	24.83	16.53	0.050
Oostburg	125	0.38	0.003	66.17	50.98	0.153
Oosterwolde	125	0.38	0.003	42	30.83	0.093
Oosthuizen	125	0.38	0.003	51.17	38.48	0.115
Oostvoorne	125	0.38	0.003	33.66	23.88	0.072
Ootmarsum	125	0.38	0.003	25.28	16.90	0.051
Ossendrecht	125	0.38	0.003	35.45	25.38	0.076
Oud Beijerland	125	0.38	0.003	21.34	13.62	0.041
Oude Pekela	125	0.38	0.003	43.72	32.27	0.097
Oude Tonge	125	0.38	0.003	32.39	22.83	0.068
Oudewater	125	0.38	0.003	56.89	43.24	0.130
Overasselt	125	0.38	0.003	26.12	17.60	0.053
Panheel	125	0.38	0.003	68.35	52.79	0.158
Papendrecht	125	0.38	0.003	31.13	21.78	0.065
Piershil	125	0.38	0.003	32.97	23.31	0.070

Putte	125	0.38	0.003	49.63	37.19	0.112
Raalte	125	0.38	0.003	34.8	24.83	0.075
Renkum	125	0.38	0.003	36	25.83	0.078
Retranchement	125	0.38	0.003	32.44	22.87	0.069
Rhenen	125	0.38	0.003	29.9	20.75	0.062
Ridderkerk	125	0.38	0.003	26.01	17.51	0.053
Riel	125	0.38	0.003	45.03	33.36	0.100
Rijen	125	0.38	0.003	40.87	29.89	0.090
Rijnsaterwoude	125	0.38	0.003	7.47	2.06	0.006
Rijsenhout	125	0.38	0.003	34.82	24.85	0.075
Rijssen	125	0.38	0.003	28.5	19.58	0.059
Rimburg	125	0.38	0.003	32.25	22.71	0.068
Roermond	125	0.38	0.003	69.49	53.74	0.161
Ronde Venen	125	0.38	0.003	42.81	31.51	0.095
Rozenburg	125	0.38	0.003	27.13	18.44	0.055
Ruurlo	125	0.38	0.003	33.58	23.82	0.071
Scheemda	125	0.38	0.003	58.44	44.53	0.134
Schelluinen	125	0.38	0.003	29.66	20.55	0.062
Scheve Klap	125	0.38	0.003	31.52	22.10	0.066
Schiermonnikoog	125	0.38	0.003	41.19	30.16	0.090
Simpelveld	125	0.38	0.003	27.03	18.36	0.055
Sint Maartensdijk	125	0.38	0.003	25.56	17.13	0.051
Sint-Oedenrode	125	0.38	0.003	38.59	27.99	0.084
Sleen	125	0.38	0.003	42.2	31.00	0.093
Sleeuwijk	125	0.38	0.003	20.76	13.13	0.039
Sliedrecht	125	0.38	0.003	33.98	24.15	0.072
Sloten	125	0.38	0.003	38.78	28.15	0.084
Smilde	125	0.38	0.003	36.62	26.35	0.079
Sneek	125	0.38	0.003	41.71	30.59	0.092

Soerendonk	125	0.38	0.003	29.44	20.37	0.061
Soest	125	0.38	0.003	27.51	18.76	0.056
Spijkenisse	125	0.38	0.003	27.44	18.70	0.056
Stadskanaal	125	0.38	0.003	55.36	41.97	0.126
Steenwijk	125	0.38	0.003	37.55	27.13	0.081
Stein	125	0.38	0.003	55.5	42.08	0.126
Stolpen	125	0.38	0.003	47.86	35.72	0.107
Stolwijk	125	0.38	0.003	33.89	24.08	0.072
Strijen	125	0.38	0.003	20.59	12.99	0.039
Susteren	125	0.38	0.003	40.19	29.33	0.088
Ter Apel	125	0.38	0.003	48.31	36.09	0.108
Terneuzen	125	0.38	0.003	51.92	39.10	0.117
Terschelling	125	0.38	0.003	48.64	36.37	0.109
Terwolde	125	0.38	0.003	60.87	46.56	0.140
Tholen	125	0.38	0.003	34.13	24.28	0.073
Tiel	125	0.38	0.003	29.67	20.56	0.062
Tilburg	125	0.38	0.003	41.2	30.17	0.091
Tollebeek	125	0.38	0.003	30.3	21.08	0.063
Tubbergen	125	0.38	0.003	53.52	40.43	0.121
Tweede Exloermond	125	0.38	0.003	57.6	43.83	0.132
Uithoorn	125	0.38	0.003	38.25	27.71	0.083
Uithuizermeeden	125	0.38	0.003	29.08	20.07	0.060
Ulrum	125	0.38	0.003	42.69	31.41	0.094
Ursem	125	0.38	0.003	40.67	29.73	0.089
Utrecht	125	0.38	0.003	32.43	22.86	0.069
Valburg	125	0.38	0.003	37.39	26.99	0.081
Varsseveld	125	0.38	0.003	44.13	32.61	0.098
Veendam	125	0.38	0.003	65.76	50.63	0.152
Veenendaal	125	0.38	0.003	25.94	17.45	0.052

Velsen	125	0.38	0.003	39.21	28.51	0.086
Venlo	125	0.38	0.003	46.89	34.91	0.105
Venray	125	0.38	0.003	27.96	19.13	0.057
Vianen	125	0.38	0.003	29.83	20.69	0.062
Vinkel	125	0.38	0.003	37.37	26.98	0.081
Vlieland	125	0.38	0.003	31.64	22.20	0.067
Vollenhove	125	0.38	0.003	27.02	18.35	0.055
Vriescheloo	125	0.38	0.003	44.72	33.10	0.099
Vroomshoop	125	0.38	0.003	45.47	33.73	0.101
Waalwijk	125	0.38	0.003	55.52	42.10	0.126
Waarde	125	0.38	0.003	40.11	29.26	0.088
Waddinxveen-Randenburg	125	0.38	0.003	39.07	28.39	0.085
Walcheren	125	0.38	0.003	48.33	36.11	0.108
Warns	125	0.38	0.003	31.14	21.78	0.065
Waspik	125	0.38	0.003	35.38	25.32	0.076
Weert	125	0.38	0.003	59.58	45.48	0.136
Weesp	125	0.38	0.003	64.43	49.53	0.149
Wehe den Hoorn	125	0.38	0.003	38.58	27.98	0.084
Wehl	125	0.38	0.003	28.23	19.36	0.058
Wervershoof	125	0.38	0.003	40.43	29.53	0.089
Westerschouwen	125	0.38	0.003	36.85	26.54	0.080
Westpoort	125	0.38	0.003	47.14	35.12	0.105
Wieringen	125	0.38	0.003	38.89	28.24	0.085
Wieringermeer	125	0.38	0.003	44.37	32.81	0.098
Wijk bij Duurstede	125	0.38	0.003	36.67	26.39	0.079
Wijk en Aalburg	125	0.38	0.003	34.99	24.99	0.075
Wijlre	125	0.38	0.003	36.74	26.45	0.079
Willem Annapolder	125	0.38	0.003	45.72	33.93	0.102

Willemstad	125	0.38	0.003	30.87	21.56	0.065
Winsum	125	0.38	0.003	72.88	56.57	0.170
Winterswijk	125	0.38	0.003	52.35	39.46	0.118
Woerden	125	0.38	0.003	46.09	34.24	0.103
Wolvega	125	0.38	0.003	42.5	31.25	0.094
Workum	125	0.38	0.003	24.09	15.91	0.048
Woudenberg	125	0.38	0.003	29.33	20.28	0.061
Zaandam Oost	125	0.38	0.003	59.65	45.54	0.137
Zaltbommel	125	0.38	0.003	42.98	31.65	0.095
Zeewolde	125	0.38	0.003	46.94	34.95	0.105
Zeist	125	0.38	0.003	23.81	15.68	0.047
Zetten	125	0.38	0.003	49.77	37.31	0.112
Zuidhorn 1	125	0.38	0.003	36.91	26.59	0.080
Zuidhorn 2	125	0.38	0.003	43.06	31.72	0.095
Zutphen	125	0.38	0.003	29.28	20.23	0.061
Zwaanshoek	125	0.38	0.003	46.06	34.22	0.103
Zwanenburg	125	0.38	0.003	32	22.50	0.068
Zwijndrecht	125	0.38	0.003	27.41	18.68	0.056
Zwolle	125	0.38	0.003	57.37	43.64	0.131

Calculation of BOD parameter

WWTPs	**Si**	**Ki**	**Wi=ki/si**	**vi=mg O_2/ L**	**qi**	**BOD (qi × Wi)**
’s-Hertogenbosch	25	0.076	0.003	4.44	14.33	0.04
Aalsmeer	25	0.076	0.003	6.67	23.63	0.07
Aalst	25	0.076	0.003	3.58	10.75	0.03
Aalten	25	0.076	0.003	3.81	11.71	0.04
Aarle-Rixtel	25	0.076	0.003	4.42	14.25	0.04
Akkrum	25	0.076	0.003	1.83	3.46	0.01
Alblasserdam	25	0.076	0.003	5.15	17.29	0.05

Alkmaar	25	0.076	0.003	5.29	17.88	0.05
Almelo-Sumpel	25	0.076	0.003	2.63	6.79	0.02
Almelo-Vissedijk	25	0.076	0.003	2.45	6.04	0.02
Almere	25	0.076	0.003	2.85	7.71	0.02
Alphen Kerk en Zanen	25	0.076	0.003	3.59	10.79	0.03
Alphen Noord	25	0.076	0.003	3.84	11.83	0.04
Ameland	25	0.076	0.003	3.97	12.38	0.04
Amersfoort	25	0.076	0.003	2.24	5.17	0.02
Ammerstol	25	0.076	0.003	3.17	9.04	0.03
Amstelveen	25	0.076	0.003	4.8	15.83	0.05
Amsterdam West	25	0.076	0.003	4.65	15.21	0.05
Apeldoorn	25	0.076	0.003	3	8.33	0.03
Arnhem	25	0.076	0.003	2.65	6.88	0.02
Asperen	25	0.076	0.003	3.08	8.67	0.03
Assen	25	0.076	0.003	10.02	37.58	0.11
Asten	25	0.076	0.003	3.07	8.63	0.03
Baarle-Nassau	25	0.076	0.003	6.49	22.88	0.07
Barendrecht	25	0.076	0.003	3.73	11.38	0.03
Bath	25	0.076	0.003	3.44	10.17	0.03
Beemster	25	0.076	0.003	5.97	20.71	0.06
Beesd	25	0.076	0.003	2.89	7.88	0.02
Beilen	25	0.076	0.003	3.26	9.42	0.03
Bellingwolde	25	0.076	0.003	3.73	11.38	0.03
Bennekom	25	0.076	0.003	1.4	1.67	0.01
Bergambacht	25	0.076	0.003	2.92	8.00	0.02
Bergharen	25	0.076	0.003	5.63	19.29	0.06
Berkenwoude	25	0.076	0.003	4.12	13.00	0.04
Beverwijk	25	0.076	0.003	9.04	33.50	0.10
Biest-Houtakker	25	0.076	0.003	4.62	15.08	0.05

Birdaard	25	0.076	0.003	4	12.50	0.04
Blaricum	25	0.076	0.003	3.29	9.54	0.03
Bodegraven	25	0.076	0.003	4.04	12.67	0.04
Bolsward	25	0.076	0.003	2.78	7.42	0.02
Bosscherveld	25	0.076	0.003	3.34	9.75	0.03
Boxtel	25	0.076	0.003	5.3	17.92	0.05
Breskens	25	0.076	0.003	6.29	22.04	0.07
Breukelen	25	0.076	0.003	3.55	10.63	0.03
Brummen	25	0.076	0.003	2.62	6.75	0.02
Bunnik	25	0.076	0.003	3.21	9.21	0.03
Burgum	25	0.076	0.003	3.32	9.67	0.03
Camperlandpolder	25	0.076	0.003	3.61	10.88	0.03
Chaam	25	0.076	0.003	4.17	13.21	0.04
Coevorden	25	0.076	0.003	3.5	10.42	0.03
Culemborg	25	0.076	0.003	4.64	15.17	0.05
Dalfsen	25	0.076	0.003	1.82	3.42	0.01
Damwoude	25	0.076	0.003	1.92	3.83	0.01
De Bilt	25	0.076	0.003	2.42	5.92	0.02
de Groote Lucht	25	0.076	0.003	3.8	11.67	0.04
De Groote Zaag	25	0.076	0.003	3.95	12.29	0.04
De Meern	25	0.076	0.003	3.25	9.38	0.03
De Verseput	25	0.076	0.003	4.86	16.08	0.05
Delfzijl	25	0.076	0.003	3.12	8.83	0.03
Den Bommel	25	0.076	0.003	5.92	20.50	0.06
Den Ham	25	0.076	0.003	2.17	4.88	0.01
Den Helder	25	0.076	0.003	9.31	34.63	0.10
Denekamp	25	0.076	0.003	2.77	7.38	0.02
Deventer	25	0.076	0.003	2.47	6.13	0.02
Dieverbrug	25	0.076	0.003	3.18	9.08	0.03

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Dinteloord	25	0.076	0.003	4.06	12.75	0.04
Dinther	25	0.076	0.003	4.3	13.75	0.04
Dinxperlo	25	0.076	0.003	1.57	2.38	0.01
Dodewaard	25	0.076	0.003	9.85	36.88	0.11
Dokhaven	25	0.076	0.003	7.33	26.38	0.08
Dokkum	25	0.076	0.003	1.95	3.96	0.01
Dongemond	25	0.076	0.003	7.83	28.46	0.09
Dordrecht	25	0.076	0.003	3.07	8.63	0.03
Drachten	25	0.076	0.003	3.05	8.54	0.03
Dreumel	25	0.076	0.003	5.88	20.33	0.06
Driebergen	25	0.076	0.003	4.35	13.96	0.04
Dronten	25	0.076	0.003	3.62	10.92	0.03
Druten	25	0.076	0.003	7.33	26.38	0.08
Dussen	25	0.076	0.003	3.38	9.92	0.03
Echten	25	0.076	0.003	2.6	6.67	0.02
Eck en Wiel	25	0.076	0.003	4.12	13.00	0.04
Ede	25	0.076	0.003	3.05	8.54	0.03
Eelde	25	0.076	0.003	4.09	12.88	0.04
Eethen	25	0.076	0.003	4.09	12.88	0.04
Eindhoven	25	0.076	0.003	3.7	11.25	0.03
Elburg	25	0.076	0.003	2.77	7.38	0.02
Emmen	25	0.076	0.003	1.5	2.08	0.01
Enschede-West	25	0.076	0.003	2.73	7.21	0.02
Epe	25	0.076	0.003	1.44	1.83	0.01
Etten	25	0.076	0.003	3	8.33	0.03
Everstekoog	25	0.076	0.003	4.59	14.96	0.04
Feerwerd	25	0.076	0.003	3.17	9.04	0.03
Foxhol	25	0.076	0.003	5.7	19.58	0.06
Franeker	25	0.076	0.003	10.14	38.08	0.11

Gaarkeuken	25	0.076	0.003	4.13	13.04	0.04
Garmerwolde	25	0.076	0.003	6.39	22.46	0.07
Geestmerambacht	25	0.076	0.003	3.23	9.29	0.03
Geldermalsen	25	0.076	0.003	4.67	15.29	0.05
Gendt	25	0.076	0.003	7.83	28.46	0.09
Genemuiden	25	0.076	0.003	2.22	5.08	0.02
Gennep	25	0.076	0.003	5.33	18.04	0.05
Gieten	25	0.076	0.003	7.61	27.54	0.08
Glanerbrug	25	0.076	0.003	2.74	7.25	0.02
Goedereede	25	0.076	0.003	2.01	4.21	0.01
Goor	25	0.076	0.003	4.1	12.92	0.04
Gorinchem	25	0.076	0.003	3.04	8.50	0.03
Gorredijk	25	0.076	0.003	3.05	8.54	0.03
Gouda	25	0.076	0.003	3.74	11.42	0.03
Groede	25	0.076	0.003	7.13	25.54	0.08
Groenedijk	25	0.076	0.003	2.07	4.46	0.01
Groesbeek	25	0.076	0.003	4.89	16.21	0.05
Groot-Ammers	25	0.076	0.003	2.94	8.08	0.02
Grou	25	0.076	0.003	1.66	2.75	0.01
Haaften	25	0.076	0.003	6.97	24.88	0.07
Haaksbergen	25	0.076	0.003	2.47	6.13	0.02
Haaren	25	0.076	0.003	4.15	13.13	0.04
Haarlem Schalkwijk	25	0.076	0.003	4.65	15.21	0.05
Haarlem Waarderpolder	25	0.076	0.003	4.37	14.04	0.04
Haarlo	25	0.076	0.003	1.97	4.04	0.01
Haastrecht	25	0.076	0.003	3.33	9.71	0.03
Halsteren	25	0.076	0.003	9.81	36.71	0.11
Hapert	25	0.076	0.003	3.8	11.67	0.04

Hardenberg	25	0.076	0.003	3.27	9.46	0.03
Harderwijk	25	0.076	0.003	2.94	8.08	0.02
Hardinxveld	25	0.076	0.003	5.9	20.42	0.06
Harlingen	25	0.076	0.003	1.1	0.42	0.00
Harnaschpolder	25	0.076	0.003	2.55	6.46	0.02
Hattem	25	0.076	0.003	3.14	8.92	0.03
Heemstede	25	0.076	0.003	7.34	26.42	0.08
Heenvliet	25	0.076	0.003	3.16	9.00	0.03
Heerde	25	0.076	0.003	2.68	7.00	0.02
Heerenveen	25	0.076	0.003	6.11	21.29	0.06
Heiloo	25	0.076	0.003	3.48	10.33	0.03
Heino	25	0.076	0.003	1.49	2.04	0.01
Hellevoetsluis	25	0.076	0.003	2.82	7.58	0.02
Hengelo	25	0.076	0.003	2.95	8.13	0.02
Hessenpoort	25	0.076	0.003	3.42	10.08	0.03
Heugem	25	0.076	0.003	1.93	3.88	0.01
Hilversum	25	0.076	0.003	2.09	4.54	0.01
Hoensbroek	25	0.076	0.003	3.9	12.08	0.04
Holten	25	0.076	0.003	6.08	21.17	0.06
Hoogezand	25	0.076	0.003	3.88	12.00	0.04
Hoogvliet	25	0.076	0.003	5.14	17.25	0.05
Horstermeer	25	0.076	0.003	2.24	5.17	0.02
Houten	25	0.076	0.003	2.44	6.00	0.02
Houtrust	25	0.076	0.003	4.01	12.54	0.04
Huizen	25	0.076	0.003	2.68	7.00	0.02
Hulst	25	0.076	0.003	4.61	15.04	0.05
Joure	25	0.076	0.003	2.06	4.42	0.01
Kaatsheuvel	25	0.076	0.003	2.97	8.21	0.02
Kaffeberg	25	0.076	0.003	2.39	5.79	0.02

Kampen	25	0.076	0.003	3.79	11.63	0.03
Katwijk	25	0.076	0.003	4.68	15.33	0.05
Katwoude	25	0.076	0.003	6.09	21.21	0.06
Kloosterzande	25	0.076	0.003	4.39	14.13	0.04
Kootstertille	25	0.076	0.003	1.73	3.04	0.01
Kortenoord	25	0.076	0.003	4.14	13.08	0.04
Kralingseveer	25	0.076	0.003	3.62	10.92	0.03
Lage Zwaluwe	25	0.076	0.003	7.16	25.67	0.08
Land van Cuijk	25	0.076	0.003	5.86	20.25	0.06
Leek	25	0.076	0.003	2.91	7.96	0.02
Leerdam	25	0.076	0.003	3.98	12.42	0.04
Leeuwarden	25	0.076	0.003	3.9	12.08	0.04
Leiden Noord	25	0.076	0.003	4.07	12.79	0.04
Leiden Zuid-West	25	0.076	0.003	5.61	19.21	0.06
Leidsche Rijn	25	0.076	0.003	4.47	14.46	0.04
Leimuiden	25	0.076	0.003	2.08	4.50	0.01
Lelystad	25	0.076	0.003	3.62	10.92	0.03
Lemmer	25	0.076	0.003	1.99	4.13	0.01
Lichtenvoorde	25	0.076	0.003	3.38	9.92	0.03
Lienden	25	0.076	0.003	3.8	11.67	0.04
Limmel	25	0.076	0.003	4.26	13.58	0.04
Lisse	25	0.076	0.003	2.96	8.17	0.02
Loenen	25	0.076	0.003	7.38	26.58	0.08
Lopik	25	0.076	0.003	4.43	14.29	0.04
Losser	25	0.076	0.003	2.4	5.83	0.02
Maarssen	25	0.076	0.003	5.59	19.13	0.06
Maarssenbroek	25	0.076	0.003	2.33	5.54	0.02
Maasbommel	25	0.076	0.003	3.71	11.29	0.03
Marum	25	0.076	0.003	4.92	16.33	0.05

Mastgat	25	0.076	0.003	7.28	26.17	0.08
Meijel	25	0.076	0.003	5.59	19.13	0.06
Meppel	25	0.076	0.003	3.23	9.29	0.03
Middelharnis	25	0.076	0.003	2.18	4.92	0.01
Millingen	25	0.076	0.003	3.52	10.50	0.03
Montfoort	25	0.076	0.003	6.4	22.50	0.07
Nieuwe Waterweg	25	0.076	0.003	2.71	7.13	0.02
Nieuwe Wetering	25	0.076	0.003	2.79	7.46	0.02
Nieuwegein	25	0.076	0.003	2.92	8.00	0.02
Nieuwgraaf	25	0.076	0.003	2.1	4.58	0.01
Nieuwveen	25	0.076	0.003	3.04	8.50	0.03
Nieuwveer	25	0.076	0.003	4.07	12.79	0.04
Nieuw-Vossemeer	25	0.076	0.003	3.83	11.79	0.04
Nijkerk	25	0.076	0.003	2.56	6.50	0.02
Nijmegen	25	0.076	0.003	4.61	15.04	0.05
Nijverdal	25	0.076	0.003	3.99	12.46	0.04
Noordwijk	25	0.076	0.003	4.31	13.79	0.04
Numansdorp	25	0.076	0.003	2.77	7.38	0.02
Oijen	25	0.076	0.003	3.05	8.54	0.03
Olburgen	25	0.076	0.003	2.84	7.67	0.02
Oldenzaal	25	0.076	0.003	2.73	7.21	0.02
Olst-Wijhe	25	0.076	0.003	2.56	6.50	0.02
Ommen	25	0.076	0.003	3.31	9.63	0.03
Onderdendam	25	0.076	0.003	5.33	18.04	0.05
Ooltgensplaat	25	0.076	0.003	2.36	5.67	0.02
Oostburg	25	0.076	0.003	18.4	72.50	0.22
Oosterwolde	25	0.076	0.003	3.47	10.29	0.03
Oosthuizen	25	0.076	0.003	5.11	17.13	0.05
Oostvoorne	25	0.076	0.003	2.53	6.38	0.02

Ootmarsum	25	0.076	0.003	2.31	5.46	0.02
Ossendrecht	25	0.076	0.003	7.8	28.33	0.09
Oud Beijerland	25	0.076	0.003	2.31	5.46	0.02
Oude Pekela	25	0.076	0.003	3.95	12.29	0.04
Oude Tonge	25	0.076	0.003	3.87	11.96	0.04
Oudewater	25	0.076	0.003	6.56	23.17	0.07
Overasselt	25	0.076	0.003	3.74	11.42	0.03
Panheel	25	0.076	0.003	14.36	55.67	0.17
Papendrecht	25	0.076	0.003	5.53	18.88	0.06
Piershil	25	0.076	0.003	4.81	15.88	0.05
Putte	25	0.076	0.003	8.15	29.79	0.09
Raalte	25	0.076	0.003	2.25	5.21	0.02
Renkum	25	0.076	0.003	4.56	14.83	0.04
Retranchement	25	0.076	0.003	6.04	21.00	0.06
Rhenen	25	0.076	0.003	3.5	10.42	0.03
Ridderkerk	25	0.076	0.003	2.39	5.79	0.02
Riel	25	0.076	0.003	6.27	21.96	0.07
Rijen	25	0.076	0.003	5.54	18.92	0.06
Rijsenhout	25	0.076	0.003	3.18	9.08	0.03
Rijssen	25	0.076	0.003	1.92	3.83	0.01
Rimburg	25	0.076	0.003	2.29	5.38	0.02
Roermond	25	0.076	0.003	7.76	28.17	0.08
Ronde Venen	25	0.076	0.003	3.33	9.71	0.03
Rozenburg	25	0.076	0.003	3.66	11.08	0.03
Ruurlo	25	0.076	0.003	2.61	6.71	0.02
Scheemda	25	0.076	0.003	7.68	27.83	0.08
Schelluinen	25	0.076	0.003	3.06	8.58	0.03
Scheve Klap	25	0.076	0.003	2.47	6.13	0.02
Schiermonnikoog	25	0.076	0.003	3	8.33	0.03

Simpelveld	25	0.076	0.003	3.82	11.75	0.04
Sint Maartensdijk	25	0.076	0.003	2.98	8.25	0.02
Sint-Oedenrode	25	0.076	0.003	4.64	15.17	0.05
Sleen	25	0.076	0.003	5.96	20.67	0.06
Sleeuwijk	25	0.076	0.003	3.17	9.04	0.03
Sliedrecht	25	0.076	0.003	3.57	10.71	0.03
Sloten	25	0.076	0.003	2.55	6.46	0.02
Smilde	25	0.076	0.003	3.2	9.17	0.03
Sneek	25	0.076	0.003	2.41	5.88	0.02
Soerendonk	25	0.076	0.003	3.87	11.96	0.04
Soest	25	0.076	0.003	1.99	4.13	0.01
Spijkenisse	25	0.076	0.003	2.29	5.38	0.02
Stadskanaal	25	0.076	0.003	5.22	17.58	0.05
Steenwijk	25	0.076	0.003	3.08	8.67	0.03
Stein	25	0.076	0.003	12.03	45.96	0.14
Stolpen	25	0.076	0.003	5.47	18.63	0.06
Stolwijk	25	0.076	0.003	2.96	8.17	0.02
Strijen	25	0.076	0.003	1.5	2.08	0.01
Susteren	25	0.076	0.003	6.04	21.00	0.06
Ter Apel	25	0.076	0.003	5.85	20.21	0.06
Terneuzen	25	0.076	0.003	10.19	38.29	0.11
Terschelling	25	0.076	0.003	3.81	11.71	0.04
Terwolde	25	0.076	0.003	4.08	12.83	0.04
Tholen	25	0.076	0.003	4.66	15.25	0.05
Tiel	25	0.076	0.003	3.32	9.67	0.03
Tilburg	25	0.076	0.003	3.24	9.33	0.03
Tollebeek	25	0.076	0.003	1.99	4.13	0.01
Tubbergen	25	0.076	0.003	3.5	10.42	0.03
Tweede Exloermond	25	0.076	0.003	8.24	30.17	0.09

Uithoorn	25	0.076	0.003	3.38	9.92	0.03
Uithuizermeeden	25	0.076	0.003	2.59	6.63	0.02
Ulrum	25	0.076	0.003	3.35	9.79	0.03
Ursem	25	0.076	0.003	4.33	13.88	0.04
Utrecht	25	0.076	0.003	3.81	11.71	0.04
Valburg	25	0.076	0.003	6.85	24.38	0.07
Varsseveld	25	0.076	0.003	5.2	17.50	0.05
Veendam	25	0.076	0.003	6.49	22.88	0.07
Veenendaal	25	0.076	0.003	1.93	3.88	0.01
Velsen	25	0.076	0.003	5.98	20.75	0.06
Venlo	25	0.076	0.003	4.3	13.75	0.04
Venray	25	0.076	0.003	2.03	4.29	0.01
Vianen	25	0.076	0.003	3.11	8.79	0.03
Vinkel	25	0.076	0.003	3.35	9.79	0.03
Vlieland	25	0.076	0.003	1.65	2.71	0.01
Vollenhove	25	0.076	0.003	2.14	4.75	0.01
Vriescheloo	25	0.076	0.003	4.94	16.42	0.05
Vroomshoop	25	0.076	0.003	3.66	11.08	0.03
Waalwijk	25	0.076	0.003	4.78	15.75	0.05
Waarde	25	0.076	0.003	5.48	18.67	0.06
Waddinxveen-Randenburg	25	0.076	0.003	3.56	10.67	0.03
Walcheren	25	0.076	0.003	7.91	28.79	0.09
Warns	25	0.076	0.003	1.68	2.83	0.01
Waspik	25	0.076	0.003	2.92	8.00	0.02
Weert	25	0.076	0.003	14.38	55.75	0.17
Weesp	25	0.076	0.003	11.69	44.54	0.13
Wehe den Hoorn	25	0.076	0.003	5.19	17.46	0.05
Wehl	25	0.076	0.003	3.04	8.50	0.03
Wervershoof	25	0.076	0.003	4.72	15.50	0.05

Westerschouwen	25	0.076	0.003	5.19	17.46	0.05
Westpoort	25	0.076	0.003	5.51	18.79	0.06
Wieringen	25	0.076	0.003	4.78	15.75	0.05
Wieringermeer	25	0.076	0.003	7.79	28.29	0.08
Wijk bij Duurstede	25	0.076	0.003	5.32	18.00	0.05
Wijk en Aalburg	25	0.076	0.003	4.16	13.17	0.04
Wijlre	25	0.076	0.003	6.21	21.71	0.07
Willem Annapolder	25	0.076	0.003	7.6	27.50	0.08
Willemstad	25	0.076	0.003	3.96	12.33	0.04
Winsum	25	0.076	0.003	13.13	50.54	0.15
Winterswijk	25	0.076	0.003	4.15	13.13	0.04
Woerden	25	0.076	0.003	5.42	18.42	0.06
Wolvega	25	0.076	0.003	2.86	7.75	0.02
Workum	25	0.076	0.003	1.57	2.38	0.01
Woudenberg	25	0.076	0.003	1.68	2.83	0.01
Zaandam Oost	25	0.076	0.003	6.46	22.75	0.07
Zaltbommel	25	0.076	0.003	7.16	25.67	0.08
Zeewolde	25	0.076	0.003	3.8	11.67	0.04
Zeist	25	0.076	0.003	2.27	5.29	0.02
Zetten	25	0.076	0.003	9.95	37.29	0.11
Zuidhorn 1	25	0.076	0.003	2.79	7.46	0.02
Zuidhorn 2	25	0.076	0.003	5.59	19.13	0.06
Zutphen	25	0.076	0.003	1.57	2.38	0.01
Zwaanshoek	25	0.076	0.003	4.71	15.46	0.05
Zwanenburg	25	0.076	0.003	4.34	13.92	0.04
Zwijndrecht	25	0.076	0.003	2.85	7.71	0.02
Zwolle	25	0.076	0.003	5.33	18.04	0.05

The WQI calculation of Dutch WWTPs effluent

WWTPs	N (qi × Wi)	P (qi × Wi)	COD (qi × Wi)	BOD (qi × Wi)	WQI=$\frac{\sum_{i=0}^{n} qi \times Wi}{\sum_{i=1}^{n} Wi=1}$
’s-Hertogenbosch	0.43	0.38	0.084	0.04	0.934
Aalsmeer	0.22	0.09	0.1	0.07	0.48
Aalst	0.13	0.24	0.068	0.03	0.468
Aalten	0.07	0.13	0.072	0.04	0.312
Aarle-Rixtel	0.21	0.35	0.1	0.04	0.7
Akkrum	0.06	0.14	0.086	0.01	0.296
Alblasserdam	0.11	0.15	0.084	0.05	0.394
Alkmaar	0.18	0.14	0.103	0.05	0.473
Almelo-Sumpel	0.14	0.19	0.082	0.02	0.432
Almelo-Vissedijk	0.11	0.27	0.075	0.02	0.475
Almere	0.18	0.34	0.071	0.02	0.611
Alphen Kerk en Zanen	0.02	0.02	0.071	0.03	0.141
Alphen Noord	0.02	0.01	0.088	0.04	0.158
Ameland	0.06	0.2	0.12	0.04	0.42
Amersfoort	0.37	0.28	0.088	0.02	0.758
Ammerstol	0.04	0.17	0.059	0.03	0.299
Amstelveen	0.66	0.51	0.087	0.05	1.307
Amsterdam West	0.28	0.41	0.097	0.05	0.837
Apeldoorn	0.44	0.75	0.085	0.03	1.305
Arnhem	0.33	0.32	0.048	0.02	0.718
Asperen	0.05	0.16	0.056	0.03	0.296
Assen	0.14	0.14	0.12	0.11	0.51
Asten	0.02	0.06	0.065	0.03	0.175
Baarle-Nassau	0.12	0.07	0.101	0.07	0.361

Barendrecht	0.07	0.02	0.058	0.03	0.178
Bath	0.34	0.98	0.112	0.03	1.462
Beemster	0.28	0.49	0.103	0.06	0.933
Beesd	0.04	0.1	0.05	0.02	0.21
Beilen	0.08	0.09	0.076	0.03	0.276
Bellingwolde	0.05	0.05	0.098	0.03	0.228
Bennekom	0.06	0.02	0.051	0.01	0.141
Bergambacht	0.03	0.11	0.073	0.02	0.233
Bergharen	0.08	0.14	0.085	0.06	0.365
Berkenwoude	0.03	0.11	0.102	0.04	0.282
Beverwijk	0.41	0.99	0.14	0.1	1.64
Biest-Houtakker	0.13	0.05	0.102	0.05	0.332
Birdaard	0.08	0.22	0.091	0.04	0.431
Blaricum	0.04	0.06	0.07	0.03	0.2
Bodegraven	0.02	0.02	0.085	0.04	0.165
Bolsward	0.11	0.16	0.098	0.02	0.388
Bosscherveld	0.03	0.14	0.054	0.03	0.254
Boxtel	0.15	0.08	0.072	0.05	0.352
Breskens	0.14	0.53	0.082	0.07	0.822
Breukelen	0.09	0.01	0.068	0.03	0.198
Brummen	0.08	0.02	0.065	0.02	0.185
Bunnik	0.07	0.04	0.057	0.03	0.197
Burgum	0.03	0.09	0.083	0.03	0.233
Camperlandpolder	0.04	0.05	0.061	0.03	0.181
Chaam	0.06	0.02	0.062	0.04	0.182
Coevorden	0.09	0.05	0.121	0.03	0.291
Culemborg	0.11	0.33	0.074	0.05	0.564
Dalfsen	0.05	0.04	0.061	0.01	0.161

Damwoude	0.07	0.07	0.069	0.01	0.219
De Bilt	0.08	0.04	0.062	0.02	0.202
de Groote Lucht	0.4	1.34	0.074	0.04	1.854
De Groote Zaag	0.06	0.04	0.076	0.04	0.216
De Meern	0.12	0.12	0.063	0.03	0.333
De Verseput	0.04	0.03	0.077	0.05	0.197
Den Bommel	0.03	0.14	0.062	0.06	0.292
Den Ham	0.1	0.18	0.064	0.01	0.354
Den Helder	0.05	0.19	0.153	0.1	0.493
Denekamp	0.17	0.07	0.076	0.02	0.336
Deventer	0.02	0.31	0.075	0.02	0.425
Dieverbrug	0.33	0.06	0.071	0.03	0.491
Dinteloord	0.1	0.06	0.065	0.04	0.265
Dinther	0.08	0.5	0.08	0.04	0.7
Dinxperlo	0.17	0.1	0.05	0.01	0.33
Dodewaard	0.04	0.18	0.101	0.11	0.431
Dokhaven	0.25	0.69	0.092	0.08	1.112
Dokkum	0.87	0.09	0.067	0.01	1.037
Dongemond	0.06	0.41	0.094	0.09	0.654
Dordrecht	0.61	0.28	0.095	0.03	1.015
Drachten	0.27	0.04	0.089	0.03	0.429
Dreumel	0.08	0.17	0.092	0.06	0.402
Driebergen	0.08	0.05	0.081	0.04	0.251
Dronten	0.06	0.07	0.085	0.03	0.245
Druten	0.14	0.26	0.084	0.08	0.564
Dussen	0.12	0.21	0.058	0.03	0.418
Echten	0.07	0.44	0.08	0.02	0.61
Eck en Wiel	0.26	0.12	0.063	0.04	0.483
Ede	0.09	0.18	0.108	0.03	0.408

Eelde	0.25	0.12	0.09	0.04	0.5
Eethen	0.07	0.42	0.072	0.04	0.602
Eindhoven	0.14	0.24	0.065	0.03	0.475
Elburg	0.28	0.3	0.091	0.02	0.691
Emmen	0.17	0.02	0.034	0.01	0.234
Enschede-West	0.06	0.3	0.081	0.02	0.461
Epe	0.25	0	0.048	0.01	0.308
Etten	0.03	0.33	0.086	0.03	0.476
Everstekoog	0.25	0.05	0.097	0.04	0.437
Feerwerd	0.07	0.07	0.073	0.03	0.243
Foxhol	0.08	0.07	0.107	0.06	0.317
Franeker	0.05	0.15	0.149	0.11	0.459
Gaarkeuken	0.17	0.11	0.091	0.04	0.411
Garmerwolde	0.09	0.12	0.103	0.07	0.383
Geestmerambacht	0.36	0.28	0.082	0.03	0.752
Geldermalsen	0.31	0.06	0.065	0.05	0.485
Gendt	0.1	0.23	0.124	0.09	0.544
Genemuiden	0.16	0.01	0.069	0.02	0.259
Gennep	0.09	0.12	0.074	0.05	0.334
Gieten	0.12	0.06	0.129	0.08	0.389
Glanerbrug	0.13	0.02	0.081	0.02	0.251
Gorinchem	0.14	0.25	0.059	0.03	0.479
Gorredijk	0.04	0.07	0.086	0.03	0.226
Gouda	0.06	0.03	0.08	0.03	0.2
Groede	0.06	0.75	0.09	0.08	0.98
Groenedijk	0.17	0.05	0.057	0.01	0.287
Groesbeek	0.01	0.1	0.081	0.05	0.241
Groot-Ammers	0.09	0.24	0.066	0.02	0.416
Grou	0.15	0.02	0.074	0.01	0.254

Haaften	0.02	0.13	0.09	0.07	0.31
Haaksbergen	0.07	0.06	0.065	0.02	0.215
Haaren	0.03	0.03	0.065	0.04	0.165
Haarlem Schalkwijk	0.09	0.17	0.107	0.05	0.417
Haarlem Waarderpolder	0.06	0.77	0.075	0.04	0.945
Haarlo	0.19	0.01	0.064	0.01	0.274
Haastrecht	0.03	0.18	0.079	0.03	0.319
Halsteren	0.04	0.1	0.113	0.11	0.363
Hapert	0.11	0.02	0.065	0.04	0.235
Hardenberg	0.06	0.08	0.118	0.03	0.288
Harderwijk	0.08	0.23	0.096	0.02	0.426
Hardinxveld De Peulen	0.32	0.33	0.1	0.06	0.81
Harlingen	0.11	0.16	0.048	0	0.318
Harnaschpolder	0.01	0.26	0.077	0.02	0.367
Hattem	0.29	0.31	0.054	0.03	0.684
Heemstede	0.03	0.07	0.064	0.08	0.244
Heenvliet	0.26	0.16	0.059	0.03	0.509
Heerde	0.05	0.08	0.077	0.02	0.227
Heerenveen	0.08	0.78	0.181	0.06	1.101
Heiloo	0.23	0.17	0.091	0.03	0.521
Heino	0.1	0.03	0.041	0.01	0.181
Hellevoetsluis	0.04	0.07	0.052	0.02	0.182
Hengelo	0.06	0.37	0.129	0.02	0.579
Hessenpoort	0.51	0.06	0.076	0.03	0.676
Heugem	0.06	0.07	0.038	0.01	0.178
Hilversum	0.06	0.04	0.054	0.01	0.164
Hoensbroek	0.09	0.12	0.063	0.04	0.313
Holten	0.14	0.25	0.121	0.06	0.571

Hoogezand	0.15	0.04	0.089	0.04	0.319
Hoogvliet	0.01	0.07	0.106	0.05	0.236
Horstermeer	0.23	0.03	0.058	0.02	0.338
Houten	0.06	0.05	0.052	0.02	0.182
Houtrust	0.03	0.42	0.079	0.04	0.569
Huizen	0.53	0.01	0.065	0.02	0.625
Hulst	0.1	0.18	0.08	0.05	0.41
Joure	0.05	0.01	0.134	0.01	0.204
Kaatsheuvel	0.03	0.05	0.047	0.02	0.147
Kaffeberg	0.03	0.01	0.043	0.02	0.103
Kampen	0.01	0.04	0.075	0.03	0.155
Katwijk	0.08	0.71	0.095	0.05	0.935
Katwoude	0.4	0.28	0.141	0.06	0.881
Kloosterzande	0.18	0.06	0.054	0.04	0.334
Kootstertille	0.08	0.05	0.056	0.01	0.196
Kortenoord	0.02	0.17	0.075	0.04	0.305
Kralingseveer	0.17	0.6	0.08	0.03	0.88
Lage Zwaluwe	0.26	0.11	0.106	0.08	0.556
Land van Cuijk	0.09	0.47	0.105	0.06	0.725
Leek	0.24	0.15	0.096	0.02	0.506
Leerdam	0.05	0.03	0.08	0.04	0.2
Leeuwarden	0.1	0.52	0.094	0.04	0.754
Leiden Noord	0.12	0.3	0.076	0.04	0.536
Leiden Zuid-West	0.12	0.12	0.101	0.06	0.401
Leidsche Rijn	0.1	0.05	0.084	0.04	0.274
Leimuiden	0.09	0.01	0.058	0.01	0.168
Lelystad	0.03	0.14	0.102	0.03	0.302
Lemmer	0.15	0.07	0.083	0.01	0.313
Lichtenvoorde	0.03	0.24	0.102	0.03	0.402

Lienden	0.06	0.1	0.067	0.04	0.267
Limmel	0.08	0.33	0.067	0.04	0.517
Lisse	0.35	0.08	0.075	0.02	0.525
Loenen	0.07	0.42	0.091	0.08	0.661
Lopik	0.12	0.06	0.08	0.04	0.3
Losser	0.06	0.06	0.074	0.02	0.214
Maarssen	0.02	0.05	0.107	0.06	0.237
Maarssenbroek	0.12	0.22	0.046	0.02	0.406
Maasbommel	0.03	0.09	0.064	0.03	0.214
Marum	0.07	0.11	0.1	0.05	0.33
Mastgat	0.13	0.07	0.089	0.08	0.369
Meijel	0.16	0.06	0.097	0.06	0.377
Meppel	0.11	0.15	0.073	0.03	0.363
Middelharnis	0.04	0.02	0.047	0.01	0.117
Millingen	0	0.11	0.062	0.03	0.202
Montfoort	0.08	0.13	0.104	0.07	0.384
Nieuwe Waterweg	0.12	0.4	0.084	0.02	0.624
Nieuwe Wetering	0.12	0.03	0.076	0.02	0.246
Nieuwegein	0.05	0.66	0.069	0.02	0.799
Nieuwgraaf	0.41	0.61	0.051	0.01	1.081
Nieuwveen	0.28	0.03	0.101	0.03	0.441
Nieuwveer	0.03	0.79	0.072	0.04	0.932
Nieuw-Vossemeer	0.45	0.02	0.054	0.04	0.564
Nijkerk	0.07	0.03	0.068	0.02	0.188
Nijmegen	0.09	0.72	0.067	0.05	0.927
Nijverdal	0.41	0.54	0.198	0.04	1.188
Noordwijk	0.09	0.09	0.082	0.04	0.302
Numansdorp	0.07	0.04	0.046	0.02	0.176

Oijen	0.04	0.7	0.062	0.03	0.832
Olburgen	0.08	1.57	0.063	0.02	1.733
Oldenzaal	0.27	0.1	0.075	0.02	0.465
Olst-Wijhe	0.09	0.11	0.064	0.02	0.284
Ommen	0.06	0.07	0.097	0.03	0.257
Onderdendam	0.06	0.1	0.085	0.05	0.295
Ooltgensplaat	0.1	0.14	0.05	0.02	0.31
Oostburg	0.07	0.59	0.153	0.22	1.033
Oosterwolde	0.24	0.07	0.093	0.03	0.433
Oosthuizen	0.05	0.18	0.115	0.05	0.395
Oostvoorne	0.14	0.26	0.072	0.02	0.492
Ootmarsum	0.05	0.08	0.051	0.02	0.201
Ossendrecht	0.06	0.07	0.076	0.09	0.296
Oude Tonge	0.03	0.17	0.068	0.04	0.308
Oudewater	0.12	0.05	0.13	0.07	0.37
Overasselt	0.06	0.17	0.053	0.03	0.313
Panheel	0.05	0.72	0.158	0.17	1.098
Papendrecht	0.52	0.05	0.065	0.06	0.695
Piershil	0.04	0.26	0.07	0.05	0.42
Putte	0.11	0.07	0.112	0.09	0.382
Raalte	0.1	0.01	0.075	0.02	0.205
Renkum	0.04	0.47	0.078	0.04	0.628
Retranchement	0.19	0.22	0.069	0.06	0.539
Rhenen	0.04	0.05	0.062	0.03	0.182
Ridderkerk	0.09	0.12	0.053	0.02	0.283
Riel	0.05	0.12	0.1	0.07	0.34
Rijen	0.06	0.09	0.09	0.06	0.3
Rijssen	0.29	0.04	0.059	0.01	0.399
Rimburg	0.04	0.04	0.068	0.02	0.168

Roermond	0.04	0.22	0.161	0.08	0.501
Ronde Venen	0.58	0.04	0.095	0.03	0.745
Rozenburg	0.06	0.19	0.055	0.03	0.335
Ruurlo	0.08	0.04	0.071	0.02	0.211
Scheemda	0.07	0.13	0.134	0.08	0.414
Schelluinen	0.08	0.17	0.062	0.03	0.342
Scheve Klap	0.01	0.15	0.066	0.02	0.246
Schiermonnikoog	0.02	0.22	0.09	0.03	0.36
Simpelveld	0.03	0.03	0.055	0.04	0.155
Sint Maartensdijk	0.09	0.07	0.051	0.02	0.231
Sint-Oedenrode	0.07	0.05	0.084	0.05	0.254
Sleen	0.06	0.08	0.093	0.06	0.293
Sleeuwijk	0.14	0.08	0.039	0.03	0.289
Sliedrecht	0.08	0.03	0.072	0.03	0.212
Sloten	0.11	0.08	0.084	0.02	0.294
Smilde	0.1	0.04	0.079	0.03	0.249
Sneek	0.05	0.08	0.092	0.02	0.242
Soerendonk	0.06	0.01	0.061	0.04	0.171
Soest	0.04	0.22	0.056	0.01	0.326
Spijkenisse	0.25	0.61	0.056	0.02	0.936
Stadskanaal	0.03	0.06	0.126	0.05	0.266
Stein	0.08	0.1	0.126	0.14	0.446
Stolpen	0.06	0.29	0.107	0.06	0.517
Stolwijk	0.46	0.01	0.072	0.02	0.562
Susteren	0.03	0.32	0.088	0.06	0.498
Terneuzen	0.24	0.16	0.117	0.11	0.627
Terschelling	0.06	0.21	0.109	0.04	0.419
Terwolde	0.15	0.24	0.14	0.04	0.57

Tholen	0.13	0.04	0.073	0.05	0.293
Tiel	0.47	0.53	0.062	0.03	1.092
Tilburg	0.09	0.2	0.091	0.03	0.411
Tollebeek	0.24	0.46	0.063	0.01	0.773
Tubbergen	0.3	0.44	0.121	0.03	0.891
Tweede Exloermond	0.29	0.06	0.132	0.09	0.572
Uithoorn	0.22	0.06	0.083	0.03	0.393
Uithuizermeeden	0.08	0.04	0.06	0.02	0.2
Ulrum	0.15	0.17	0.094	0.03	0.444
Ursem	0.06	0.03	0.089	0.04	0.219
Utrecht	0.07	0.27	0.069	0.04	0.449
Valburg	0.12	0.33	0.081	0.07	0.601
Varsseveld	0.32	0.09	0.098	0.05	0.558
Veendam	0.13	0.2	0.152	0.07	0.552
Veenendaal	0.12	0.08	0.052	0.01	0.262
Velsen	0.08	0.36	0.086	0.06	0.586
Venlo	0.06	0.12	0.105	0.04	0.325
Venray	0.26	0	0.057	0.01	0.327
Vianen	0.42	0.19	0.062	0.03	0.702
Vinkel	0.05	0.09	0.081	0.03	0.251
Vlieland	0.04	0.19	0.067	0.01	0.307
Vollenhove	0.06	0.07	0.055	0.01	0.195
Vriescheloo	0.04	0.07	0.099	0.05	0.259
Vroomshoop	0.06	0.08	0.101	0.03	0.271
Waalwijk	0.05	0.26	0.126	0.05	0.486
Waddinxveen-Randenburg	0.06	0.01	0.085	0.03	0.185
Walcheren	0.14	0.45	0.108	0.09	0.788
Warns	0.09	0.08	0.065	0.01	0.245

Waspik	0.02	0.04	0.076	0.02	0.156
Weert	0.43	0.64	0.136	0.17	1.376
Weesp	0.05	0.09	0.149	0.13	0.419
Wehe den Hoorn	0.01	0.18	0.084	0.05	0.324
Wehl	0.7	0.05	0.058	0.03	0.838
Wervershoof	0.64	0.25	0.089	0.05	1.029
Westerschouwen	0.13	0.13	0.08	0.05	0.39
Westpoort	0.1	0.35	0.105	0.06	0.615
Wieringen	0.16	0.19	0.085	0.05	0.485
Wieringermeer	0.08	0.3	0.098	0.08	0.558
Wijk bij Duurstede	0.29	0.04	0.079	0.05	0.459
Wijk en Aalburg	0.17	0.24	0.075	0.04	0.525
Wijlre	0.19	0.04	0.079	0.07	0.379
Willem Annapolder	0.11	0.08	0.102	0.08	0.372
Willemstad	0.13	0.29	0.065	0.04	0.525
Winsum	0.14	0.22	0.17	0.15	0.68
Winterswijk	0.22	0.05	0.118	0.04	0.428
Woerden	0.1	0.1	0.103	0.06	0.363
Wolvega	0.12	0.15	0.094	0.02	0.384
Workum	0.11	0.1	0.048	0.01	0.268
Woudenberg	0.14	0.02	0.061	0.01	0.231
Zaandam Oost	0.08	0.28	0.137	0.07	0.567
Zaltbommel	0.02	0.14	0.095	0.08	0.335
Zeewolde	0.06	0.04	0.105	0.04	0.245
Zeist	0.55	0.03	0.047	0.02	0.647
Zetten	0.09	0.44	0.112	0.11	0.752

Zuidhorn 1	0.06	0.08	0.08	0.02	0.24
Zuidhorn 2	0.16	0.22	0.095	0.06	0.535
Zwaanshoek	0.11	0.8	0.103	0.05	1.063
Zwanenburg	0.1	0.2	0.068	0.04	0.408
Zwolle	0.21	1.35	0.131	0.05	1.741

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Appendix G: Interview questionnaires

F1: Interview with Dr. Leo Carswell

	Interview questions
1	What is Advanced Process Control and how does it exactly work?
2	How is treatment process optimized by APC?
3	What are the roles of involved sensors in APC?
4	How much is the cost of the implementation of APC?
5	How do you calculate the costs?
6	How much is the carbon footprint of APC?
7	How do you calculate the carbon footprint of APC?
8	What is the removal efficiency of APC? Can you give me a percentage?
9	How do you calculate the removal efficiency of APC?
10	What is the TRL level of APC in your opinion?

F2: Interview with Mirabella Mulder (wastewater treatment expert)

	Interview questions
1	What are (PACAS and Ozone+ Sand filtration) and how do they exactly work?
2	How is treatment process optimized by the implementation of PACAS and Ozone+ Sand filtration?
3	Is PACAS, fit, and function compatible with the available operational environment or renovation needs to be done to implement PACAS? What about Ozone+ Sand filtration
4	How much is the cost of the implementation of PACAS and Ozone+ Sand filtration
5	How do you calculate the costs? Is there any mechanism to calculate cost?
6	How much is the carbon footprint of those technologies?
7	How do you calculate the carbon footprint?
8	What is the removal efficiency of PACAS and Ozone+ Sand filtration? Can you give me a percentage?

	By increasing PAC dosage removal efficiency increased? 25 mg/l 75%? What if 50 mg/l?
9	How do you calculate the removal efficiency of the implementation of PACAS and Ozone+ Sand filtration?
10	What is the TRL level of PACAS and Ozone+ Sand filtration in your opinion?

F3: Interview with Ron van der Oost (water quality expert)

	Interview questions
1	Firstly, could you please explain about SIMONI index?
2	What are endpoints?
3	How can I find the endpoints for each WWTP?
4	How can I have the lowest BEQ of endpoint for calculating Safe BEQ?
5	For HC5 BEQ we need SSD graphs, how can I provide this graph for each WWTP?
6	Would you please explain about the Benchmark for Background BEQ?
7	How can I use bioassay you use for each WWTPs?
8	Would you please explain about determining Bioassay and it`s response?
9	What are the benefits of SIMONI strategy?
10	Would you please tell us about the challenges of SIMONI?

F4: Interview with Dr Arthur Meuleman (General Manager/CEO, Secretary board of the Brabantse Delta (The Netherlands)

	Interview questions
1	What are the main criteria for Dutch water managers on the implementation of innovative technologies at WWTPs?
2	Apart from costs and environmental impacts, what are the other important criteria to make a decision on the application of innovative technologies?
3	You said impact on environment is important, would you elaborate on this and tell us what you exactly mean?
4	How does decision-making process work on the implementation of new technologies?

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5	Who are involved in the decision-making process?
6	As we understood you prepare all information such as costs, carbon footprint and water quality impact of the implementation technology and send it to elected water board to make decision on it?
7	What are the main technical challenges that you have on the implementation of new technologies?
8	How long does it take if you want to make a decision on the implementation of new technologies?
9	
10	