Deliverable D6.5
Health and environmental risk management for the operation of the greenfield demo site at Vendée

The project "Innovation Demonstration for a Competitive and Innovative European Water Reuse Sector" (DEMOWARE) has received funding from the European Union's 7th Framework Programme for research, technological development and demonstration, theme ENV.2013.WATER INNO&DEMO-1 (Water innovation demonstration projects) under grant agreement no 619040

Deliverable Title	D6.5 Health and environmental risk management for the operation of the greenfield demo site at Vendée
Related Work Package:	WP6
Deliverable lead:	KWB
Author(s):	Wolfgang Seis, Christian Remy
Contact for queries	KWB: Wolfgang Seis Kompetenzzentrum Wasser Berlin gGmbH Cicerostr. 24 D-10709 Berlin T +49 30 53653 807 E wolfgang.seis@kompetenz-wasser.de
Dissemination level:	Restricted
Due submission date:	31/12/2016 (M36)
Actual submission:	30/01/2017
Grant Agreement Number:	619040
Instrument:	FP7-ENV-2013-WATER-INNO-DEMO
Start date of the project:	01.01.2014
Duration of the project:	36 months
Website:	www.demoware.eu
Abstract	This report presents the assessment of the planned water reuse scheme at Le Jaunay reservoir (Vendée) in its potential risks for human health and ecosystems, and also in its overall environmental impacts. Methods of risk assessment (quantitative microbial and chemical risk assessment) and Life Cycle Assessment are used to characterize the potential hazards associated with the use of reclaimed water, but also the environmental benefits compared to other options for additional drinking water supply. The assessments show that water reuse can be operated without unacceptable risks for humans and the environment, and that it is competitive to other options of water supply in its energy demand and greenhouse gas emissions. Data quality should be improved in a demonstrator phase to validate the outcomes of this first assessment.

Versioning and Contribution History

Version	Date	Modified by	Modification reason
v.01	18.11.2016	Wolfgang Seis, Christian Remy	
v.02	06.12.2016	Wolfgang Seis, Christian Remy	Comments of Julien Orsoni addressed
v.03	20.12.2016	Jessica François, Charlotte Arnal, Armelle Hébert (VERI)	Initial review
Final	27.01.2017	Wolfgang Seis, Christian Remy	Comments addressed

Table of contents

List of figures

List of tables

Glossary

AA-EQS	Annual Average Environmental Quality Standard
ADI	Acceptable Daily Intake
AF	Assessment factor
AMPA	Aminomethylphosphonic acid
CCO	Communauté de communes des Olonnes
CED	Cumulative energy demand
CTU	Comparative toxic unit
DALY	disability adjusted life years
DWTP	Drinking water treatment plant
EDR	Electrodialysis Reversal
EQS	Environmental Quality Standards
ET	Ecotoxicity
EU	European Union
FEP	Freshwater eutrophication potential
GWP	Global warming potential
HT	Human toxicity
IHCP	Institute for Health and Consumer Protection
IPR	Indirect potable reuse
LCA	Life Cycle Assessment
MAC-EQS	Maximum Allowable Concentration Environmental Quality Standard
MAR	Managed aquifer recharge
MEP	Marine eutrophication potential
µGAC	Micro-granular activated carbon
PAC	Powdered activated carbon
PI (d)	Risk of infection in an individual exposed to a single pathogen dose
PNEC	Predicted No Environmental Concentration
RfD	Reference Dose
RNA	Ribonucleic acid
RO	Reverse osmosis
RQ	Risk quotient
SUSP	Suspended
TAP	Terrestrial acidification potential
TDI	Tolerable Daily Intake
TGD	Technical guidance document
TTC	Threshold of Toxicological Concern
UF	Ultrafiltration
UV	Ultraviolet

WAF	Water availability footprint
WFP	Water footprinting
WIIX	Water Impact Index
WQF	Water quality footprint
WQI	Water quality index
WSP	Water safety plan
WWTP	Wastewater treatment plant

Executive summary

The planned water reuse scheme at Le Jaunay reservoir in the Vendée region should mitigate potential shortages in drinking water supply during dry seasons by refilling the freshwater reservoir with reclaimed water from a local wastewater treatment plant after adequate tertiary treatment. This scheme of indirect potable reuse (IPR) can pose a valuable option in a strategic planning of securing the future water supply in this region (= west coast of Vendée).

This report summarizes the results of risk assessment and Life Cycle Assessment to quantify potential hazards of IPR for human health and ecosystems, and also the overall environmental impacts of water reuse compared to other options of additional drinking water supply. This first assessment of the planned IPR scheme is based on a set of monitoring data for water quality and the planned design of the tertiary treatment developed during the DEMOWARE project.

Quantitative microbial risk assessment shows that no unacceptable risks for human health is associated with the IPR scheme, given the multiple barriers for microbial contaminants in tertiary treatment and drinking water production. Although bathing is forbidden in the drinking water reservoir microbial risk from recreational activities has been assessed as a complementary scenario. For recreational activities in the reservoir, additional risks for human health due to input of reclaimed water are well below acceptable limits of the EU Bathing Water Directive.

Chemical risk assessment was based on monitoring campaigns planned and conducted by VERI. Based on a single substance approach it revealed that health risks from the monitored 138 individual substances are below most guideline values for drinking water quality, even when taking the higher range of detected concentrations in the reclaimed water (“realistic worst-case approach”). However, selected substances should be monitored more closely to confirm the results of this study with more data. Several substances in reclaimed water may pose an additional risk for ecosystems, which should also be further investigated in future studies. In addition, expected elimination rates of trace organics in tertiary treatment and drinking water treatment should be validated with a demonstrator, and frequent monitoring. Moreover, effect based monitoring strategies should be considered.

Life Cycle Assessment shows that water reuse is competitive in energy demand and associated greenhouse gas emissions when compared to water import from another reservoir (La Balingue) or seasonal water storage in a mining quarry. Seawater desalination requires twice as much energy and +40% greenhouse gas emissions than water reuse. Water reuse can also alleviate the local water stress by providing additional drinking water without exploiting the local freshwater resources, which is represented by a low water footprint of IPR compared to existing drinking water supply or water import. Additional benefits of IPR include the reduction of emissions into the marine environment with secondary effluent, but IPR may also cause an increased risk of eutrophication in the reservoir which has to be analysed during the demonstrator phase.

Overall, both risk assessment and Life Cycle Assessment confirm that an IPR scheme at Le Jaunay reservoir could be operated without unacceptable risks for human health and ecosystems, and with overall environmental benefits compared to water import or seawater desalination. However, results of this first assessment are based on a small set of monitoring data and many design assumptions for the tertiary treatment. Moreover, effect based monitoring should be considered given the lack of knowledge regarding general toxicity as well as low dose mixture and chronic effects of many chemicals. Both aspects should be further investigated in future studies with a demonstrator of tertiary treatment and targeted monitoring of selected substances also in drinking water treatment to validate and support the conclusions drawn in the present study.

1 Introduction

In the Vendée region in North-West of France, the reclamation of secondary effluent from a wastewater treatment plant (WWTP) for indirect potable reuse (IPR) can be an option for augmentation of freshwater resources for drinking water supply. As the local reservoir of Le Jaunay has experienced very low water levels in recent summer periods with high water demand and low natural water availability in the influent river, the local operator Vendée Eau wants to explore the options for water reuse to provide additional drinking water "on-demand" during times of water scarcity. The project DEMOWARE supports this exploration with different tasks, and the present report focusses on risk assessment and environmental impacts of the reuse scheme.

Risk assessment

Regarding the assessment of risk, the report focuses on both health and environmental aspects caused by the discharge of selected chemicals and pathogens present in municipal wastewater. Environmental risk is assessed for the freshwater environments of the river and freshwater reservoir in Le Jaunay. Health risk assessment is conducted for the consumption of drinking water as well as for recreational activities in the reservoir. The study is based on monitoring data from a monitoring campaign which was planned and conducted by VERI and only includes the analysed substances. Effect based monitoring would have been a more general way to characterize environmental risk, but as this kind of information was not available a substance specific approach has been used. Moreover, "classical" risks like the ones resulting from THM formation due to drinking water chlorination, which are expected to be part of the existing safety management at the drinking water treatment, are not addressed.

The risk assessment aims at supporting the decision making process by early identifying and prioritizing potentially relevant chemical substances and existing knowledge gaps. Risk in this context is interpreted as the probability of not achieving a certain target due to incomplete information or insufficient wastewater treatment.

Targets in turn may differ in their character and origin. Some legally binding limit values, which serve as targets, may be stricter than toxicologically derived guideline values. In these cases, being "at risk" or "of concern" does not necessarily mean that adverse health effects are to be expected, but rather that given the information currently available the targets defined by society will potentially not be achieved. The consequence derived from an assessment of being "of concern" depends on the quality of information used for the assessment. If the identified risk is based on a solid dataset at an already existing treatment scheme, further measures for risk reduction have to be considered. If, as in Vendée, the assessment is based on a small data set and planning data for tertiary treatment schemes, the following steps should be taken:

a. the model and the assumptions about the model inputs should be refined by getting more site specific information, i.e. taking more measurements of the substances "of concern"
b. the proposed target values of trace organic substances should be agreed on with responsible environmental and health authorities
c. the design of the tertiary treatment schemes may be adapted in order to reduce substances "of concern" below target values

In general, effect-based monitoring could provide added value in terms of better benchmark residual uncertainties with regards to low doses chemical mixtures and better assessment of their related primary toxic effects that may elicit later adverse effects, especially via endocrine disruption pathways or oxidative stress pathways.

Specifics of these working steps are addressed more closely in the related sections of this report. Uncertainties are addressed explicitly by using scenario approaches for chemicals risk assessment and Bayesian Monte Carlo simulation for microbial risk. Thereby, a reproducible way of how to quantify notions of probability and risk as well as of how to address explicitly the current state of knowledge will be demonstrated using the site specific boundary conditions of Vendée.

Life Cycle Assessment

However, tertiary treatment of reclaimed WWTP effluent will also cause other environmental impacts during construction and operation, which can be associated to electricity, chemicals and infrastructure required for the different treatment steps. A prominent example is the emission of greenhouse gases in power plants running on fossil fuels, leading to an increase in global warming and causing climate change. These “indirect” effects of IPR have to be compared to the environmental impacts of other options for additional drinking water supply to quantify the environmental footprint of different options. Aside from additional efforts in energy and associated emissions, water reuse can also provide beneficial effects by reducing local water stress on limited natural resources. The method of Life Cycle Assessment (LCA) is a suitable tool to quantify all direct and indirect environmental impacts of technical systems and compare them in a defined framework with a set of scientifically based environmental indicators.

Structure of this report

The present report describes the definitions, input data and results of both risk assessment and LCA of the projected water reuse scheme at Le Jaunay reservoir in Vendée. In particular, the report builds upon the data generated within tasks 6.1 to 6.4 of the DEMOWARE project and the respective deliverables. It is structured as follows:

- **Chapter 2:** **Risk assessment** with definitions, input data, results and conclusions
- **Chapter 3:** **Life Cycle Assessment** with definition of goal and scope, input data, results, and conclusions
- **Chapter 4:** **Summary** of the outcomes and outlook

2 Risk assessment and management

Risk based management and implementation processes are considered good practice in the 21st century and are supported by the World Health Organisation (WHO) for both drinking water supply systems and water reuse and sanitation systems.

For drinking water system Water Safety Plans (WSP) are promoted for the management of drinking water supply systems since 2004 and lots of information and experience is available in this field. A comparable knowledge base and best practice examples for water reuse systems is still in development. For example, while the practical "Water Safety Plan Manual" was published in 2006 it took until 2016 for the release of a comparable manual for "Sanitation Safety Planning" for the step-by-step implementation of the "WHO guidelines for the safe use of wastewater, excreta and greywater in agriculture". The most comprehensive guidance for elaborating risk based implementation strategies is currently given by the "Australian Guidelines for Water Recycling". Within a set of guidance documents a complete picture of various applications for water reuse is given, including specific applications as managed aquifer recharge (MAR) and the augmentation of drinking water supplies. Table 2.1 summarizes similarities and differences between risk assessment for Drinking water supply systems and water reuse systems. As in Vendée reclaimed water will be used to augment a drinking water reservoir aspect of both areas are considered.

Table 2.1 Similarities and differences between risk assessment for drinking water and water reuse systems.

Parameters	Drinking Water	Water reuse
Exposure route	Drinking water consumption Ingestion Inhalation (e.g. legionella spp. ,DBPs / THMs) Cutaneous	Depending on use category, generally several different routes of exposure during various steps of water reuse (pre-treatment, storage, post-treatment, distribution)
Water quality	Protected groundwater source (usually of high microbiological quality), high variations in surface water quality as (open) source, hard to predict source water quality at a given time	Low microbial quality of secondary effluent but: Quality of source water (effluent wastewater treatment) can be controlled and predicted to a certain extent
Sources of contamination (chemical & pathogen)	Surface water: often multiple sources of contamination, hard to identify unknown sources, microbial source tracking as a major field of research	Main sources of pollution: human and animal faeces (toilet flushing, surface runoff), prior information of presence of pathogens exist through epidemiological data
Risk management approaches	Water Safety Plans	Sanitation Safety Plans, Water Reuse Safety Plans
Typical nature of exposure	High volume (0.5-2L) intentionally ingested Shower/ Bath/ inhalation + cutaneous routes of exposure	Usually small volumes unintentionally ingested (except from potable reuse applications)
Type of barriers	Multiple barrier principle (source protection, treatment, network, installations in buildings), Focus on water quality control HACCP / Water Safety Plan	Control measures may include treatment and non-treatment options aiming at water quality and exposure reduction, respectively.

2.1 Risk Assessment at the water reuse site in Vendée

In Vendée tertiary treated wastewater is intended to be reused for augmenting the local drinking water reservoir. Downstream of the existing wastewater treatment plant, two different process schemes for tertiary treatment have been proposed during the DEMOWARE project. The two options have not yet been constructed. An overview of the planned water reuse system is illustrated in Figure 2.1.

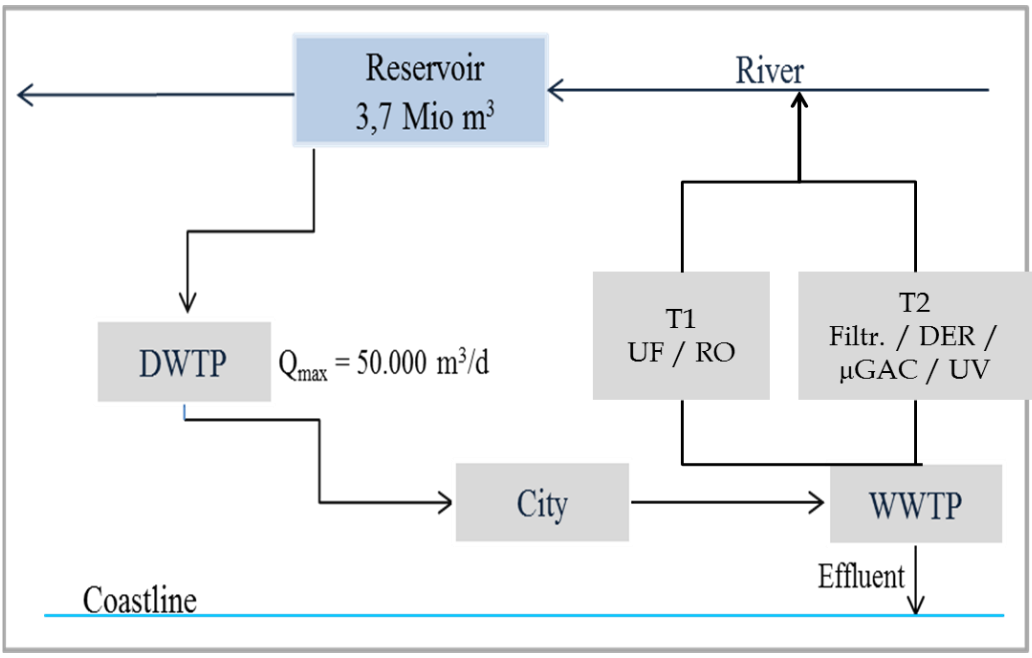

Figure 2.1 Overview of the planned indirect potable reuse scheme in Vendée

Risk Assessment is a necessary process in order to guarantee safety in water supply systems. Risk can be expressed in several ways ranging from qualitative descriptions over semi-quantitative approach to fully quantitative approaches. Regardless of the used approach all risk assessments have to find expressions for a. the hazards and the (hazardous) events they are aiming at, b. the probability, that the event occurs and c. the resulting consequences. Differences can be made between risk under "normal" and "incident conditions".

The general and fundamental message of any risk assessment is "know your system". There will never be a system which is completely risk free and it is not a sensible goal to achieve a level of zero risk, as in risk theory such a level simply does not exist. The added value of risk assessments in any form lies in the systematic approach of making hazards, counter measures, consequences and knowledge gaps transparent and thereby identifying areas of improvement and making better decisions.

2.1.1 Goal and scope

The present study aims at contributing to the successful incremental implementation of the reuse site in Vendée by assessing the environmental and human health risk based on the available information of these sampling campaigns. Nutrients and the resulting potential for eutrophication will not been assessed in this study as the issue has already been addressed in deliverable 6.3 of the DEMOWARE project.

Additionally to the discharges of the WWTP two treatment options for tertiary wastewater will be compared based on the proposals elaborated during the DEMOWARE project. Although there has not been a decision on which treatment option will be implemented and operational data of the system performance is not available, risk assessment early in the planning process will give valuable insights about potential hazards and which treatment scheme is more suitable to reduce environmental and human health risk to acceptable levels.

The results of the risk assessment are intended to support the decision making process for both the decision about which treatment option to implement and potential operational modification of the individual treatment schemes. For example, the performance of the planned UV disinfection can be controlled by the energy intake and various pre-treatment options to reduce turbidity. However, as the UV disinfection is not planned in detail so far, the present study uses the range of plausible assumptions for the performance and investigates the effect of the uncertainty on the potential outcome.

Thus, the results of this risk assessment have to be seen as an early to intermediate stage assessment which aims at making a meaningful contribution to the ongoing monitoring programme and risk based implementation process. Limitation of the present study given by conducted monitoring campaign. This limitations consist of:

1) the small number of analysed samples
2) the lack of effect based sampling using e.g. bioassays

However, as risk assessment is always conditional on the available information, the available information was used using available RA methodologies for this kind of information. Further investigations could be envisaged by including effect-based monitoring.

2.2 Available information and data quality

During the DEMOWARE project 130 organic substances have been analysed in three sampling campaigns in the effluent of the wastewater treatment plant (WWTP), the river and the reservoir. Moreover, samples have been analysed for heavy metals, nutrients, faecal indicator organisms and pathogens (Enterovirus, *Cryptosporidium spp., Giardia spp.*).

The results of these three sampling campaigns have been used as a basis for risk assessment. Due to this limited dataset, additional information from relevant literature has been used to update assumptions about water quality parameters. Especially for microbial parameters with lognormal distributions where parameter uncertainty changes assumptions by orders of magnitude, weakly informative priors from literature have been added in order to regularize parameter estimations.

Moreover, the system design of the wastewater treatment plan (WWTP), the drinking water treatment plant (DWTP) and the environmental conditions in Vendée have been taken into account by using local information of the flow patterns and volumes of the reservoir. Furthermore, the intended tertiary treatment options have been assessed.

2.3 Methodology

For chemical and microbial risk assessment, different methodological approaches have been used. Microbial risk was estimated using probabilistic modelling based on Monte Carlo simulation and focused on health risk from pathogenic microorganisms (see chapter 2.3.2). For chemical risk assessment, the modelling approaches of the European Technical Guidance document on risk assessment of new and existing substances (TGD) have been used (see chapter 2.3.3). Moreover, chemical risk assessment addressed both health and environmental endpoints. Finally, uncertainties have been addressed differently. For chemical risk assessment, point estimates and scenario approaches have been used based on frequentist statistical approaches. Microbial parameters have been modelled using Bayesian parameter estimation methods. Weakly informative priors for regularizing lognormally distributed parameters have been added from literature. All calculations have been done using the programming language “R”. For Bayesian parameter estimation the program “Stan” in combination with the r-package “rstan” has been used.

2.3.1 Iterative approach to risk assessment

In the present risk assessment, a systematic and iterative approach is pursued. This means that the assessment is considered to be finalized as soon as it can be shown that the predefined health target is met. E.g. given that the effluent concentration of a certain chemical compound is already below acceptable level for health risk assessment, this compound will no longer be part of the subsequent assessment step. In the given example the subsequent assessment step would be the assessment of the proposed tertiary treatment options. Accordingly, if hygienic water quality targets would already be met by wastewater treatment no further assessment would be conducted.

2.3.2 Methodology for microbial risk assessment

The most common and widespread health risk associated with waterborne microbial pathogens is gastroenteritis. The general approach for assessing microbial risk is to estimate the concentrations of pathogenic microorganisms in the influent of the wastewater treatment plant followed by an assessment of the performance of each treatment step up to the point of exposure. Thereby the water quality after each individual barrier is calculated. The water quality after the final treatment step is used as a measure for residual risk. In quantitative microbial risk assessment (QMRA) the calculated concentration of pathogenic microorganisms are combined with available dose response relationships and end-use specific exposure scenarios to calculate the probability of infection. In some countries were QMRA is obligatory, like e.g. in the Netherlands, risk calculation stops at the “risk of infection level”. Other approaches like the ones used by WHO and Australia further calculate the disease burden caused by the selected reference pathogens. As a measure of the resulting disease burden the DALY indicator is used, which stands for *disability adjusted life years*. For this, first the probability of illness is calculated and multiplied by a severity factor specific for the different health outcomes the illness might cause. Thereby the DALY indicator makes different kinds of diseases comparable.

Since not all infections lead to disease, the probability of illness is calculated by multiplying the probability of infection by a factor which accounts for the disease per infection probability. These factors are specific for each pathogen. In this risk assessment DALYs per person per year were calculated using average severity factors which have been published by (Havelaar and Melse 2003).

In order to set a benchmark for acceptable risk the WHO proposed a benchmark value of 10^{-6} additional DALYs per person per year (pppy), which corresponds to a probability of infection of 10^{-3}-10^{-4} per person per year for mild diarrhea. Although the WHO Guidelines for Drinking Water Quality underline that benchmark setting is the responsibility of the national health authorities, the present risk assessment uses the WHO benchmark to benchmark the level of residual risk.

Figure 2.2 gives an overview of the different steps of QMRA for water reuse systems. In the specific case of Vendée both the reservoir and the drinking water treatment plant have to be added (see chapter 2.3.2.3).

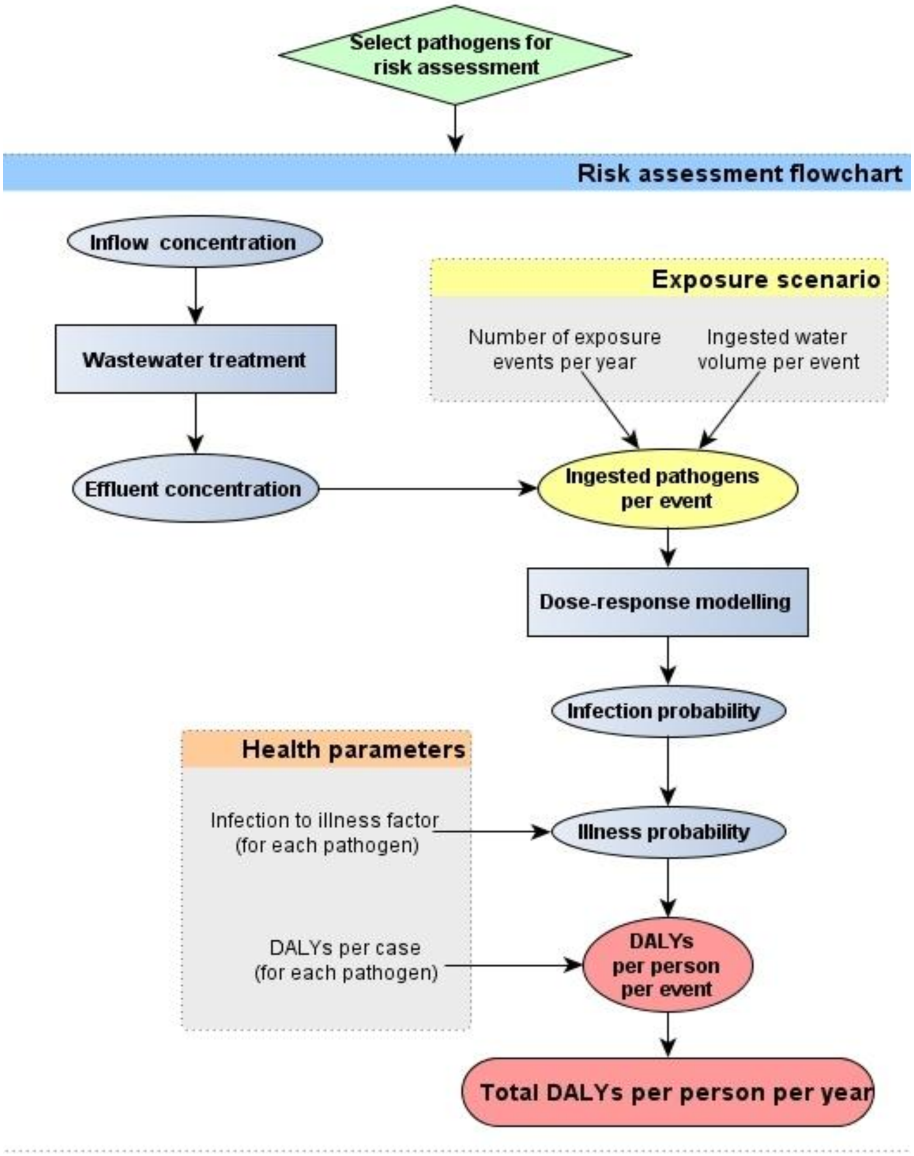

Figure 2.2 **Conceptual overview of the different steps of quantitative microbial risk assessment.**
The box for wastewater treatment plant contains all individual treatment steps.

Although QMRA is conceptually simple there are various subtle aspects on how to deal with various pieces of information regarding the input variables and the related uncertainty. Since risk assessments are and should be made as early in the decision making process as possible it is logical that early in the process only limited site specific information and data will be available. In order to cope with uncertainty about input variable it is the current state-of-the-art to use probability distributions instead of point estimates as input variables. By sampling a high number (e.g. 10000) of samples from each distribution and calculating again 10000 possible combinations of various inputs the uncertainty is propagated through the model. This approach is called Monte Carlo Simulation and is easy to implement by using random number generators, which are available in every statistical software package.

However, even in this straightforward approach, there are multiple challenges when working with probability distributions in risk assessment, like the pointwise (referring to data point) updating of information. A single data point does not contain a lot of information. However, how strongly a single measurement is able to influence our assumptions about the range of plausible values of an input variable depends upon how much we already know (prior information) about that variable. This prior information can be the results of earlier measurements, literature information or expert knowledge. The less data are available the more the assessment relies on prior information. Consequently, the derivation which probability distribution should be used for a certain input has to weigh the site specific information in the data against the available prior information. In order to do that in a transparent way Bayesian inference provides a framework in which assumptions are made explicit and reproducible. Figure 2.3 gives an overview of how literature information (prior distribution) and data information (likelihood distribution) have been used to estimate effluent concentration of *Giardia* cysts in Vendée. The prior in this case regularizes the estimation about the distribution of plausible means in comparison to the data, making the model more “sceptical” due to the limited number of data points.

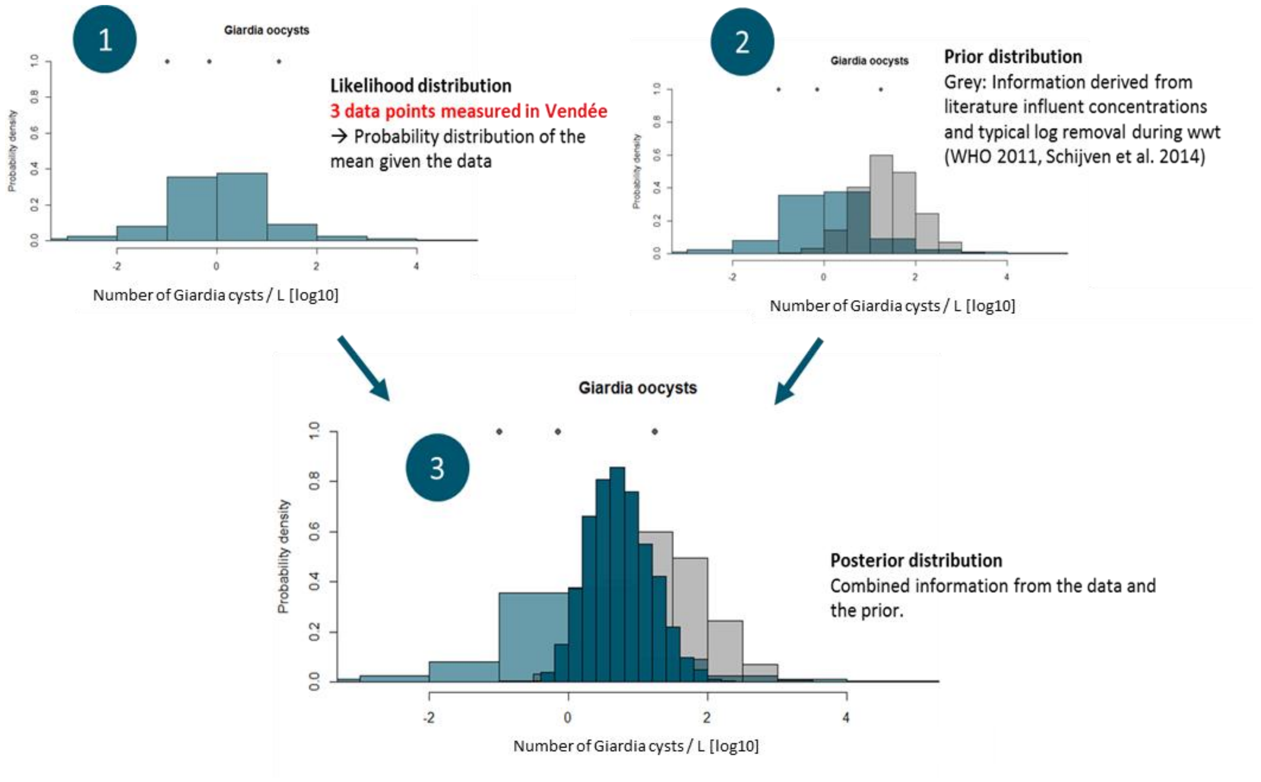

Figure 2.3 Conceptual overview of estimating effluent concentrations including weakly informative priors (example Giardia cysts). 1. Posterior distribution of the mean assuming flat (uninformative) prior. 2. Illustration of the informative prior (grey) 3. Combination and posterior distribution of the mean after adding data points to literature information (dark blue)

The following sections summarize the estimation used for risk calculations, the exposure scenarios as well as the equations used for risk calculations.

2.3.2.1 Concentrations of reference pathogens in the wastewater influent

For QMRA *rotavirus*, *Campylobacter jejuni*, *Cryptosporidium* and *Giardia* were selected as reference pathogens for viral, bacterial and parasitic pathogens. Measured data on pathogens were only available for *Giardia* and *Cryptosporidium*

Table 2.2 Monitoring data from WWTP CCO in Vendée

Microbial parameters	N	Units	Volume	Concentration Value	Used for
E.coli	3	MPN	100mL	26470, 896, 31130	Estimating bathing water quality
Intestinal *Enterococci*	3	MPN	100mL	6340, 1200, 5840	
Sulfite reducing bacteria	3	MPN	100mL	100, 1400, 1800	Not used
Cryptosporidum spp.	3	N	10L	53, 1, 15	Estimation of effluent concentrations
Giardia spp.	3	N	10L	173, 1, 7	
F-specific RNA bacteriophage?	3	pfu	1mL	21, 1, 1	Not used

For pathogenic viruses no direct measurements were available in the influent of the wastewater treatment plant. As a first estimate, Rotavirus concentrations measured in the WWTP of Braunschweig collected within DEMOWARE have been used assuming that the order of magnitude of rotavirus infections and thus wastewater concentration is comparable. Measured value ranged between 104 -106 genome copies per liter. As a worst case assumption it has been assumed that every genome copy represents an infective virus.

For *Campylobacter* no measured data was available within the DEMOWARE project. Therefore, data published within the WHO guidelines for Drinking Water Quality have been used (100 - 10^6 N / L).

2.3.2.2 Assumptions for treatment performance

The wastewater treatment plant in Vendée currently consists of a classical activated sludge wastewater treatment plant, which includes primary and secondary wastewater treatment. Against the background of the planned indirect potable reuse scheme two options are considered for further tertiary treatment.

1) Tertiary treatment with ultrafiltration and reverse osmosis
2) Tertiary treatment with filtration, electrodialysis, carboplus (EDR/µGAC), UV-disinfection

For both scenarios literature values as well as data from comparable reuse sites are used for estimating the treatment performance regarding virus removal.

Since only effluent data are available in Vendée treatment performance could not be assessed by site specific data. Moreover, the two treatment options of concern are still in the planning phase. Therefore, acknowledging the fact that for example a UV disinfection unit might be adapted to the local needs, partly broad ranges of plausible values for treatment performance have been applied. Table 2.3 gives an overview on the assumed reduction of each treatment step again viruses, bacteria, and parasites respectively.

Table 2.3 **Assumption used for calculating treatment performance of the wastewater treatment plant**
(NRMMC-EPHC-AHMC 2006, WHO 2006)

Treatment process	Viruses	Bacteria	Parasites
Primary	0 – 0.1	*0 – 0.5*	*0.5 – 1*
Secondary	0.5 – 2	*1 – 3*	*0.5 – 1.5*
UF	2.5 – 7	*4 – 7*	*4 – 7*
RO (95%)	1 – 2	*1 – 2*	*1 – 2*
Filtration	0.5 – 1.5	*0 – 1*	*1- 3*
EDR/µGAC	0	*0*	*0*
UV	2 – 5	*2 – 4*	*2.5 – 4*

2.3.2.3 Assumptions for treatment performance of the drinking water treatment plant

As mentioned above probability distributions are used for various input parameters for assessing the uncertainty using Monte Carlo Simulation. The chosen distribution should express the prior information about the problem. For expressing the prior information found in literature about the performance of the individual treatment steps of the DWTP both normal (N(µ, σ)) and gamma distributions (Gamma(shape, rate)) have been used. Gamma distribution were chosen since Gaussian distributions with a mean close to 1 tend to become negative which is considered not to be plausible for the assignment of treatment performances. Uniform or triangular distributions which both have hard constraints on both sides were avoided as the present estimate should serve as prior when further information is intended to be included in the assessment. Table 2.4 summarises the reviewed plausible ranges of treatment performance as well as the parameterisation used to express the given range.

Table 2.4 **Overview of the assumption made for drinking water treatment at Le Jaunay**
(NRMMC-EPHC-AHMC 2006, WHO 2006, WHO 2011)

Treatment	Cryptosporidium	Giardia	Viruses	Bacteria
Coagulation + flocculation + flotation	*1 – 2* *N (1.5, 0.2)*	*0.6 -2.3* *N (1.5, 0.2)*	*0.4 – 2.7* *Gamma(20, 15)*	*0.4– 2* *Gamma(20, 19)*
Breakpoint chlorination	*0 – 1* *Gamma(10, 35)*	*0.7 – 3.1* *Gamma(25, 15)*	*0.7 – 3.4* *Gamma(25, 15)*	*1 – 4* *Gamma(46, 20)*
Intermediate ozonation	*0.6 – 3.2* *Gamma(25, 15)*	*0.6 – 3.2* *Gamma(25, 15)*	*0.6 – 3.2* *Gamma(25, 15)*	*0.6 – 3.2* *Gamma(25, 15)*
Powdered activated carbon	*0*	*0*	*0*	*0*
Chlorination II	*0 – 1* *Gamma(10, 35)*	*0.7- 3* *Gamma(25, 15)*	*0.6 – 3.7* *Gamma(25, 15)*	*0.6 – 3.1* *Gamma(25, 15)*
Filtration	*0.4 – 3.3* *Gamma(18, 12)*	*0.5 – 3* *Gamma(18, 12)*	*0.5 – 2.5* *Gamma(20, 15)*	*0.5 – 4* *N (2.3, 0.5)*
Chlorination III	*0 – 1* *Gamma(10, 35)*	*0.7 – 3.3* *Gamma(25, 15)*	*0.7 – 3.3* *Gamma(25, 15)*	*0.7 – 3.3* *Gamma(25, 15)*
Lime treatment	*0 – 2* *Gamma(11, 15)*	*0. 15 – 1.8* *Gamma(11, 15)*	*1.3 – 4.8* *N (3, 0.5)*	*1 – 3* *Gamma(46, 25)*

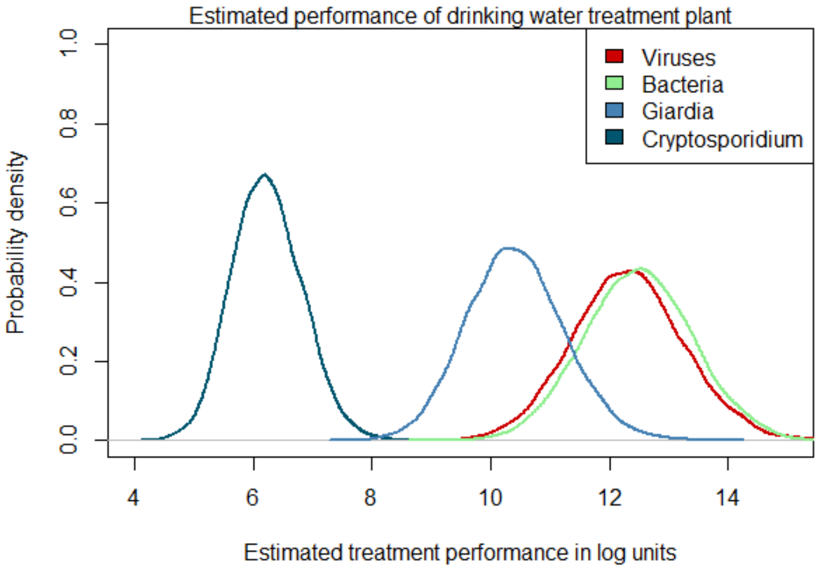

Figure 2.4 Estimated cumulated treatment performance of the drinking water treatment plant at Le Jaunay

2.3.2.4 Exposure scenarios

For microbial risk assessment three different scenarios have been calculated. The scenarios differ in the volume of ingested water. Triangular distributions have been chosen to express uncertainty. Exposure scenarios have been constructed for drinking and recreational activities. Recreational activities were considered from a precautionary view in case that some people might ignore the existing prohibition of swimming in the reservoir. Assumptions are summarized in Table 2.5.

Table 2.5 Overview of considered exposure scenarios (Dorevitch, Panthi et al. 2011)

Exposure activity	Volume ingested per exposure event	Number of exposure events	Distribution
Drinking	1-2 L	*365*	*Triangular*
Swimming	4.5 – 34.8 ml	*26*	*Triangular*
Kayaking	3.6 -26.8 ml	*40*	*Triangular*

2.3.2.5 Risk calculation

For calculating the risk of infection and the risk expressed in disability adjusted life years (DALYs) the following procedure is used:

1) Estimation of pathogen concentration at the point of exposure (drinking water, recreational activities)
2) Estimating the dose per exposure event by combining expected concentrations with assumed volumes per exposure event.
3) Using available dose response relationships to calculate the probability of infection per exposure event and per year
4) Translation into DALYs per person per year (pppy) by multiplying the calculated annual probability with the disease per infection ration for each pathogen, the percentage of susceptible people

within the population and a pathogen specific severity factor, which represents the severity of the possible health outcomes.

The following dose repose models have been used for the different pathogens. The simplest dose-response model is formulated by an exponential relationship and is used for *Giardia* and *Cryptosporidium*.

$$P_I(d) = 1 - e^{-r*d}$$

$$-r = \frac{\ln{(0.5)}}{N_{50}}$$

$P_I(d)$ = *probability of infection*
d = *dose*
r = *infectivity constant*
N_{50} = *median infectious dose*

The exponential model assumes that the probability of infection is constant for all pathogens of the same kind as well as for all people exposed to that kind of pathogen (Haas, Rose et al. 1999).

In reality not all pathogens of the same species are equally infective. Moreover, not all human show the same response on the exposure of the same amount of a certain pathogens. Old people as well as children may have a less strong immune system than adults. Consequently, they will be more easily become infected than an adult person. In order to consider such variations other functional relations are used. Most frequently the Beta-Poisson-model finds application (Campylobacter, Rotavirus, partly Norovirus).

$${}_1F_1(\alpha,\alpha+\beta,d) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)}\sum_{j=1}^{\infty}\left(\frac{\Gamma(\alpha+j)}{\Gamma(\alpha+\beta+j)} * \frac{(-1)^{j-1}*(d)^j}{j!}\right)$$

α, β = Beta-Poisson model parameters
d = dose

The approximation holds true for β ≥ 1 and α ≤ β (Petterson, Signor et al. 2006) and low pathogen exposure. The approximation can be rewritten as:

$$P_I(d) = 1 - [1 + \frac{d}{N50}\left(2^{\frac{1}{\alpha}} - 1\right)]^{-\alpha}$$

A more complicated formulation for the dose-response relation was published by (Teunis, Moe et al. 2008) for the infectivity of aggregated Norovirus particles. The additional parameter in the equation accounts for virus aggregation.

$$P_I(d,a,\alpha,\beta) = {}_2F_1\left(\alpha;\frac{-d}{\log(1-\alpha)},\alpha+\beta,\frac{-a}{1-a}\right)$$

d = dose
α, β = model parameters
a = constant for the aggregation of virus particles

$$P_{I,\,year} = 1 - \prod_{i=1}^{N}(1 - P_{i,\,event})$$

Having calculated the annual probability of infection the disease burden related to this probability can be calculated by:

$$\text{DALY pppy} = P_{I,\,year} * \text{P(ill|inf)} * \text{fs} * \text{db}$$

PI.year	Probability of infection per year
P(ill|inf)	Ratio of people becoming ill given infection
fs	Ratio of susceptible people in the population
db	DALYs per case of disease

Table 2.6 Susceptible fraction, average disease burden per case and disease per infection ration for selected reference pathogens

Parameter	Rotavirus*	Campylobacter	Cryptosporidium
fs	0.06	1	1
db	$1.4*10^{-2} – 2.6*10^{-2}$	$4.6*10^{-3}$	$1.5*10^{-3}$
P(ill|inf)	0.5	0.3	0.7

2.3.3 Methodology for chemical risk assessment

For chemical risk assessment both risk for human health as well as environmental endpoints have been assessed following the four steps of risk assessment

1) Hazard identification and selection
2) Hazard characterization/Effects assessment
3) Exposure assessment
4) Risk characterization.

An overview of the general procedure is shown in Figure 2.7. The used method follows a single substance approach. Mixture toxicity is not covered by this kind of substance assessment.

2.3.3.1 Hazard identification

Three sampling campaigns have been conducted collecting 24h mixed samples at the effluent of the WWTP. For substance selection and monitoring setup please see DEMOWARE deliverables 6.1 and 6.3.. Out of the 130 organic substances which were monitored, only those substances were selected which were positively detected at least once. Thereby the number of substances was reduced from 130 to 36.

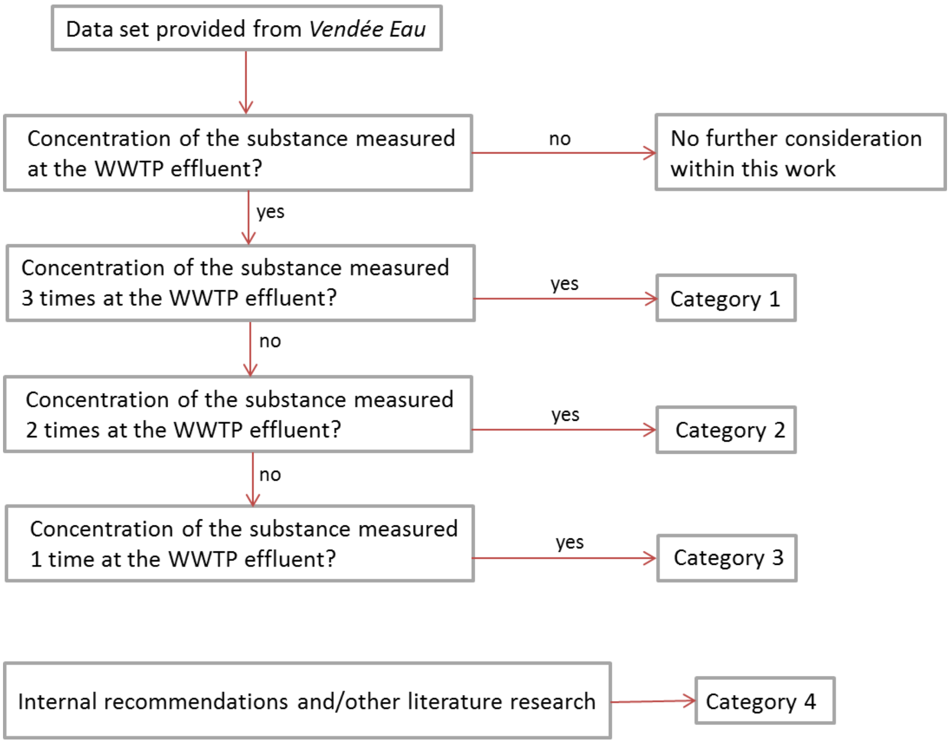

Figure 2.5 Categorization of chemical compounds based on number of positive analysis in the effluent of the drinking water treatment plant.

Moreover, a literature review of typical concentration of trace organics in municipal wastewater was conducted. Substances with concentrations (> 1 µg/L) were considered additional to the measured data in Vendée. Furthermore, within Berlin Center of Competence for Water, additional organic micro-pollutants (EDTA and Benzotriazole) were proposed for further consideration as they are known to be present in high concentration in municipal wastewater. The additional compounds were classified as category 4 and their concentration measured at the WWTPs found in literature are shown in Figure 2.6.

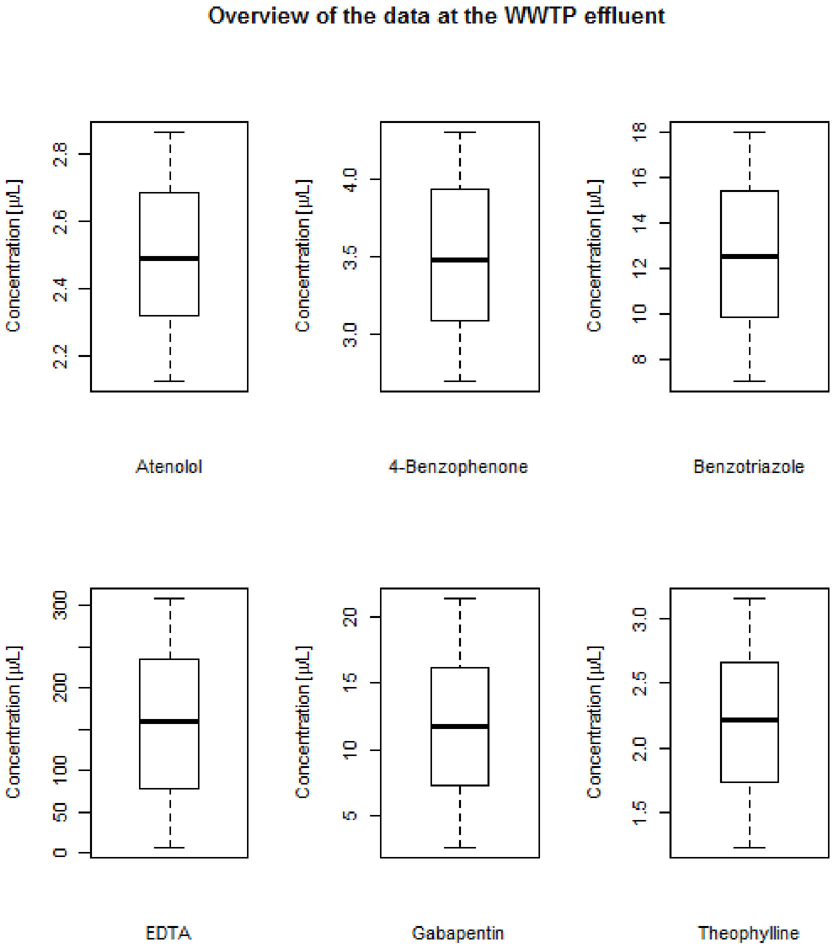

Figure 2.6 **Concentration of micro-pollutants added by literature review and experience from other regions**
(Petrie, Barden et al. 2015)

2.3.3.2 Effects assessment

Effects assessment was based on a literature review on available limit values and toxicity information of the selected substances. Limit and guidelines values can have different qualities regarding their purpose and the legal restrictiveness.

While limit value given by national standards for drinking water quality are legally binding and require immediate action is not met, precautionary values indicate a potential disturbance which is worth to be aware of. Both kinds as of value are not necessarily based on toxicological information but may include “moral” and “practical” aspects, too. An example for practical aspects on how to deal with the lack of “knowledge” may be a default precautionary value of 0.1 µg/L as it is applied in Germany or the Netherlands. Moral or aesthetic aspects may be given in situations were a substance may show low toxicity, but the vision of drinking water being “pristine” drives authorities to target values far below the actual toxicity limit. An example is given by EDTA in Germany, for which toxicity based guidelines values of 600 µg/L are derived by WHO but a precautionary value of 10 µg/L is set. Toxicological values for chemical substances are usually expressed as acceptable daily intake or tolerable daily intakes. Usually an amount of 10% may be attributed to drinking water consumption to derive toxicologically derived guideline values.

For environmental endpoints predicted no-effect concentration (PNECs) are used which are the result of toxicological testing and assessment factors which account for the uncertainty due to limited testing. The more test have been conducted the lesser the assessment factor becomes. This means that if risk quotients (RQ) are calculated to be > 1 it may either be the result of actual toxicity against the measured concentration or the results of very limited information due to scare testing and high assessment factors.

In the present study uncertainty about which benchmark value to use in case that more than one limit or guideline value is available is addressed benchmarking all of them against the modelled concentrations.

For the general assessment legally binding benchmarks will be preferred, followed by available toxicity information. If none of the above was available the so called TTC (threshold of toxicological concern has been applied). Figure 2.8 summarizes the general procedure. The lower part of the figure includes the benchmark value selection adapted from (Schriks, Heringa et al. 2010, Etchepare and van der Hoek 2015).

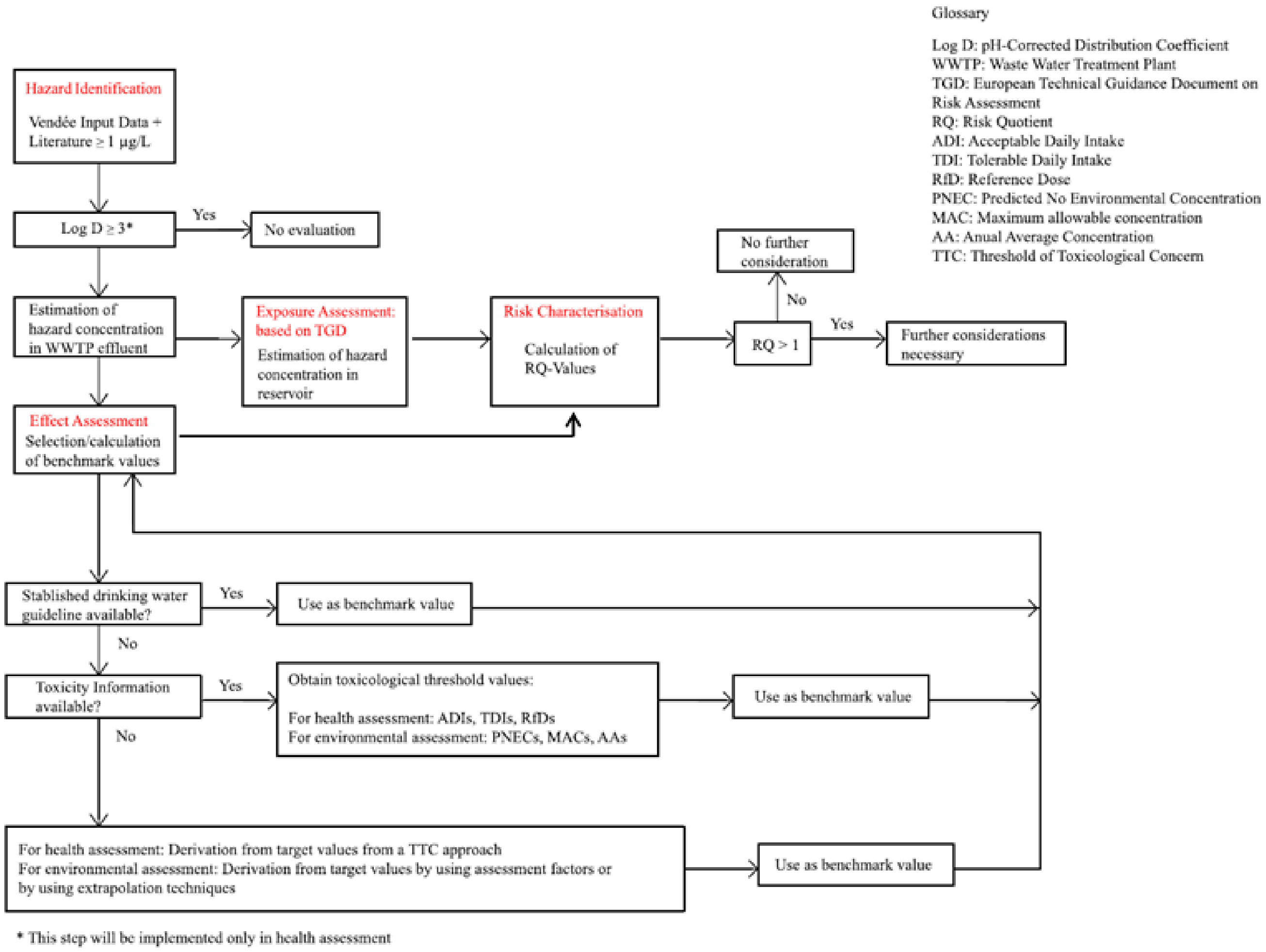

Figure 2.7 Overview of risk assessment procedure and benchmark value selection
(adapted from (Etchepare and van der Hoek 2015)

2.3.3.3 Exposure assessment

Exposure assessment was conducted steps wise. After each step the calculated concentration were compared to benchmark values, determining the risk quotient (RQ) as a ratio of predicted concentration and benchmark. Following the iterative and systematic approach as soon as concentrations fell below the benchmark value (RQ < 1), no further assessment was done and the assessment was considered to be finalized. Following this approach, the effort of estimating treatment performances of each treatment step can be reduced to the substance “of concern”.

Thus, risk quotients for the environment were assessed after:

1) The effluent of the Olonnes WWTP
2) The reservoir assuming no tertiary treatment
3) Effluent of the two tertiary treatment options
4) The reservoir after tertiary treatment

2.3.3.3.1 Estimating the effluent of the Olonnes WWTP

Addressing the questions, which concentration to apply based on only three data point is crucial. In contrast to microbial risk assessment where short term periods of elevated pathogen concentrations might cause infections, chemical risk assessment of wastewater treatment plants effluents focuses on the average concentration, since acute toxicity of single substances is considered to be unlikely. For addressing uncertainties of parameter estimation (mean) the 95% quantile of the Bayesian posterior distribution of the mean has been used as a point estimate for making a realistic worst case assumption given the data. This estimate has an equivalent value as the upper bound of a “classical” 95% t-confidence interval given that set of outcomes. However, the interpretation of both intervals is different. The Bayesian interval is fixed conditioned on the data while the frequentist interval is random containing the “true” value in 95% of the resampled cases. Figure 2.8 illustrates both approaches. It has to be underlined that the Bayesian estimate of the mean is the whole grey distribution.

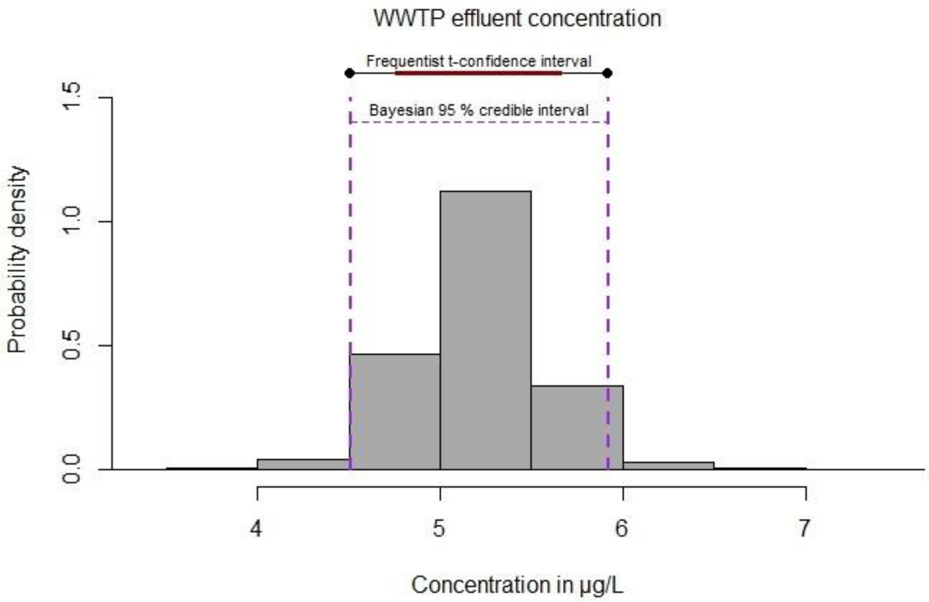

Figure 2.8 **Comparison of a frequentist 95% t- confidence interval with a marginal posterior distribution of the mean with non-informative prior and unknown variance**

2.3.3.3.2 Calculation of reservoir concentrations

The model used to estimate the concentration of the hazards in fresh water follows the approach specified by the Technical Guidance document on risk assessment (IHCP 2003). The calculation of freshwater concentration accounts for sorption and dilution processes.

$$C_{local\_water} = \frac{C_{local\_effluent}}{\left(1 + K_p * SUSP * 10^6\right) * Dilution}$$

C_{local_eff}	concentration of the substance in the WWTP effluent [mg/L]
$K_{p,susp}$	solids-water partitioning coefficient of suspended matter [L/kg]
SUSP	water concentration of suspended matter in the river [mg/L]
Dilution	dilution factor [-]
C_{local_water}	local concentration in surface water during emission episode [mg/L]

The dilution factor is estimated by:

$$Dilution = \frac{Effluent_{WWTP}}{FLOW * Effluent_{WWTP}}$$

$Effluent_{WWTP}$	effluent discharge rate of WWTP [L/d]
FLOW	flow rate of the river [L/d]

As seasonal fluctuations affect river flow rates, low-flow rates are used to apply a realistic worst case scenario (IHCP 2003).

The concentration of suspended matter in the river is determined based on the data provided from Vendée. The lowest value is used as the suspended matter concentration in the river to help predict the highest hazard concentration that may arise in the reservoir.

The solids-water partitioning coefficient of suspended matter is determined by multiplying the weight fraction of organic carbon in suspended solids (Foc_{susp}) with the partition coefficient carbon-water (Koc). Since no reference data for the Foc parameter were available, the default environmental value pf 0.1 kg/kg as recommended by (IHCP 2003) was used.

$$Kp_{susp} = Foc_{susp} * Koc$$

Foc_{susp}	weight fraction of organic carbon in suspended solids [0.1 kg/kg]
Koc	partition coefficient organic carbon-water [L/kg]

The Koc value represents the ratio between the concentration of a compound on organic carbon and the concentration of the compound in water. The parameter serves as a measure for the mobility and sorption affinity of compounds to the solid phase. Organic substances with high Koc values tend to be immobile in the solid phase and therefore to adsorb on organic carbon, while substances with low values are highly mobile in this phase, what leads to a higher tendency to be washed out of the compart.

$$Koc = \frac{Coc}{Cow}$$

Coc	concentration of compound on organic carbon [mg/g]
Cw	concentration of compound in water [mg/L]

Koc values were determined mainly through literature research. In several cases Koc values are given as a range. In these cases the lowest Koc value was taken for further calculations in order to maximize hazard water concentration.

If no Koc value could be found directly in literature, values were derived from the octanol-water partition coefficient (Kow). Koc values were determined through the following correlation (EC 2001, IHCP 2003).

$$\mathrm{LogKoc} = 0.82 \log\mathrm{Kow} + 0.14$$

2.3.3.3.3 Assumptions for tertiary and drinking water treatment

For those substances with risk quotients > 1 (i.e. concentration in secondary effluent above benchmark), tertiary treatment performance has been assessed. Furthermore, for those substances where the related RQ is still > 1 in the reservoir, removal in drinking water treatment is considered. The following tables summarize the made assumption and sources for the treatment performance of the two different tertiary treatment options as well as for the drinking water treatment plant. As far as available peer reviewed literature has been used to estimate treatment performances. If no citable literature was available, expert knowledge from the Technical University of Berlin has been used, which conducted long term research on the removal of pharmaceuticals by activated carbon.

Table 2.7 Performance estimation of EDR/µGAC for the removal of organic substance

Substance	Min. removal EDR/µGAC [%]	Max. removal EDR/µGAC [%]	Source
AMPA	*0*	*26*	*(Mailler, Gasperi et al. 2016)*
Bezafibrate	*53*	*55*	*(Mailler, Gasperi et al. 2016)*
Carbamazepine	*80*	*94*	*(Mailler, Gasperi et al. 2016)]*
Clarithromycin	*72*	*90*	*(LfULG 2009)*
Diclofenac	*71*	*97*	*(Mailler, Gasperi et al. 2016)*
Diuron	*50*	*99*	*(Mailler, Gasperi et al. 2016)*
Erythromycin	*43*	*77*	*(Mailler, Gasperi et al. 2016)*
Fipronil	*50*	*100*	*[Expert guess]****
Glyphosate	*0*	*50*	*(Mailler, Gasperi et al. 2016)*
Oxazepam	*74*	*91*	*(Mailler, Gasperi et al. 2016)*
Propranolol	*94*	*98*	*(Mailler, Gasperi et al. 2016)*
Bisphenol A	*56*	*83*	*(Mailler, Gasperi et al. 2016)*
Fluoxetine	*32*	*95*	*(Lee, Howe et al. 2009)*
Iopamidol	*0*	*55*	*(Mailler, Gasperi et al. 2016)*
Benzophenone	*50*	*100*	*[Expert guess]****
Gabapentin	*0*	*15*	*[Expert guess]****

** personal communication with Dr. Frederik Zietschmann, TU Berlin

Table 2.8 Performance estimation of RO for the removal of organic substance

Substance	Min. removal RO [%]	Max. removal RO [%]	Source
AMPA	62	84	[Expert guess]**
Bezafibrate	*62*	*97*	(WHO 2011)
Carbamazepine	*85*	*99*	(Taheran, Brar et al. 2016)
Clarithromycin	*62*	*97*	(WHO 2011)
Diclofenac	*90*	*99*	(EPA 2010, Sudhakaran, Lattemann et al. 2013)
Diuron	*72*	*90*	(Rodriguez-Mozaz, Ricart et al. 2015)
Erythromycin	*95*	*99*	(EPA 2012) (Sudhakaran, Lattemann et al. 2013)
Fipronil	*67*	*99*	(Rodriguez-Mozaz, Ricart et al. 2015) (Kresimir Kosutic and Kunst 2001)
Glyphosate	62	84	[Expert guess]**
Oxazepam	*62*	*97*	(WHO 2011)
Propranolol	*62*	*97*	(WHO 2011)
Bisphenol A	18	*99*	(Kimura, Toshima et al. 2004) (Luo, Guo et al. 2014)
Fluoxetine	*77*	*95*	(EPA 2010)
Iopamidol	*62*	*97*	(WHO 2011)
Benzophenone	*94*	*84*	[(EPA 2010)
Gabapentin	*62*	*84*	[Expert guess]**

** personal communication with Dr. Frederik Zietschmann, TU Berlin for molecular weight < 200 g/mol

Table 2.9 Assumption for drinking water treatment plant

Substance	Coagulation + flocculation	**Breakpoint chlorination**	O_3*	PAC	Chlorination	Filtration	Chlorination	Lime treatment
AMPA	0%	10%	80%.	0%	10%	0%	10%	0%
Diclofenac	*0%*	10%	70%	30%	10%	0%	10%	0%
Diuron	*0%*	10%	0%	50%	10%	0%	10%	0%
Glyphosate	0%	10%	80%	50%	10%	0%	10%	0%
Iomeprol	0%	10%	42%	28%	10%	0%	10%	0%
Iopamidol	*0%*	10%	50%	60%	10%	0%	10%	0%
Sulfamethoxazole	*0%*	10%	99%	56%	10%	0%	10%	0%
Benzotriazole	*0%*	10%	70%	97%	10%	0%	10%	0%
EDTA	*0%*	10%	10%	0%	10%	0%	10%	0%
Gabapentin	*0%*	10%	50%	0%	10%	0%	10%	0%

* 0.65 – 0.75 g O_3/g DOC

2.3.3.4 Risk characterization

In order to quantify and characterise the potential risk of the monitored chemicals substances, risk quotients were calculated by relating the maximal estimated or calculated concentration to the benchmark value. According to (Hernando, Mezcua et al. 2006), three different outputs can be computed when building risk quotients.

- **Compounds with a RQ >1:** there is a risk that drinking water or environmental targets are not met. Those substances are classified as being "of concern" and considered for further assessment
- **Compounds with a 0.1 < RQ < 1:** there is a medium risk that drinking water of environmental targets are not met These compounds are not further assessed but should be further monitored and investigated in order to validate input concentrations
- **Compounds with a RQ < 0.1**: there is a low risk that environmental of drinking water targets are not met. These substances will not be further considered

2.4 Results

The following sections summarize the results of microbial and chemical risk assessment. Risk was assessed after each treatment step. The final points of assessment are the reservoir for recreational activities and freshwater environment and after the drinking water treatment plant for health risk assessment due to drinking water consumption.

2.4.1 Results for microbial risk assessment

Risk was first calculated after tertiary treatment. In case that drinking water requirements would have been already fulfilled already after tertiary wastewater treatment no further assessment would have been conducted. Figure 2.9 and Figure 2.10 show the calculated risk expressed in DALYs per person per year after tertiary treatment with UF/RO and filtration- reverse electrodialysis- EDR/µGAC and UV, respectively. The results show that for parasites both treatment options are already fall below acceptable concentrations given by WHO standards for drinking water supply. For bacteria and viruses additional the calculated risk is still above the WHO benchmark. Consequently additional drinking water treatment is still necessary, which is described in the following section.

For treatment option 1 (UF/RO), this is caused by the fact that only 95% of the wastewater is intended to be desalinated. This reduces the log performance of RO unit from > 6 log to 1-2 log assuming the RO to be an absolute barrier.

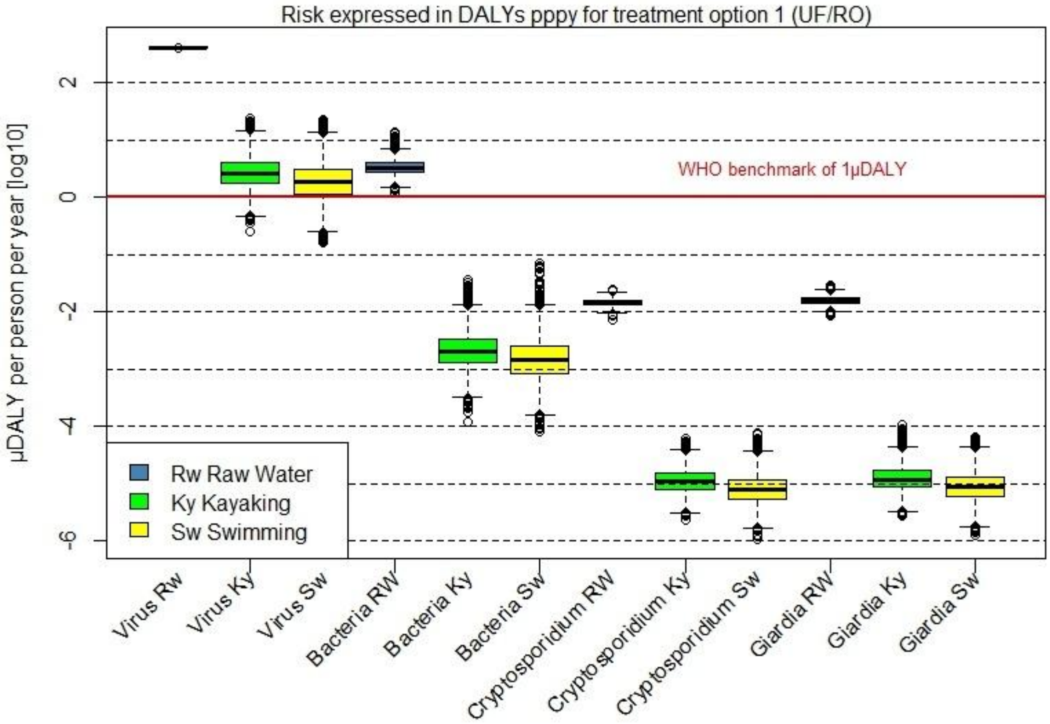

Figure 2.9 Calculated risk of infection after tertiary treatment of 95% of the WWTP effluent for three different exposure scenarios

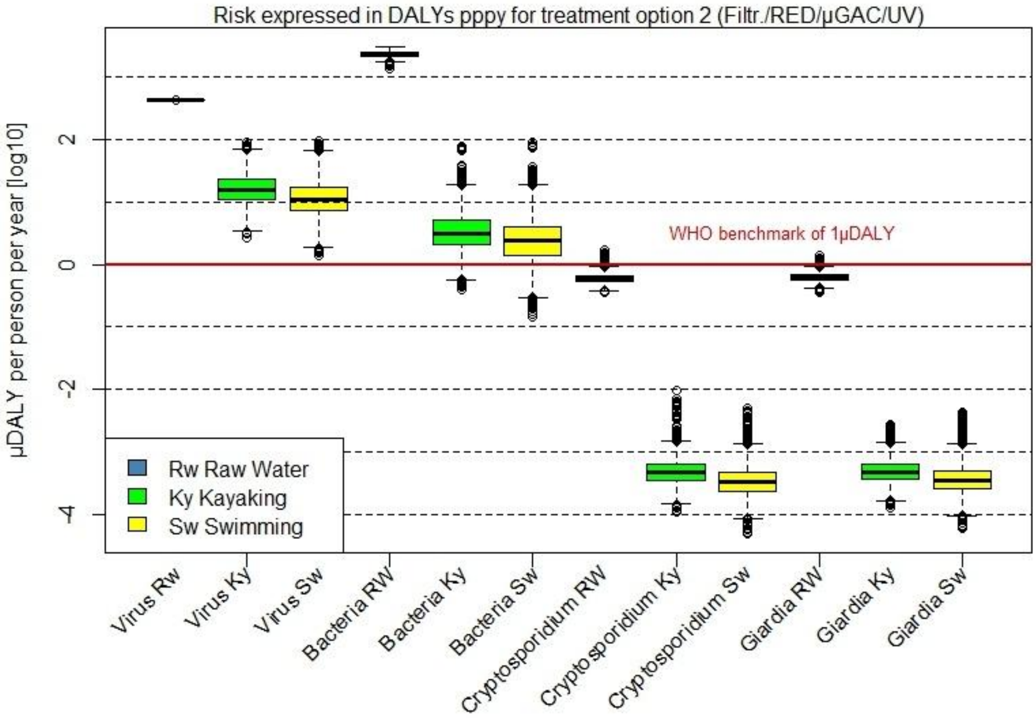

Figure 2.10 Calculated risk of infection after tertiary treatment of 95% of the WWTP effluent for three different exposure scenarios

For the recreational scenarios risk was calculated both in terms of DALYs per person per year as well as in comparison to current European legislation. When applying the same benchmark for recreational activities as for drinking water consumption tertiary treatment as planned in Vendée would be likely not achieve a health target of 1 µDALY per person per year.

However, the DALY is not commonly applied to recreational water. Therefore, additional comparisons to European bathing water standards have been made in Figure 2.11 and Figure 2.12. In Figure 2.11 the calculated concentration of faecal indicator organisms normalised by the EU bathing water limit value for “sufficient” bathing water quality is shown. The figure shows that concentrations are expected to be multiple orders of magnitude below the bathing water target.

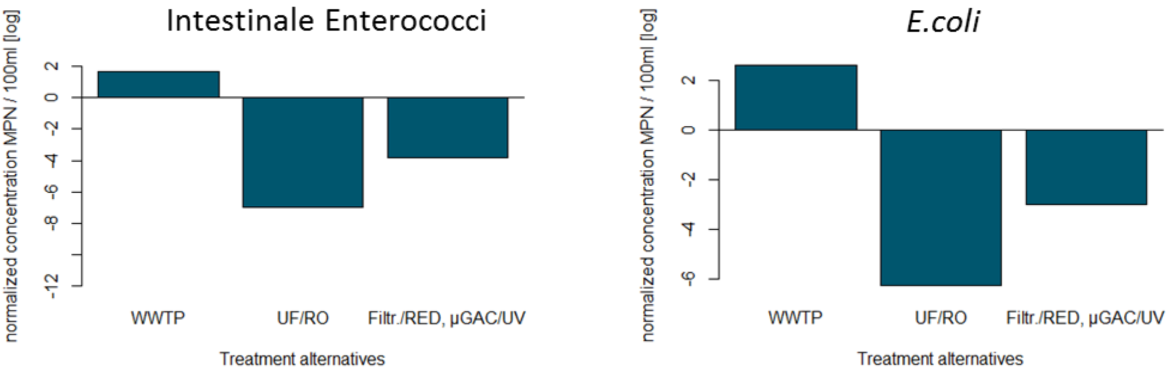

Figure 2.11 Comparison of expected effluent quality to limit values for sufficient quality of the European bathing water directive.

Moreover, the bathing water criteria outlined in the European bathing water directive inherently set values for an acceptable probability of illness as they are based on epidemiological studies. Thus, the criteria for “sufficient” bathing water quality for Intestinal Enterococci equal an accepted risk of infection between 5 and 8.4%, “good quality” a level between 3 and 5% and “excellent quality” a risk level below 3%. These levels were compared to the calculated probability of illness (Figure 2.12).

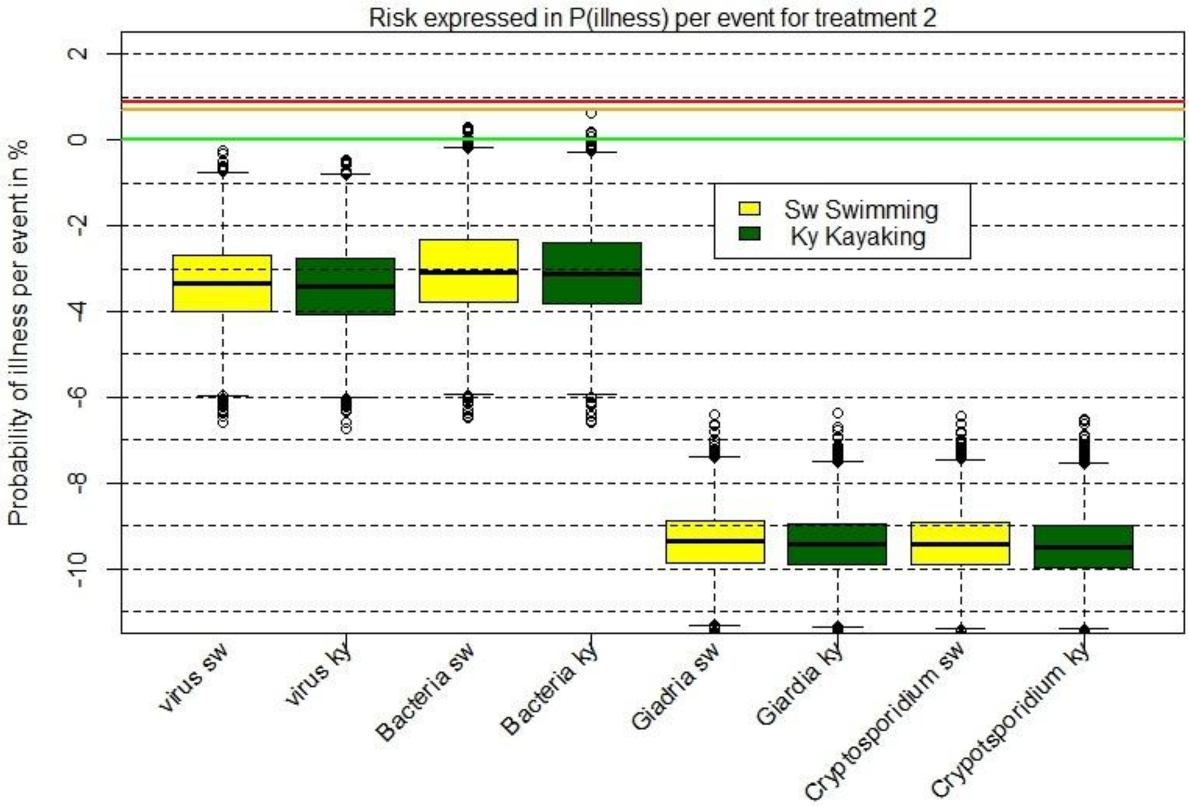

Figure 2.12 Comparison of calculated probability of illness to the accepted probability of illness derived from the European Union Bathing Water Directive.

Below green line: excellent bathing water quality, below orange line: good bathing water quality, below red line: sufficient bathing water quality.

Since both tertiary treatment options fail to deliver drinking water quality additional to tertiary treatment the performance of the drinking water treatment plant was considered (Figure 2.13 and Figure 2.14).

The results show that the calculated risk is well below WHO drinking water standards. Also the high resistance of Cryptosporidium against Chlorination becomes evident now being the reference pathogen of highest relevance.

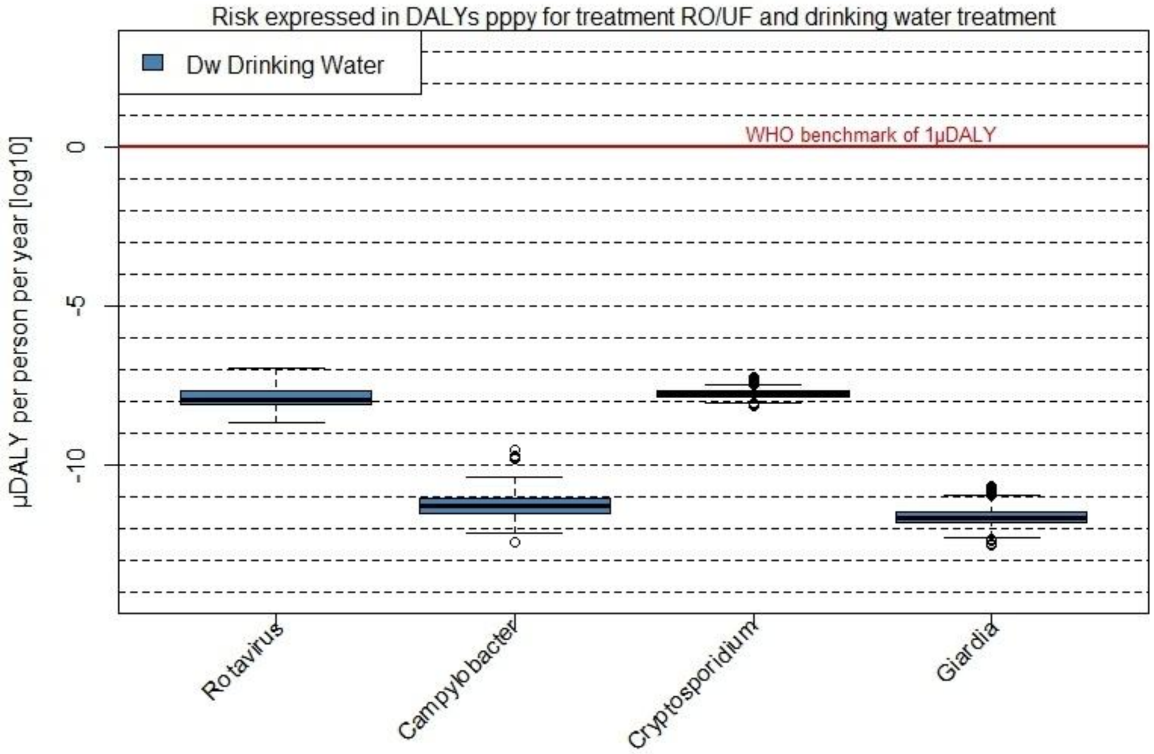

Figure 2.13 Risk expressed in DALYs pppy after UF/RO and drinking water treatment

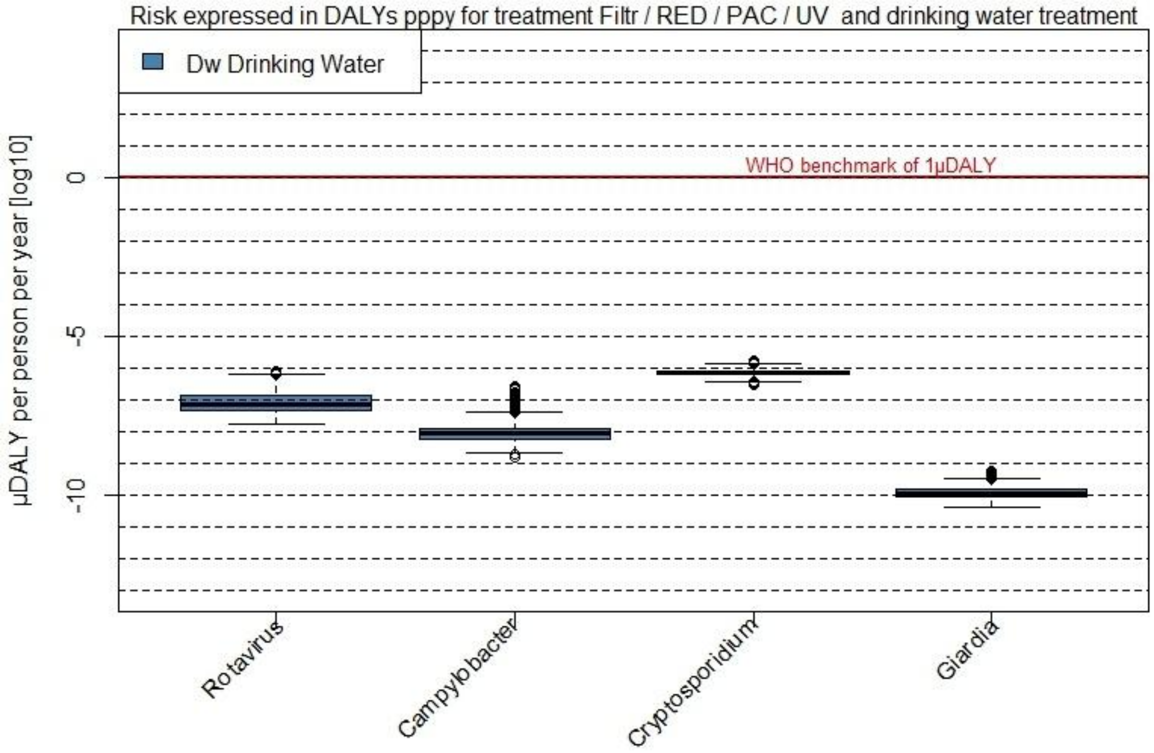

Figure 2.14 Risk expressed in DALYs pppy after Filtration/EDR/µGAC/UV and drinking water treatment

2.4.2 Results for chemicals risk assessment

Figure 2.15 and Figure 2.16 show the estimated effluent and freshwater concentrations of the analysed substances.

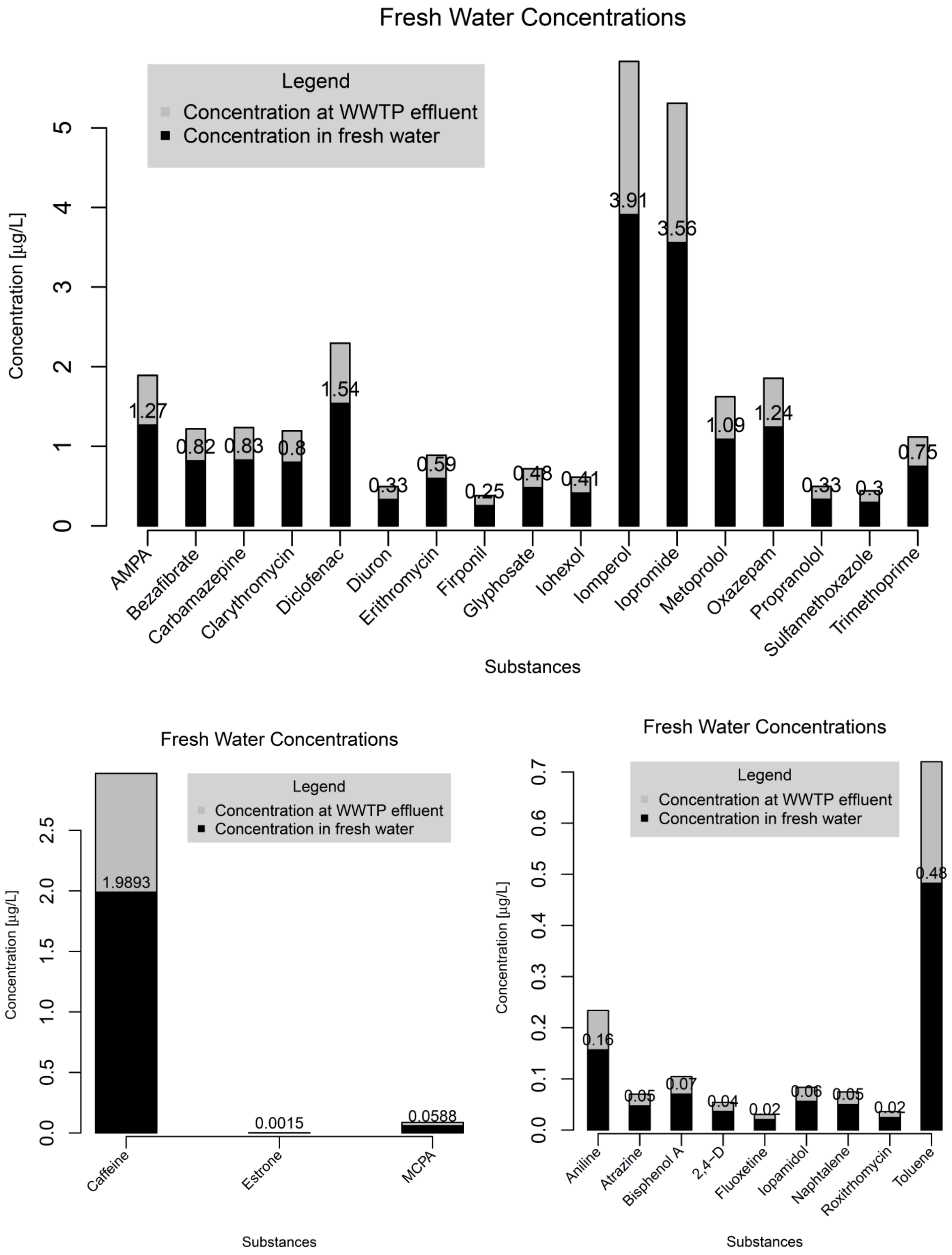

Figure 2.15 Overview of estimated concentrations of organic substances in freshwater without tertiary treatment.

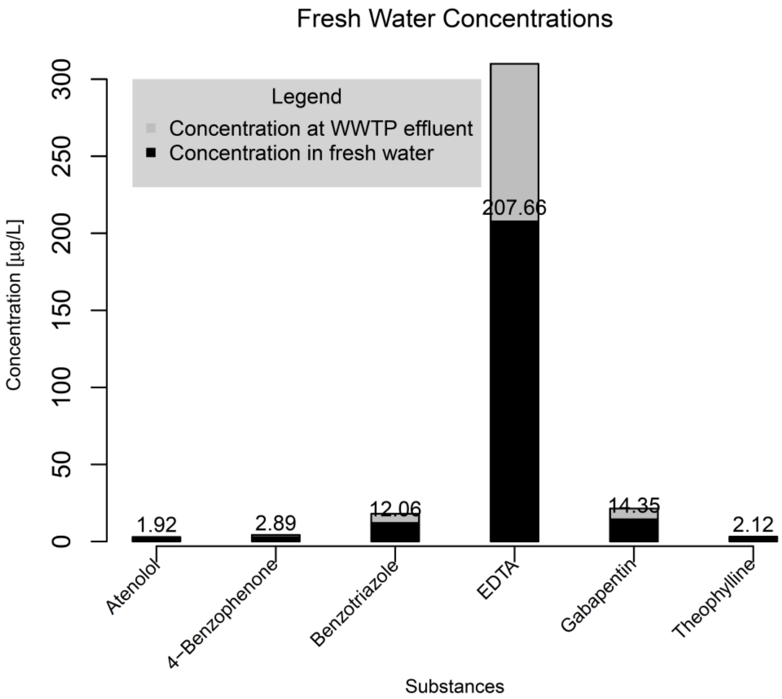

Figure 2.16 Overview of estimated concentrations of organic substances in freshwater without tertiary treatment.

2.4.2.1 Environmental risk assessment after secondary treatment

Figure 2.17 and Figure 2.18 show the calculated risk quotients after secondary treatment. The different symbols represent the different environmental benchmark values. Out of the 37 assessed substances, there are 12 substances left for further investigation. Only for the substances with an RQ > 1, a detailed refinement of the assessment after tertiary treatment is done. For the other substances tertiary treatment provides also an additional barrier so that RQ will be further reduced.

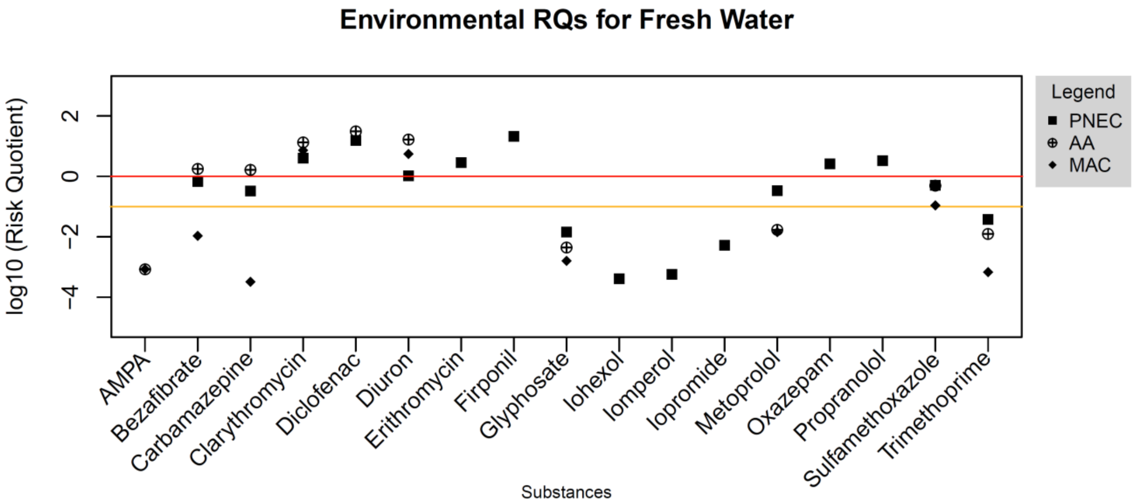

Figure 2.17 Overview of calculated risk quotients for environmental and human health risks after secondary wastewater treatment.

Red line indicates RQ = 1, orange line indicates RQ = 0.1.

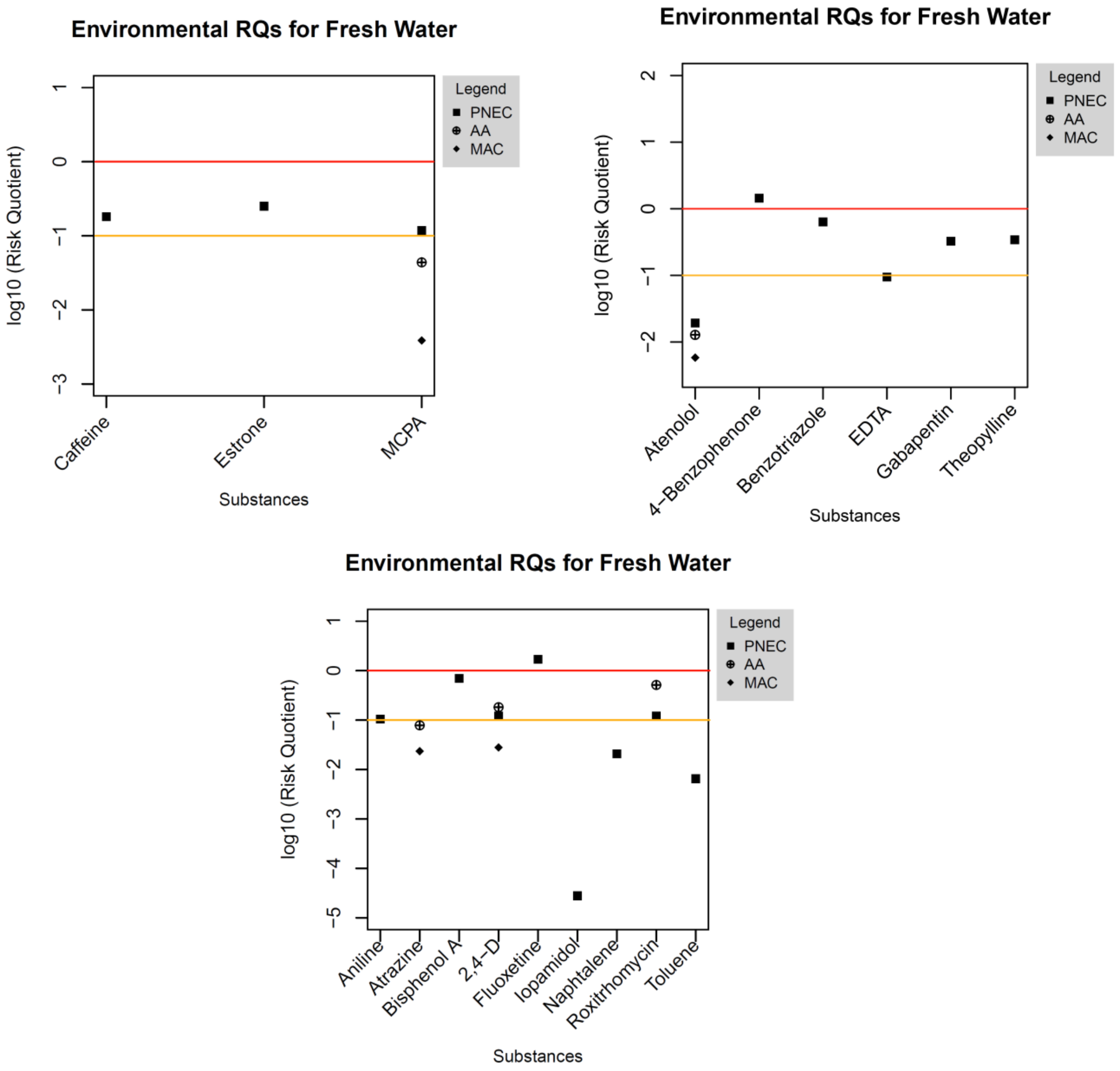

Figure 2.18 **Overview of calculated risk quotients for environmental and human health risks after secondary wastewater treatment.**

Red line indicates RQ = 1, orange line indicates RQ = 0.1.

Figure 2.20 shows the ratio between PEC and PNEC_{water} for heavy metals.

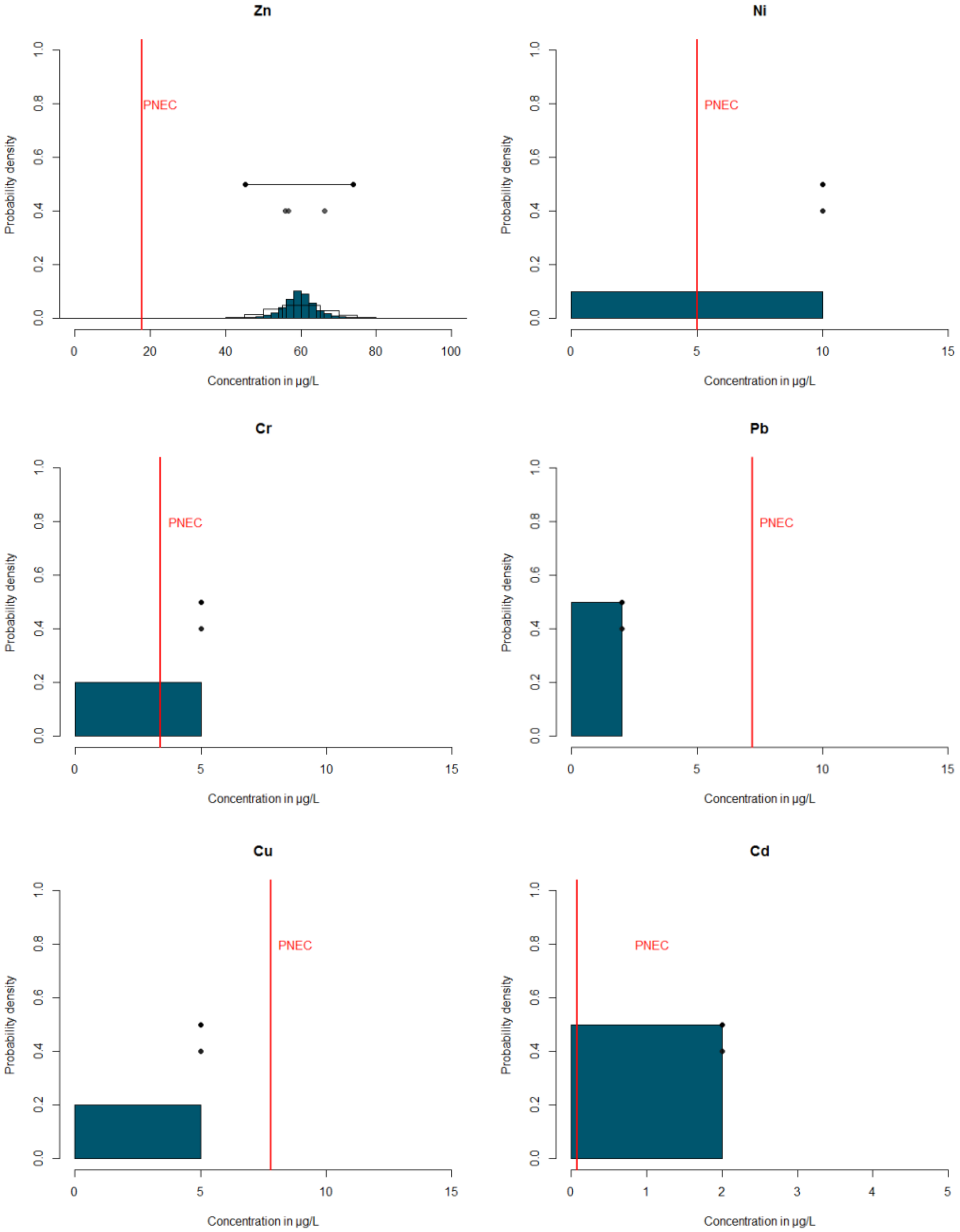

Figure 2.19 Comparison of measured effluent concentrations of heavy metal (blue histograms) to predicted no effect concentration for freshwater environments (PNEC) (red lines).

Black dots indicate data points. If histograms consist of just one blue area all samples have been below the detection limit. The upper bound of the area represents the detection limit.

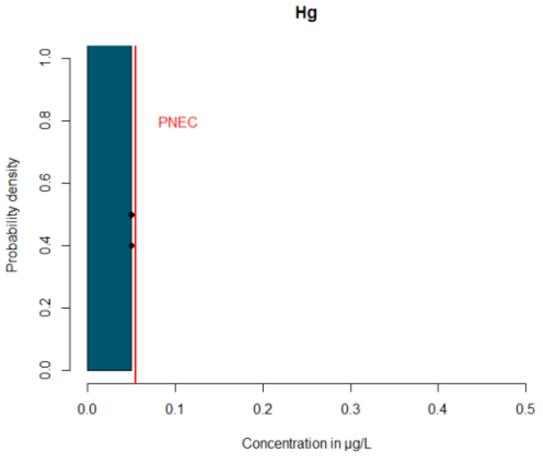

Figure 2.20 Comparison of measured effluent concentrations of heavy metal (blue histograms) to predicted no effect concentration for freshwater environments (PNEC) (red lines).
Black dots indicate data points. If histograms consist of just one blue area all samples have been below the detection limit. The upper bound of the area represents the detection limit.

For heavy metals all measurements except from zinc have been below their respective limit of quantification. However, partly the existing PNEC values lie below the limit of quantification. If the half of the detection limit is applied as an estimate for metal concentration Cadmium and Nickel would still be "of concern" with Ni having an RQ of exactly 1.

2.4.2.2 Environmental assessment after tertiary treatment

Figure 2.21 shows the calculated risk quotients after tertiary treatment.

The different geometric points represent several benchmark values while the colour code indicates the applied pre-treatment and scenario. Black and purple stand for the conservative and best case RO scenario, while blue and green stand for the conservative and best case EDR/µGAC scenario.

The calculations indicate that out of the 12 substances which have been "of concern" the two treatment options show a different potential of reducing the concentration of organic substances. For four substances (4-Benzophenone, Bezafibrat, Carbamazepine, Bisphenol A) risk is estimated to fall below tolerable concentrations regardless of the technology implemented.

The best case with EDR/µGAC presents the best outcomes with only three substances (Bezafibrate, Clarithromycin and Diclofenac) having a RQ higher than 1. For the best case with RO, four compounds (Clarithromycin, Diclofenac, Diuron and Fipronil) still represent a potential risk to the environment (RQ > 1).

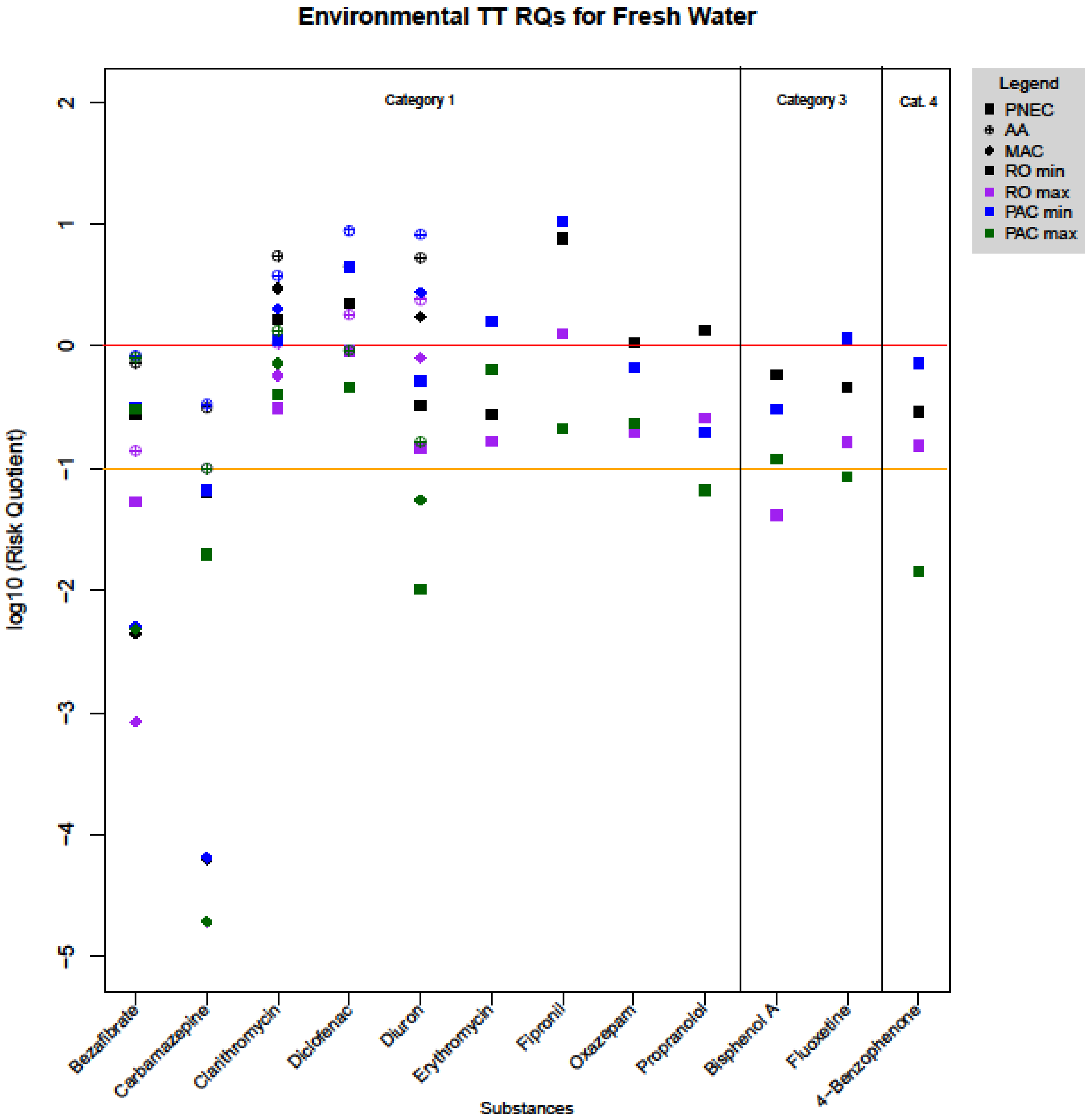

Figure 2.21 Calculated risk quotients after tertiary treatment.
Different symbols indicate different benchmark values, different colours the min and max performance of the assessed treatment options. Red line indicates RQ = 1, orange line indicates RQ = 0.1.

The conservative scenario for RO would be capable of reducing the risk of over7 of the compounds below 1, while the conservative case for EDR/µGAC would only be able to reduce the risk of 6 of the compounds. It can be noticed, that none of the scenarios would be able to reduce the risk for Clarithromycin and Diclofenac below 1. Moreover, for two compounds (Diuron and Fipronil) only one scenario (EDR/µGAC max) would be able to minimise the risk associated to these substances.

Regarding heavy metals both treatment scheme provide sufficient reduction potential to reduce environmental risks below the applied PNEC in water.

2.4.2.3 Health risk after secondary treatment

After secondary treatment, 11 out of 38 assessed substances exceeded at least one available benchmark value and were considered for further assessment. Figure 2.22 and Figure 2.23 summarize the calculated risk quotients.

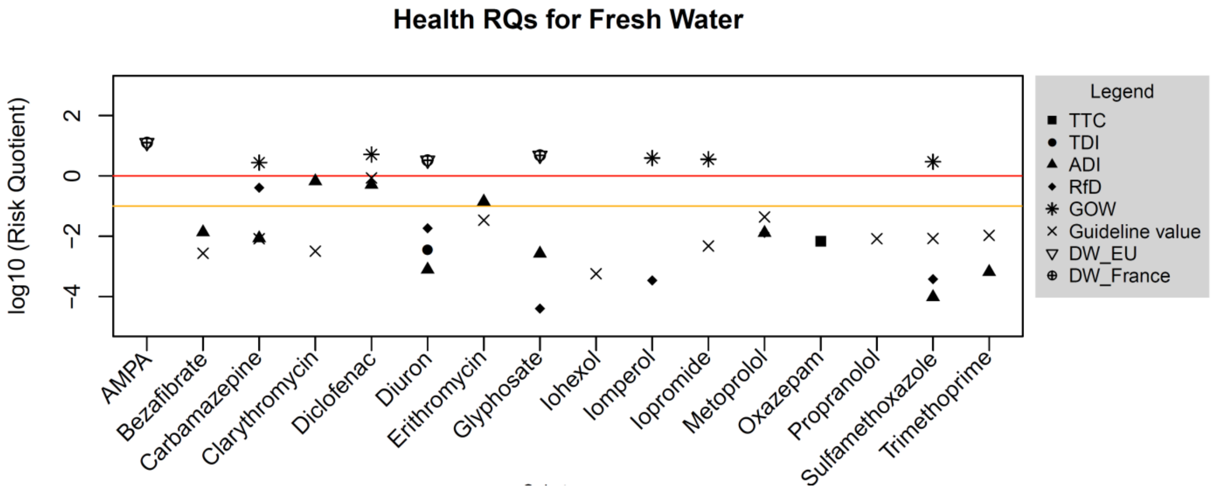

Figure 2.22 Risk quotients for health assessment after secondary treatment
Red line indicates RQ = 1, orange line ind. RQ = 0.1.

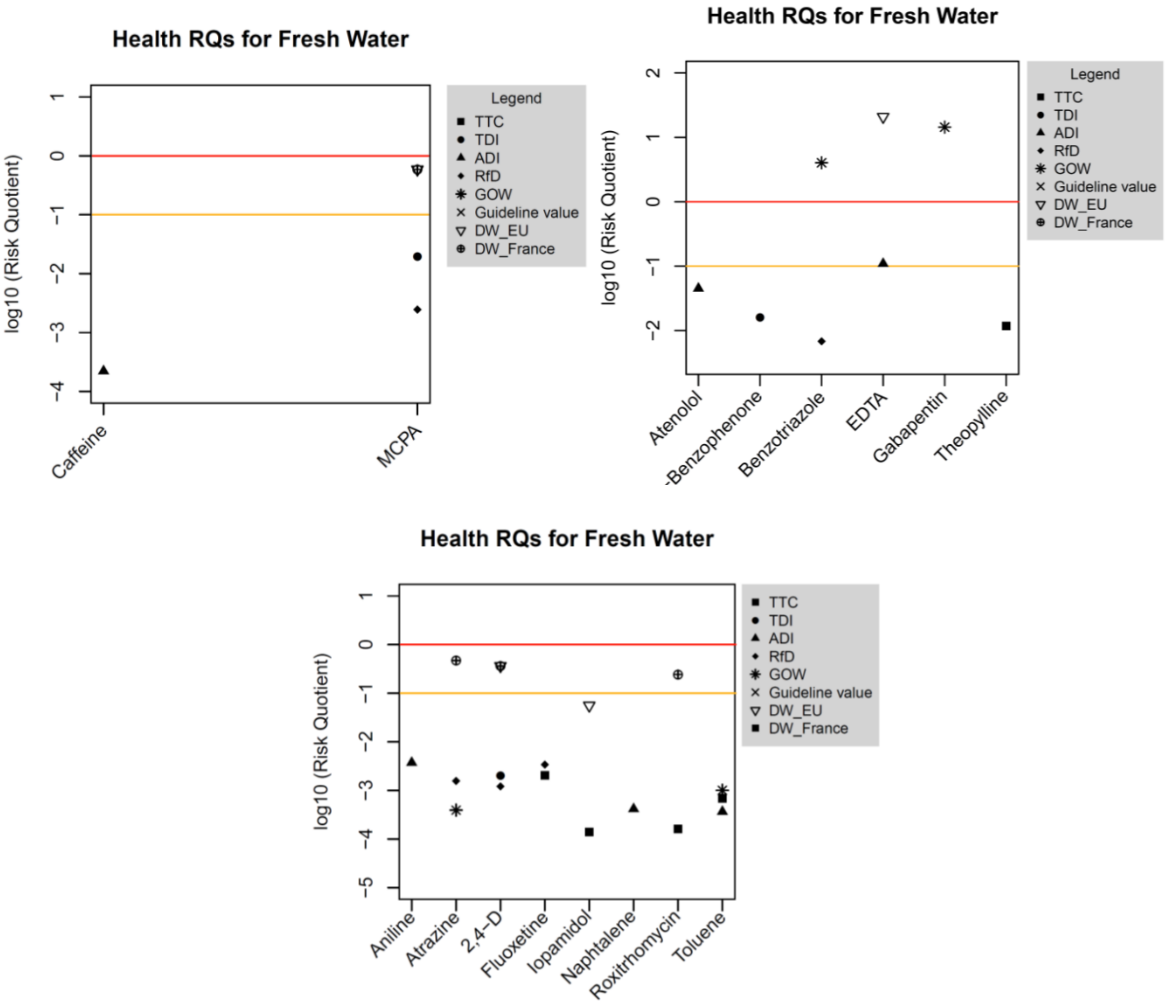

Figure 2.23 Risk quotients for health assessment after secondary treatment.
Red line indicates RQ = 1, orange line ind. RQ = 0.1.

2.4.2.4 Health risk assessment after tertiary treatment

Risk quotients after tertiary treatment are shown in Figure 2.24. Different symbols represent different benchmark values, while different colours illustrate the variation in treatment performance of EDR/µGAC and RO.

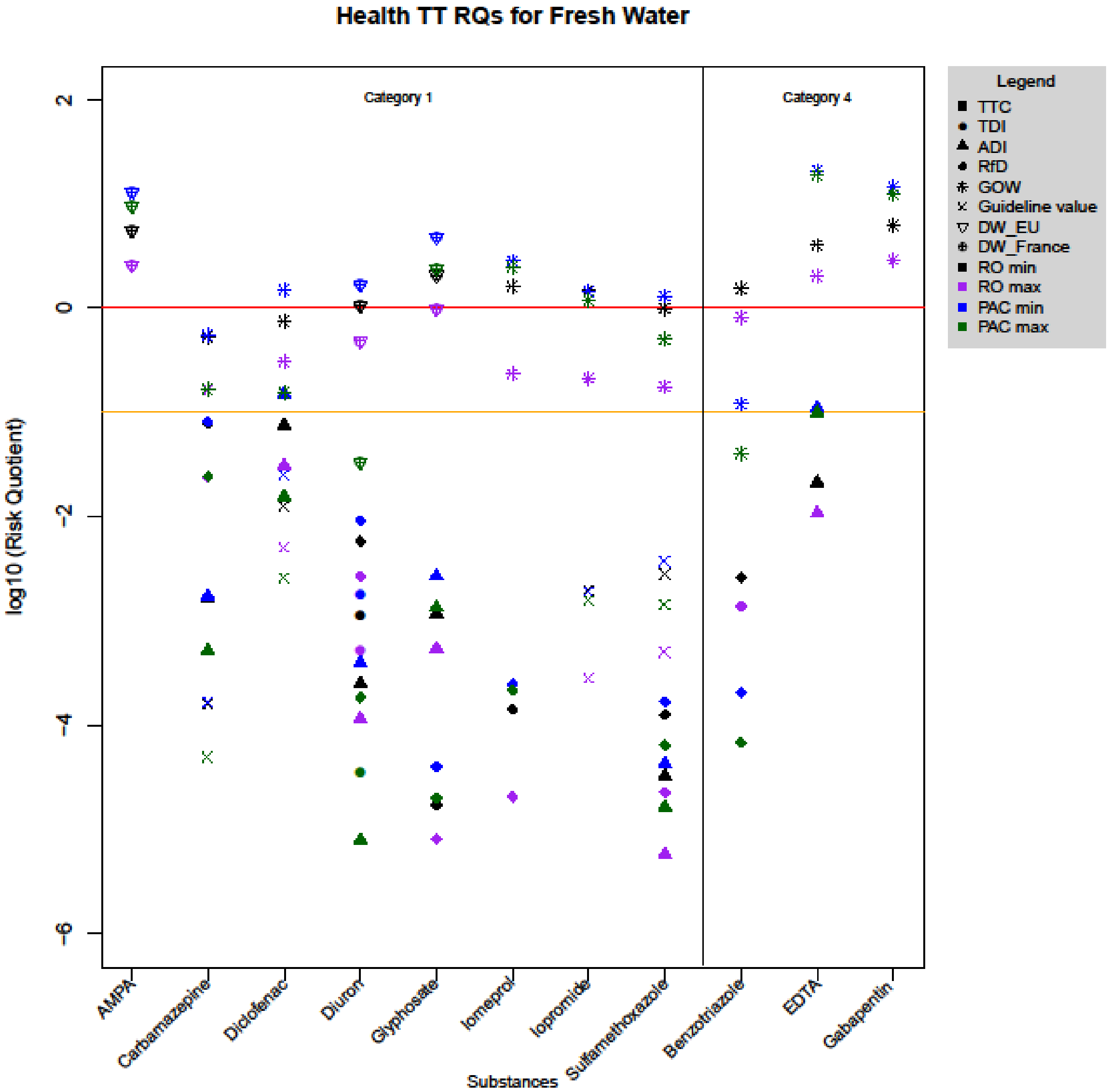

Figure 2.24 Risk quotients for health assessment after tertiary treatment.
Red line indicates RQ = 1, orange line indicates RQ = 0.1.

With respect to the health assessment, the best outcomes are achieved with the best case scenarios for EDR/µGAC and RO. EDR/µGAC would be able to reduce the RQ below 1 for 45 % of the compounds (Carbamazepine, Diclofenac, Diuron, Sulfamethoxazole and Benzotriazole), while RO would achieve the same outputs for 55 % of the substances (Carbamazepine, Diclofenac, Diuron, Iomeprol, Iopromide and Sulfamethoxazole). No scenario is capable of minimising the risk (RQ < 1) for AMPA, Glyphosate, EDTA, and Gabapentin. The only substance which falls below acceptable level for all benchmark values is Carbamazepine. The remaining substances are considered for further assessment during drinking water treatment.

2.4.2.5 Health risk assessment after drinking water treatment

After drinking water treatment, differences by applying different benchmark values become evident, especially regarding the assessment for AMPA and Glyphosate. AMPA is a metabolite of the pesticide Glyphosate. In the European Drinking Water Directive, pesticides are regulated with a limit value of

0.1µg/L. When using this value for AMPA, RQs > 1 are calculated for the DER/µGAC treatment under the made assumptions.

However, to the best of our knowledge, neither Glyphosate nor AMPA are considered “pesticides and relevant metabolites” under European regulation. This would mean that the limit value of 0.1µg/L would not be relevant for the two substances due to their low toxicity. In German regulation, a Drinking water limit value of 10 µg/L is used, which supports this hypothesis. In the WHO Drinking Water guidelines, both substances have toxicological guidelines values of 900 µg / L (Schriks, Heringa et al. 2010). This is 9000 times higher than the benchmark applied in this study. Up to now, no information of special regulation in France has been found so far and should be checked.

From the remaining 8 substances, **none of the actually measured substances** has exceeded the applied benchmark value. However, for the two added substances Gabapentin and EDTA, an exceeding of the precautionary values could not be excluded under the given assumptions. Both substances have been added as they are known to be present in municipal wastewater are very recalcitrant against biological degradation, and are difficult to remove by drinking water treatment. Regarding the latter, only limited information was found regarding the effect of chlorination on the removal of EDTA and Gabapentin. Therefore, conservative estimates of 10% have been applied for these oxidation steps. Verification of the drinking water treatment plant removal should be checked as well as the actual concentration on the wastewater. Moreover, while the precautionary value for EDTA is 10µg/L, the toxicologically derived guideline value lies at 600µg/L (Schriks, Heringa et al. 2010). Consequently, health risks due to the expected EDTA concentrations considered to be unlikely, although the applied benchmark of 10 µg/L led to RQ >1.

In Figure 2.25, RQs for the discussed substances are calculated once with the benchmark values of the Drinking Water Directive for pesticides and precautionary values for EDTA (upper plot) as well as for the application of WHO guidelines values based on toxicological information (lower plot).

Given that only toxicological values are used, the only substance left exceeding the benchmark value (1 µg/L) is Gabapentin. However, Gabapentin was added by literature data and the HPV value is very conservative. Thus, the findings on of the present evaluation should be interpreted correctly. There is no evidence of acute or chronic health impacts of Gabapentin due to IPR but the lack of available site specific information in combination with information about Gabapentin being highly recalcitrant against water treatment leads to the conclusion that this substance should be checked for.

It could be shown that risk assessment is highly sensitive to the used benchmark. Thus, the different risk quotients with precautionary, limit and toxicological values should encourage operators and health authorities to elaborate a mutual understanding of acceptable residual risk. Moreover, complementary effect-based monitoring to better integrate mixtures of known and unknown synergistic primary toxic effects to better ensure the safety assessment of human exposure should be considered.

In summary, from approximately 140 substances 36 have been analysed and assessed in this study. **Of the actually measured 36 substances, none is expected to cause drinking water concentrations leading to unacceptable health concerns after drinking water treatment in the sense that available benchmark value would be exceeded.** For AMPA it should be checked if the French regulation follows the European one, meaning that AMPA is not considered a relevant metabolite.

From a “moral” or “aesthetic” standpoint, which is equally important, there might be substances like EDTA and Gabapentin, which might not be acute hazards to human health but may arise at concentration in which discussion about acceptable level should be pursued and agreed on between all relevant stakeholders. The results of this study show that currently none of the assessed substances compromises the successful implementation of the indirect potable reuse project in general. On the contrary, by prioritizing the relevance of the analysed substances, the purpose of this risk assessment is to support the implementation process. The information elaborated in this assessment can be used to guide further investigations in order to refine the assessment regarding the substances identified as being “of concern”.

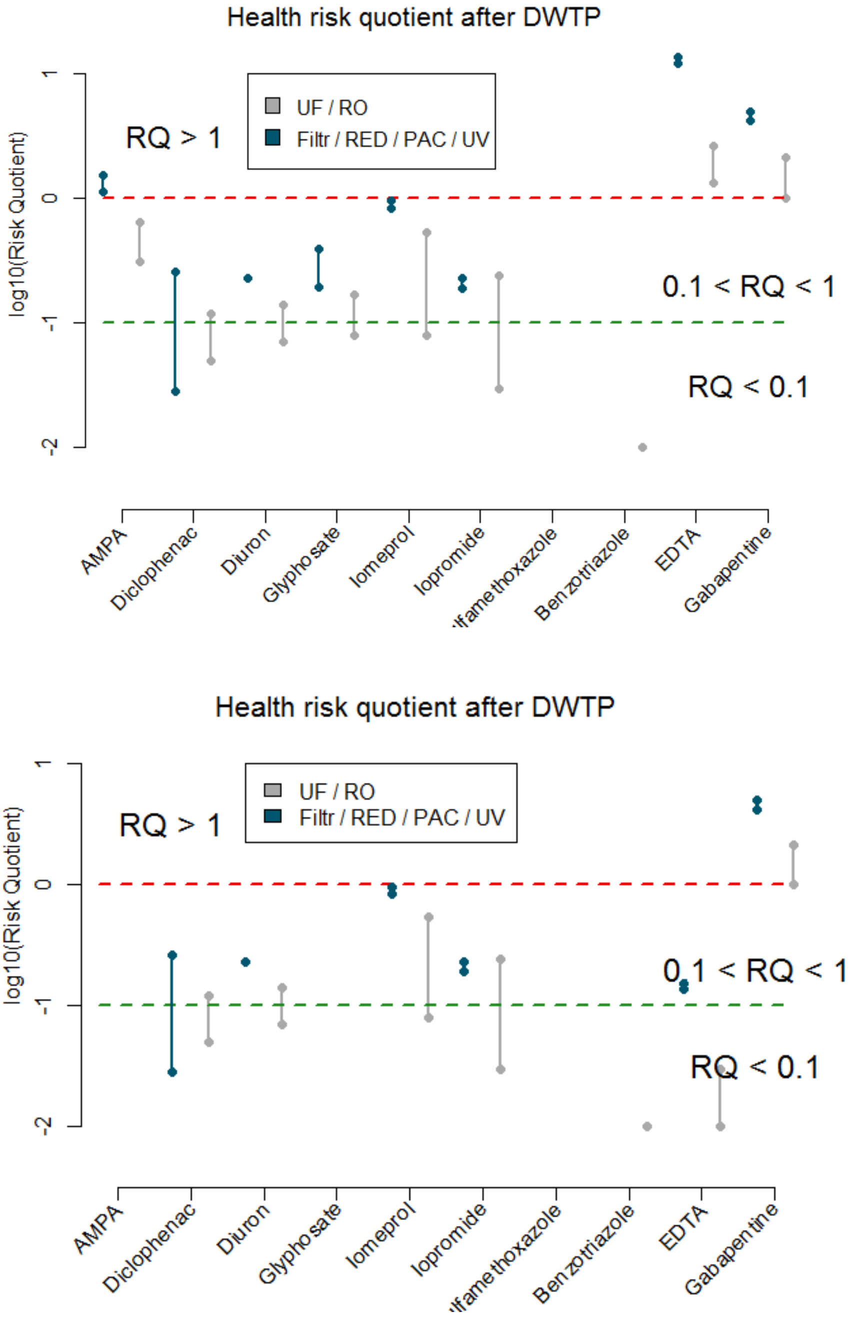

Figure 2.25 Risk quotients for health assessment after drinking water treatment.
The upper plots shows the results based on the limit values of the European Drinking Water Directive for pesticides and existing precautionary values of Germany for EDTA. The lower plot shows the results when applying toxicologically derived guideline values.

2.5 Summary and outlook

This study provided a systematic evaluation of the available information for the intended indirect potable reuse site in Vendée. The risk of infection was quantified using quantitative microbial risk assessment. Uncertainties were addressed using Bayesian updating in combination with Monte Carlo Simulation from the posterior distributions. Thus study underlined that the planned treatment options in combination with existing drinking water treatment is able to provide safe drinking water for the population in Vendée.

Due to the lack of effect based monitoring information a single substance approach has been used to evaluate the available monitoring data provided by DEMOWARE partners. Within a Bayesian framework the 95% quantile of the marginal distribution of the mean as a point estimate has been used to estimate effluent concentrations. Against the background of the very limited number of data points this approach can be seen as a realistic worst case approach.

Additional to secondary treatment, two different treatment trains as well as the drinking water treatment have been evaluated. Thereby, the number of relevant substances could be reduced from 36, which have been positively detected in the effluent of the wastewater treatment plants to below 10 for environmental endpoints and to 1 regarding human health assessment. Although there are still some substances “of concern” in the environmental risk assessment, one has to consider that at sites far off the coastline it is “common practice” to discharge secondary effluent into flowing inland surface waters. Consequently, by an additional tertiary treatment, risk will be below that of conventional wastewater treatment plants with comparable discharge and flow conditions of the receiving waters on a relative scale.

For health risk assessment the substance most likely to pass for drinking water purification is Gabapentin. The substance was not measured in Vendée but added as it was expected to of relevance caused by experiences from Germany. Assessment is based on literature information. The precautionary value for Gabapentin in Germany lies at 1 µg/L in drinking water. Worst case assumptions for concentrations and treatment performance led to the assessment that exceeding this precautionary value is a plausible outcome and should be checked.

For future implementation, one has to consider that the assessment partly relied on the use of acceptable level of countries other than France, mainly because no French regulatory approach is available. Especially for the assessment of concentration in drinking water German precautionary values have been used. For further implementation it is important that operators and the responsible authorities agree on a common level of residual risk, since in risk theory zero risk simply does not exist. This setting of targets is extremely important for implementing risk based approaches, since risk can be seen as the deviance from an intended target. Without such a target a quantitative assessment seems hard to be implemented and decisions on whether to allow and not allow such a treatment scheme rather arbitrary.

3 Life Cycle Assessment and water footprinting

This section describes the potential environmental impacts which are associated with the construction and operation of different options for additional water supply in the Vendée system. Using the method of Life Cycle Assessment (LCA) as defined in ISO standards (ISO 14040 2006, ISO 14044 2006), both direct and indirect effects of the water supply schemes are quantified and characterized with a set of environmental indicators. Whereas direct effects are related to environmental emissions from the system on-site (e.g. discharge of reclaimed water into the reservoir), indirect effects arise in the life cycle of the system due to consumption of electricity or chemicals and the need for infrastructure materials. Environmental impacts of these "background" processes are accounted with LCA datasets which describe all emissions and resource use during the life cycle of these products, e.g. emissions from coal mining or power plant for electricity production.

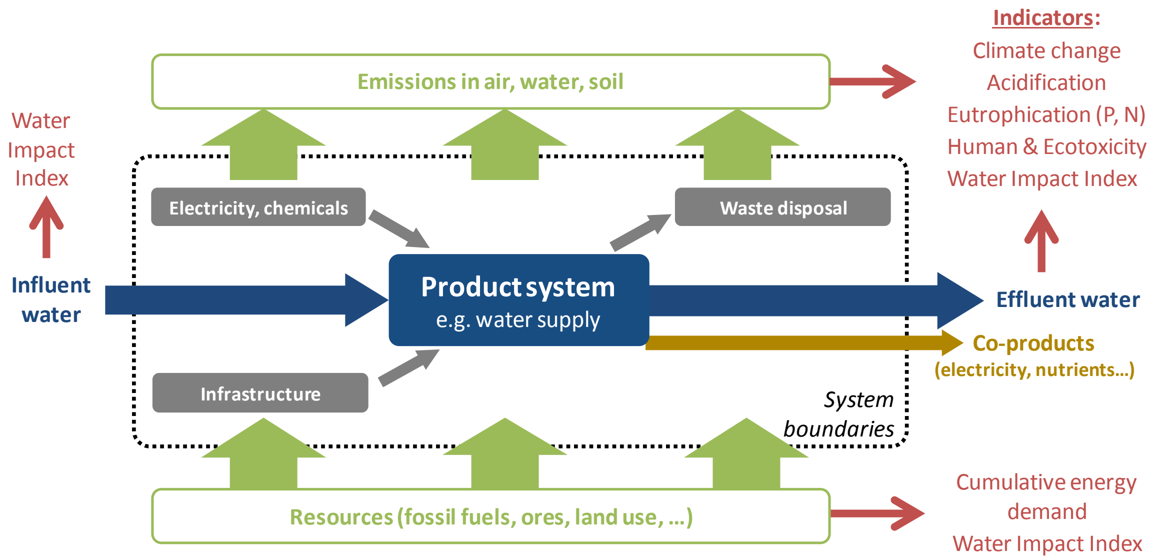

Figure 3.1 Framework of LCA for a water supply process

Due to the global life cycle perspective, LCA indicators describe only potential environmental impacts of emissions or resource use, using generalized impact assessment models which are not taking into account spatial or temporal variations of impacts or existing background conditions. Thus, LCA is not capable of predicting actual environmental impacts at a specific site (e.g. eutrophication in a reservoir), but shows a potential for environmental impacts based on annual pollutant loads and generalized characterisation factors for each substance.

Beside traditional LCA indicators for energy demand and emission-related impacts, this study also uses the method of water footprinting (WFP) as a tool to describe the effects of anthropogenic activity on the local water resources. Following the ISO definitions (ISO 14046 2014), a water footprint is based on quantitative information on water withdrawal and discharge, water scarcity, and water quality aspects. Taking the LCA perspective, WFP also takes into account direct and indirect effects in the entire life cycle of a system (i.e. also including the water use in background processes such as electricity production). From the set of available methods for WFP (Kounina, Margni et al. 2013), this study uses the Water Impact Index (WIIX) which was developed by Veolia (Bayart, Worbe et al. 2014). This method has been tested in DEMOWARE for the application in the field of water reuse, and a method feedback is provided in D3.2 (Kraus, Seis et al. 2016).

The structure of this chapter follows the ISO framework for LCA:

1) Definition of goal and scope of the study
2) Input data (Life Cycle Inventory)
3) Results for environmental indicators (Life Cycle Impact Assessment)
4) Interpretation and conclusions

3.1 Definition of goal and scope of the study

The goal of this LCA including the WIIX analysis is to quantify the potential environmental impacts associated with different options for drinking water supply in the Vendée region. In particular, this study focusses on the available options to provide additional water resources for drinking water production in addition to the existing water supply in times of high water scarcity in late summer.

Currently, drinking water in this area is supplied from the drinking water treatment plant (DWTP) of Le Jaunay. This DWTP takes freshwater from Le Jaunay reservoir and treats it to drinking water standards, supplying produced water into the regional network. For treatment of municipal wastewater, part of this area is served by the wastewater treatment plant (WWTP) of the Communauté de Communes des Olonnes (CCO), which releases treated WWTP effluent into the nearby Atlantic Ocean.

Due to high touristic activity, the supply area of DWTP Le Jaunay exhibits problems of water scarcity in dry years, especially towards the end of summer (August, September). In this study, several options have been considered to overcome local water scarcity in Le Jaunay area.

One of the options relates to the reuse of tertiary treated effluent from the WWTP CCO for refilling the drinking water reservoir Le Jaunay with reclaimed water. Other possible options include the import of drinking water via a pipeline network from the reservoir La Balingue, the seasonal storage of raw freshwater in an old mining quarry, and the desalination of seawater (Figure 3.2). La Balingue is the nearest location with suitable capacity to supply additional drinking water to Le Jaunay area.

All options for additional water supply will be operated “on demand” during the period of May-Oct, i.e. if low rainfall in spring and early summer indicates a potential problem of water supply after the high touristic season (Jul-Sep).

This LCA shows the potential environmental impacts of each option of water supply to compare them in their environmental profile and provide information for further planning of the future water supply strategies in Vendée. Consequently, the main target group of this LCA consists of the local operators of the water supply (Vendée Eau), but also relevant public stakeholders such as regulators, public administration, and the more general public in Vendée. Moreover, this LCA can also provide useful information for other professionals in the water sector such as planners, engineers and operators who are interested in the field of water reuse and its environmental assessment.

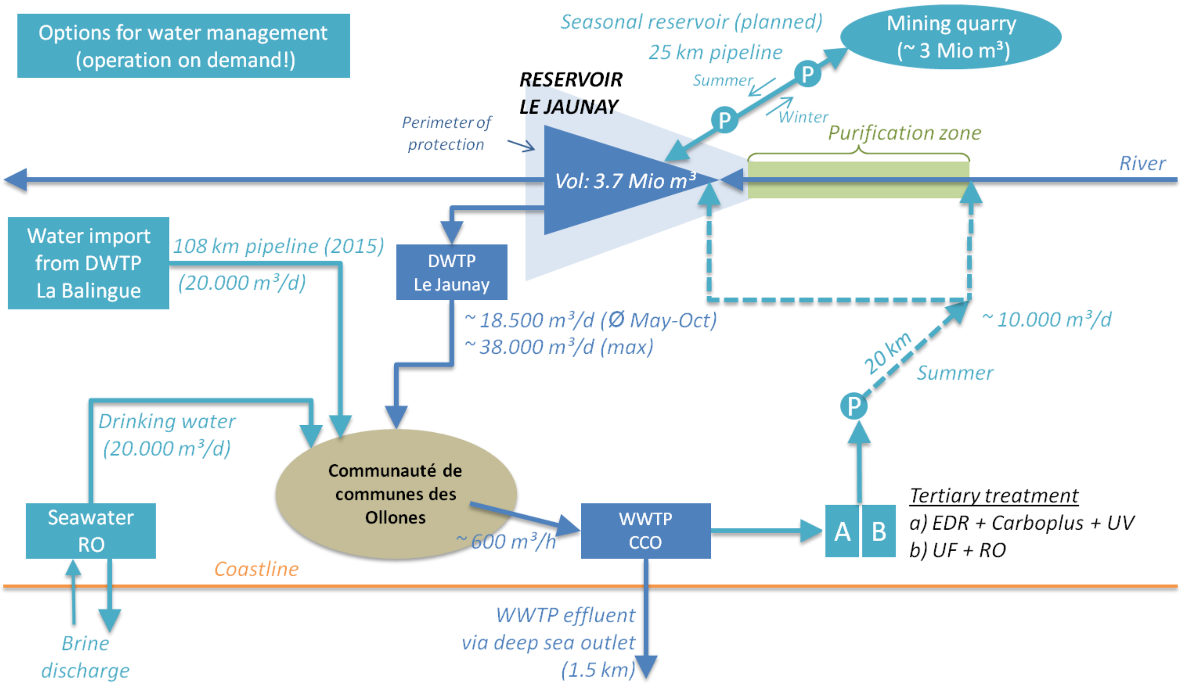

Figure 3.2 Situation at the study area in Vendée and alternatives for water supply

Function and functional unit

The system under study includes the water services for the related study area, i.e. the supply of drinking water at the network of Le Jaunay, and also the treatment of wastewater in the WWTP CCO. In addition, the system includes the additional processes that are required to augment the existing drinking water supply at Le Jaunay during the summer months.

As the production of additional drinking water is the main purpose of all investigated scenarios, the functional unit is consequently defined as *"per production of 1 m^3 of drinking water" $[m^3]^{-1}$* ready to be fed in the network of this area of Vendée. As the system boundaries include more elements than required only for the additional supply of drinking water (i.e. the existing DWTP Le Jaunay and the WWTP CCO are included in all scenarios), it was decided to show only the changes between the different scenarios of additional water supply (1-5) and the status quo (0). Subtracting the total indicator score of the baseline "0.Status quo" from the specific score of each scenario 1-5, the net environmental impacts related to the additional production of drinking water can be determined. If this net impact is divided by the annual volume of additional drinking water in each scenario (cf. Table 3.3), the environmental impacts per m^3 of additional drinking water can be calculated, focussing on the consequences that are due to the additional water service. It is important to note that WWTP effluent is dischared in most scenarios directly into the ocean, while it is partially reclaimed for drinking water production in the reuse scenarios.

Scenarios

The scenarios for this LCA and WiiX are defined according to the goal of this study and describe the existing situation in the system (status quo) and the different potential alternatives for drinking water supply in summer (May-Oct) (Table 3.1).

Table 3.1 Scenarios for LCA and data sources

(DWTP: drinking water treatment plant; WWTP: wastewater treatment plant; EDR: Electrodialysis reversal; µGAC: micro-granular activated carbon, UV: UV disinfection; UF: ultrafiltration; RO: reverse osmosis)

Scenario	Definition	Data sources
0. Status quo	DWTP Le Jaunay + WWTP CCO	Full-scale data of 2013 – 2015 (May-Oct)
1. Water import	Import from DWTP La Balingue (Jul-Sep) and DWTP Le Jaunay + WWTP CCO	Full-scale data of 2013 – 2015, including pipeline (108 km)
2. Mining quarry	Seasonal storage at mining quarry (Jul-Sep) and DWTP Le Jaunay + WWTP CCO	Pipeline (25 km) only, no change in water quality assumed
3. Seawater RO	Seawater desalination system at coastline north of Olonnes (Jul-Sep) and DWTP Le Jaunay + WWTP CCO	Data from feasibility study, literature and other sites
4. Water reuse (EDR)	Tertiary treatment at WWTP CCO (Jun-Oct): Sand filter + EDR + µGAC + UV and DWTP Le Jaunay + WWTP CCO	Data from design study (D6.3), including pipeline (20 km)
5. Water reuse (RO)	Tertiary treatment at WWTP CCO (Jun-Oct): UF + RO and DWTP Le Jaunay + WWTP CCO	Data from design study (D6.3), 5% bypass in RO, including pipeline (20 km)

In detail, the scenarios contain the following processes (Figure 3.3):

- **0. Status quo**: this scenario contains the existing drinking water treatment plant (DWTP) Le Jaunay and wastewater treatment plant (WWTP) CCO. Data is collected from full-scale plants (mean of 2013-2015) and represents operation of both plants from May-Oct, including also the infrastructure required for treatment (estimate). Networks for drinking water distribution or wastewater collection are not included in the scenario.
- **1. Water import**: in addition to the existing system, this scenario represents the import of water from the reservoir of La Balingue during months July to September. It includes treatment of the raw surface water at DWTP La Balingue and transport of the drinking water in a pipeline (108 km) up to the Vendée network. Input data represents operation of the DWTP (mean data of 2013-2015 from full-scale operation) and electricity demand for pumping of water in the pipeline, as well as infrastructure for the pipeline and DWTP (estimate). The respective pipeline has been realized by Vendée Eau in 2016 and is in operation since summer 2016.
- **2. Mining quarry**: in this scenario, the existing system is extended by a seasonal storage in a mining quarry (max. volume of 3 Mm^3). Using a new pipeline (to be built) between Le Jaunay reservoir and the quarry, water is pumped from the reservoir into the quarry in winter in times of high water availability. In summer (Jul-Sep), this water can be recycled back to the reservoir to augment this resource for drinking water production. Input data includes construction and operation of the pipeline (25 km), and also treatment of this water in the DWTP Le Jaunay. Constructional efforts in the quarry itself are unknown and thus not included in this LCA. Water quality is assumed to be unchanged during storage time in the quarry, neglecting potential impacts of long-term storage on water quality due to lack of adequate data. If water quality would be deteriorated during the storage period, a complete draining of the storage is planned by Vendée Eau to discard the degraded water and not use it for drinking water production.
- **3. Seawater RO**: this scenario extends the existing system with a plant for seawater desalination based on a double membrane process with ultrafiltration (UF) and reverse osmosis (RO). This

plant would be located at the coastline north of Olonnes, so that produced drinking water has to be delivered via pipeline (10 km) to the next point of entry into the Vendée network during months of July to September. UF backwash and brine of the RO process are discharged into the ocean. Data is based on a feasibility study of Vendée Eau and complemented with data for RO systems from literature and other sites.

- **4. Water reuse (EDR)**: this scenario of water reuse provides additional water for the reservoir of Le Jaunay by advanced treatment of the secondary effluent of WWTP CCO, operated from June to October. Tertiary treatment is based on a multi-stage process with sand filter, electrodialysis reversal (EDR), adsorption on micro-granular activated carbon (µGAC), and final UV disinfection. While backwash water from sand filter is recycled to the WWTP inlet, EDR brine is discharged to the ocean. This train aims at removal of particles, bulk and trace organics and inorganics, partial removal of salinity, and complete disinfection. After tertiary treatment, reclaimed water is pumped via pipeline (20 km) to the reservoir of Le Jaunay, where it is stored and then treated in the DWTP Le Jaunay. Data for operation and infrastructure of tertiary treatment and pipeline is based on the design study conducted in DEMOWARE D6.3 (Dupoiron, Drappier et al. 2016).
- **5. Water reuse (RO)**: as an alternative process for water reuse, this scenario describes a tertiary treatment train based on a double membrane system, operated from June to October. Secondary effluent of WWTP CCO is treated by UF and RO membranes prior to pumping of the reclaimed water to Le Jaunay reservoir as in the previous scenario. Backwash water from UF is recycled to the WWTP inlet, and RO brine is discharged to the ocean. To avoid remineralisation of fully desalinated reclaimed water, 5% of the UF permeate is by-passed around the RO system and mixed with RO permeate at the end, providing an acceptable level of salts in the final product. Input data is also based on the design study conducted in DEMOWARE D6.3 (Dupoiron, Drappier et al. 2016).

System boundaries

All scenarios include operation and infrastructure of drinking water production and wastewater treatment within the system boundaries of this LCA, including the processes required for additional water supply (Figure 3.4). Networks for wastewater collection (sewer system) and drinking water distribution are not included in this study, as they are comparable between all scenarios. Operational efforts include electricity and chemicals for water treatment and transport (pumping), as well as disposal of sludge from DWTP and WWTP. Infrastructure of water treatment and pipelines is included in the LCA. For the quarry, constructional efforts for preparing the quarry for water storage are not included. Background processes include production of electricity, chemicals, and materials for infrastructure related to construction and operation of the systems under study

Allocation

Sludge treatment is considered in the system boundaries. For WWTP sludge, it was considered to be valorised in agricultural land, and the avoided impacts are accounted by crediting the substituted production of mineral fertilizer.

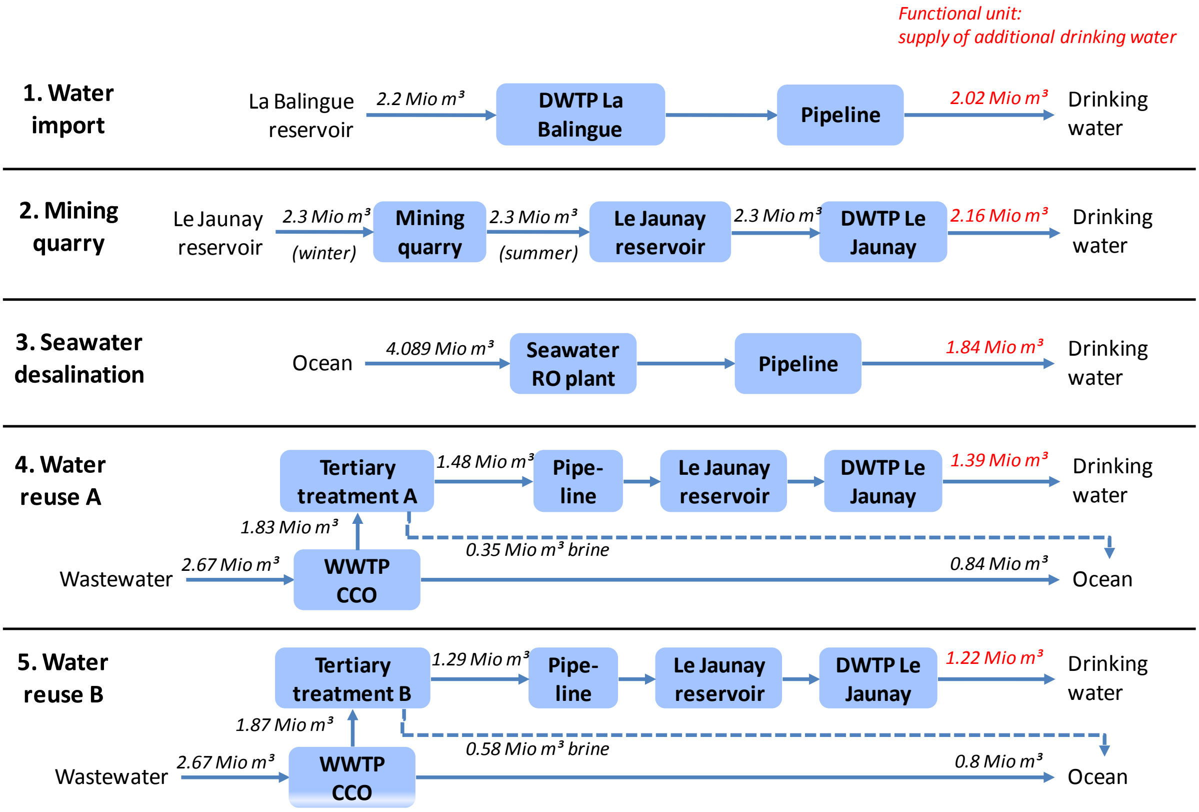

Figure 3.3 Scenarios of the LCA to produce additional drinking water

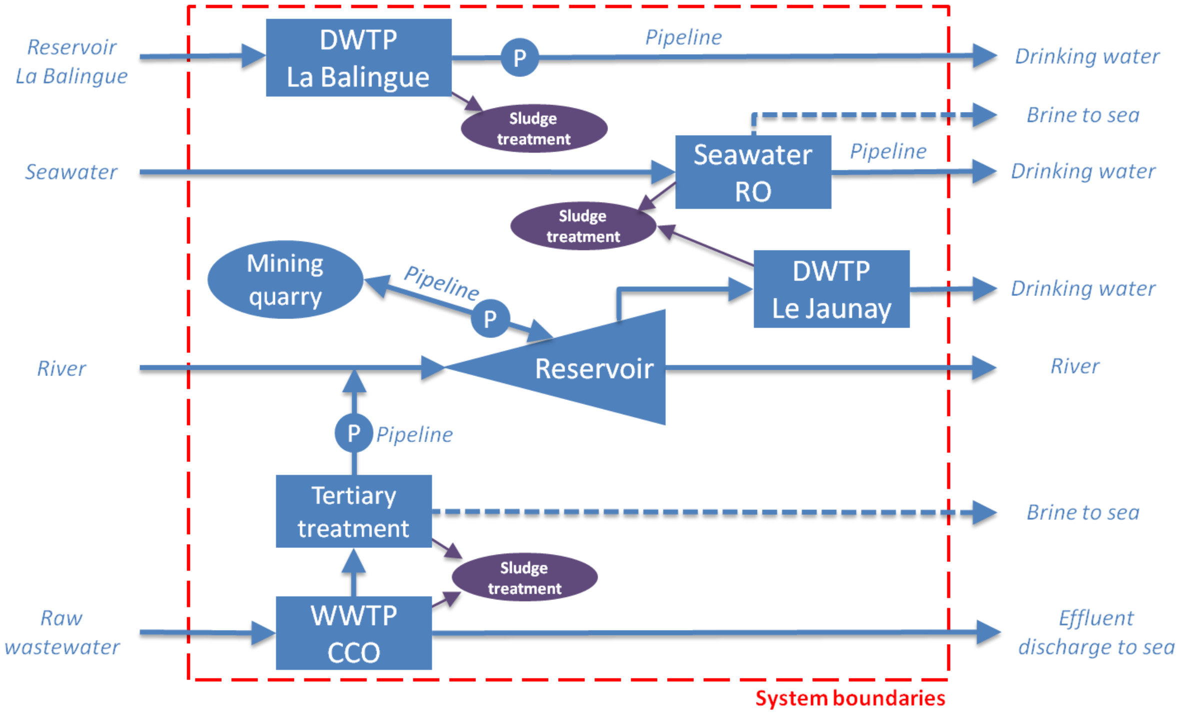

Figure 3.4 System boundaries of the LCA

(DWTP: drinking water treatment plant; WWTP: wastewater treatment plant; P: Pumping; RO: reverse osmosis)

Data quality

In general, quality of operational data is high for all systems that are already existing (i.e. DWTP Le Jaunay and La Balingue, WWTP CCO, pipeline La Balingue – CCO network), as full-scale data on water quality and consumptives was collected directly from the operators. For other alternatives of water supply, operational data was estimated based on feasibility studies (seawater RO) and information of the operator (pipeline Le Jaunay – Quarry) from planning process. Operational data for the water reuse trains is based on the design study made in DEMOWARE task 6.3 which estimated the performance and consumptives of the tertiary treatment based on previous experience by the engineering company SAUR. Hence, operational data for the planned systems has only medium quality and should be validated for the next planning step, e.g. in pilot trials.

Data for infrastructure was roughly estimated by KWB for all scenarios based on data of previous LCA studies of water treatment. Due to the long lifetime of water infrastructure, the contribution of this particular life cycle phase to the total environmental impacts is usually small (< 10%), especially if material-intensive networks are not included. However, pipeline transport of water over long distances requires a significant input of material for the pipeline construction, which was included in this study based on the pipe material (HDPE) and expected diameter.

Overall, data quality of this LCA is assessed with medium to high quality, which is seen as sufficient for a prospective LCA study. However, input data for the water reuse scenarios and also seawater desalination should be validated with pilot trials or more detailed design studies to confirm or update the outcomes of this LCA for a strategic decision.

Table 3.2 Data sources and data quality
(DWTP: drinking water treatment plant; WWTP: wastewater treatment plant; RO: reverse osmosis)

Process	Data source	Data quality
DWTP Le Jaunay	Water volume + quality: full-scale data (2011-2015) Energy/chemicals: full-scale data (2013-2015)	High High
WWTP CCO	Water volume and quality: full-scale data (2011-2015) Energy/chemicals: full-scale data (2012-2015)	High High
DWTP La Balingue	Water volume and quality: full-scale data (2011-2015) Energy/chemicals: full-scale data (2014-2015)	High HIgh
Pipeline La Balingue – CCO network	Energy for pumping: operator data	High
Pipeline Le Jaunay – Mining quarry	Energy for pumping: estimate of Vendée Eau	Medium to high
Seawater RO and pipeline	Energy/chemicals: data from feasibility study and literature Brine/sludge: literature Energy for pumping: estimate of Vendée Eau	Medium Medium Medium to high
Tertiary treatment incl. pipeline WWTP – Le Jaunay reservoir	Energy/chemicals: design data (D6.3) Water volume and quality: design data (D6.3) Brine/sludge: design data (D6.3)	Medium Medium Medium
Background processes	Ecoinvent v3.1	Medium to high

The set of environmental indicators include global warming potential (100a), terrestrial acidification potential, freshwater and marine eutrophication. The set is expanded by using the cumulative energy demand of non-renewable resources (fossil + nuclear) as defined in VDI 4600 (VDI 2012). These indicators are based on midpoint indicators of the ReCiPe method (Goedkoop, Heijungs et al. 2009), taking the hierarchist perspective without accounting for long-term emissions. Eco-toxicity and human toxicity are also evaluated. For toxicity evalation, the consensus model USEtox® is applied for the categories of freshwater ecotoxicity and human toxicity (total) (Rosenbaum, Bachmann et al. 2008). For water footprinting, the Water Impact Index is applied (Bayart, Worbe et al. 2014). More information on the indicator methods used in this LCA study can also be found in DEMOWARE deliverable D3.1 (Seis and Remy 2015).

3.2 Input data (Life Cycle Inventory)

Input data for the Life Cycle Inventory was collected from the project partners as listed in Table 3.2. Water volumes in the different scenarios are defined by Vendée Eau and are based on the capacity of the different options for additional water supply (Table 3.3). On top of the 3.65 Mio m³ of drinking water that are usually produced between May-Oct at DWTP Le Jaunay, the scenarios add between 1.22 and 2.16 Mio m³ of drinking water depending on the peak capacity of the pipelines or the tertiary treatment (Figure 3.3). It has to be noted that the water volume delivered to Le Jaunay reservoir in scenarios 2/4/5 is slightly higher, but the overall balance also accounts for the water losses in the treatment process of DWTP Le Jaunay (94% recovery).

Table 3.3 Water volumes of all scenarios for DWTP intakes, WWTP discharge, reclaimed water, and discharge into reservoir
(Volumes for complete period May – Oct)

Scenario		Intake DWTP Le Jaunay	Intake DWTP La Balingue	Intake and release Quarry	Discharge of WWTP CCO to ocean	Re-claimed water	Discharge to reservoir
0. Status quo	*[Mio m³]*	3.65	-	-	2.67	-	-
1. Water import	*[Mio m³]*	3.65	2.25	-	2.67	-	-
2. Mining quarry	*[Mio m³]*	5.95	-	2.3	2.67	-	2.3
3. Seawater RO	*[Mio m³]*	3.65	-	-	2.67	-	-
4. Water reuse (EDR)	*[Mio m³]*	5.13	-	-	0.84	1.83	1.48
5. Water reuse (RO)	*[Mio m³]*	4.95	-	-	0.8	1.87	1.29

Electricity demand of treatment and transport of water is listed in Table 3.4 together with water recovery ratio (i.e. accounting for water losses in production process via backwash, brine etc). DWTP Le Jaunay and La Balingue have comparable electricity demand, but DWTP La Balingue has lower water recovery due to the operation of an UF membrane process. Seawater RO has the highest demand for electricity and the lowest recovery (45%) of all trains. For water reuse scenarios, the EDR process has higher electricity demand than the RO process (mainly due to energy demand of the EDR process which is proportional to the salinity of influent water), but also a higher water recovery. For the water transport in pipelines, the import scenario has the highest electricity demand for pumping (108 km), followed by the quarry (25km to the quarry in winter and back to the reservoir in summer) and the seawater RO and reuse scenarios. Electricity demand of water transport was estimated by Vendée Eau based on hydraulic head and friction losses in the pipeline.

Table 3.4 Electricity demand for water treatment and transport related to influent volume into the process, and ratio of water recovery per scenario

(DWTP: drinking water treatment plant; WWTP: wastewater treatment plant; EDR: Electrodialysis reversal; RO: reverse osmosis)

Process		0. Status quo	1. Water import	2. Mining quarry	3. Seawater RO	4. Water reuse (EDR)	5. Water reuse (RO)
DWTP Le Jaunay	*[kWh/m³]*	0.64	-	0.64	-	0.64	0.64
DWTP La Balingue	*[kWh/m³]*	-	0.62	-	-	-	-
Seawater RO	*[kWh/m³]*	-	-	-	2.5	-	-
WWTP CCO	*[kWh/m³]*	0.31	0.31	0.31	0.31	0.31	0.31
Tertiary treatment at WWTP CCO	*[kWh/m³]*	-	-	-	-	1.25	0.85
Pipeline	*[kWh/m³]*	-	1.37	0.77 + 0.77	0.65	0.57	0.57
Water recovery	*[%]*	94	90	94*	45	75*	67*

* including water losses in tertiary treatment and DWTP Le Jaunay

Chemical demand for water treatment is listed in Table 3.5 for all plants. For WWTP CCO, dosing of $FeCl_3$ has not been applied so far, but is assumed for future operation of the WWTP to comply with upcoming regulatory standards of P removal efficiency in 2017. Chemical demand of DWTPs Le Jaunay and La Balingue is based on full-scale consumption data and includes chemicals for coagulation/flocculation, chemical stabilisation, removal of trace organics with powdered activated carbon (PAC), and disinfection. Oxygen for ozonation is produced on-site by pressure swing adsorption. At DWTP La Balingue, consumptives are also included for ballasted sand clarification and membrane treatment and cleaning. For seawater RO, chemicals are required for pre-treatment via coagulation, pH adjustment, disinfection, remineralisation, and membrane cleaning. Water reuse with EDR requires coagulant for pre-treatment, micro-granular activated carbon (µGAC), and chemicals for cleaning and fouling control of the EDR system. RO treatment of secondary effluent for water reuse requires coagulant for pre-treatment and additives for pH adjustment, fouling control, and membrane cleaning. For data of chemical consumption, it has to be noted that real consumption data of full-scale plants has been collected for WWTP CCO and DWTP Le Jaunay and La Balingue, while chemical demand for seawater desalination and water reuse systems is estimated based on design data in D6.3 (Dupoiron, Drappier et al. 2016) and literature.

Water quality data of DWTP intake, release of stored or reclaimed water into the reservoir Le Jaunay, and discharge of secondary effluent of WWTP CCO into the ocean is listed in Table 3.6. Water quality data of intakes and discharges in freshwater (reservoir, river water) is used for calculation of Water Impact Index and environmental emissions, whereas water intake or release to ocean is accounted as environmental emission only (e.g. accounted in indicator for eutrophication, but not in WIIX). Brine of seawater desalinaton or reclaimed water treatment is discharged to ocean. The latter discharge contains a considerable fraction of nutrients from secondary WWTP effluent, accounting for 5.7 and 8.6 t N in the annual brine flow of scenarios 'Water Reuse A' and 'Water reuse B', respectively. Drinking water quality is not assessed in this LCA, as use of drinking water is not an "emission into the environment" and thus cannot be characterized with the models of LCA. The aspect of drinking water quality and potential effect on humans is extensively analyzed in the risk assessment part of this document (cf. chapter 2.1).

Table 3.5 Chemicals demand for water treatment

(DWTP: drinking water treatment plant; WWTP: wastewater treatment plant; EDR: Electrodialysis reversal; RO: reverse osmosis; PAC: powdered activated carbon; µGAC: micro-granular activated carbon,)

Chemical		WWTP CCO	DWTP Le Jaunay	DWTP La Balingue	Seawater RO	Water reuse (EDR)	Water reuse (RO)
$AlSO_4$ (8.2%)	*[g/m³]*	-	13.7	-	-	-	-
$FeCl_3$ (41%)	*[g Fe/m³]*	7.6	21.2	17.5	1.0	2.0	2.0
$Ca(OH)_2$ (92%)	*[g/m³]*	-	65.9	52.1	94.8	-	-
NaOCl (15%)	*[g/m³]*	3.4	15.2	17.2	28.2	0.2	4.5
$NaHSO_3$ (30%)	*[g/m³]*	-	-	0.8	-	-	5.0
H_3PO_4 (75%)	*[g/m³]*	-	0.2	-	-	-	-
H_2SO_4 (96%)	*[g/m³]*	0.04	-	11.1	47.4	-	4.5
HCl (32%)	*[g/m³]*	-	-	-	9.5	0.5	-
Citric acid (100%)	*[g/m³]*	-	-	-	2.0	-	-
NaOH (30.5%)	*[g/m³]*	1.7	-	17.0	3.0	0.2	11.8
CO_2 (liquid)	*[g/m³]*	-	29.8	20.2	-	-	-
Activated carbon	*[g/m³]*	-	6.0 (PAC)*	8.9(PAC)*	-	16 (µGAC)*	-
Polymer (100%)	*[g/m³]*	-	0.4	0.6	-	-	-
Polymer (sludge)	*[g/m³]*	4.5	0.8	0.4	-	-	-
Salt (100%)	*[g/m³]*	-	-	0.3	-	0.03	-
Microsand	*[g/m³]*	-	-	7.1	-	-	-
Anti-scalant (P-based)	*[g/m³]*	-	-	-	-	2.4	2.4
RO cleaning agent	*[g/m³]*	-	-	-	-	-	0.9

** PAC is fresh activated carbon (virgin), µGAC will be regenerated after use*

Whereas water quality of the reservoirs and WWTP discharge is based on long-term monitoring of full-scale systems, water quality of reclaimed water is estimated in the design study based on projected process performance (Dupoiron, Drappier et al. 2016). Some parameters such as heavy metals are expected to be lower than the limit of quantification. Hence, they are estimated with LOQ/2 as best estimate for the assessment of water quality in the Water Impact Index. As this LCA does not evaluate marine ecotoxicity, heavy metals discharged to ocean are not accounted in this study.

For the seasonal storage in the quarry (scenario 2), water quality of the reservoir during the winter period is used as intake quality, assuming the same water quality to be discharged in summer back to the reservoir. Hence, no change in water quality is assumed during the storage period, which is a first estimate but has to be confirmed by further studies.

Table 3.6 **Water quality data for intake (freshwater) or discharge (freshwater or ocean)**

(DWTP: drinking water treatment plant; WWTP: wastewater treatment plant; EDR: Electrodialysis reversal; RO: reverse osmosis; n/a: data not available); shaded values are below limit of quantification (LOQ), accounted in Water Impact Index with LOQ/2

Parameter		Le Jaunay reservoir (summer)	Le Jaunay reservoir (winter)	La Balingue reservoir (summer)	WWTP CCO	Water reuse (EDR)	Water reuse (RO)
		Intake DWTP	Intake in quarry*	Intake DWTP	Dis-charge	Discharge Le Jaunay	Discharge Le Jaunay
Volume (May-Oct)	*Mm^3*	3.72	2.3	2.25	2.6	1.41	1.52
Biological oxygen demand	*[g O_2/m^3]*	2.93	2.31	1.91	2.0	3	3
Chemical oxygen demand	*[g O_2/m^3]*	37	23	n/a	40	26	3
Dissolved organic carbon	*[g C/m^3]*	9.26	9.55	5.31	n/a	4	2
NH_4-N	*[g/m^3]*	0.13	0.17	0.08	3.9	0	0
NO_3-N	*[g/m^3]*	0.86	3.0	7.0	1.6	0.9	1.2
Total nitrogen	*[g/m^3]*	n/a	n/a	n/a	n/a	1.9	1.6
Total phosphorus	*[g/m^3]*	0.13	0.14	0.05	0.7	0.1	0.1
Conductivity	*[mS/cm]*	0.35	0.32	0.36	2.1	0.9	0.4
Chloride	*[g/m^3]*	48	44	22	1260	190	119
Arsenic	*[mg/m^3]*	15.8	7.2	0.78	3.5	<5	<5
Cadmium	*[mg/m^3]*	<0.5	<0.5	<0.5	<2	<2	<2
Copper	*[mg/m^3]*	<5	<5	<5	<5	<5	<5
Chromium	*[mg/m^3]*	0.14	1.13	0.4	3.5	<5	<5
Lead	*[mg/m^3]*	0.79	1.43	0.46	1.4	<2	<2
Mercury	*[mg/m^3]*	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Nickel	*[mg/m^3]*	0.45	0.58	<5	<10	<10	<10
Zinc	*[mg/m^3]*	7.9	16.1	9.1	50.1	23.5	9

* water of Le Jaunay reservoir which is stored in the quarry in winter and then released back to reservoir in summer, and no change in water quality is assumed during storage

Material demand for infrastructure in all scenarios is roughly estimated based on the dimensioning of the treatment plants and pipelines required (Table 3.7). Infrastructure for DWTPs is partially accounted for each scenario by relating the total annual volume to the produced volume during the study period (cf. Table 3.3). For water import, infrastructure for pipeline only accounts the additional pipeline built to connect Vendée to the existing network (35 km). Lifetime of infrastructure is estimated to 50 years for tanks and pipelines, 12 years for machinery, and 3 years for UV lamps.

All background processes are modelled with datasets of LCA database ecoinvent v3.1 (Ecoinvent 2014). Detailed information of the datasets can be found in Table 6.2 in the annex.

Table 3.7 **Material demand for infrastructure (estimates)**
(DWTP: drinking water treatment plant; WWTP: wastewater treatment plant; EDR: Electrodialysis reversal; RO: reverse osmosis; PAC: powdered activated carbon; µGAC: micro-granular activated carbon, n/a: data not available) shaded values are below limit of quantification (LOQ), accounted in water quality index with LOQ/2

Parameter		DWTP Le Jaunay	WWTP Le Jaunay	DWTP La Balingue	Seawater RO	Quarry	Water reuse (EDR)	Water reuse (RO)
Plant								
Excavation	*m³*	500	1000	500	500	-	-	-
Concrete	*m³*	1000	1500	1000	500	-	304	235
Reinforcing steel	*t*	180	270	180	50	-	30.4	23.4
Low-alloyed steel	*t*	50	50	50	-	-	-	-
Stainless steel	*t*	20	30	20	20	-	1.2	-
Cast iron	*t*	5	10	5	5	-	1	1.5
Copper	*t*	0,5	1	0,5	-	-	-	-
Polyethylen (HDPE)	*t*	5	10	5	25	-	2.4	20
UV lamps	*pc*	-	-	-	-	-	80	-
Pipeline								
Excavation	*m³*	-	-	70000	10000	50000	42500	42500
Polyethylen (HDPE)	*t*	-	-	2800	400	2000	850	850

For the Water Impact Index, information on local water scarcity and water quality is required to characterize the different water flows in the system. Monthly water scarcity factors for Le Jaunay and La Balingue locations are taken from AWARE method (WULCA 2015) and are listed in Table 3.8. For water-stress based calculations, freshwater intake into DWTP Le Jaunay from May-Oct is distributed according to full-scale data of water consumption (0.49 Mm³ in May and June, 0.87 Mm³ in Jul, 1.01 Mm³ in Aug, 0.49 Mm³ in Sept, and 0.36 Mm³ in Oct). For the scenarios with additional water supply, intake volumes are equally distributed over three months for water import (0.75 Mm³ per month in Jul-Sep) and five months for seasonal storage (0.46 Mm³ per month in Nov-Mar). Refilling of the reservoir Le Jaunay in summer is estimated for three months in quarry operation (0.77 Mm³ per month in Jul-Sep) and five months in the water reuse scenarios (May-Oct), assuming the same distribution also for drinking water production.

Water quality is calculated via the water quality index (WQI), benchmarking water quality of the different flows against reference concentrations for good surface water quality in France (MEEM 2015, MEEM 2016) (Table 3.9). It has to be underlined here that WQI is determined for some water flows by pollutants which are estimated below LOQ (e.g. Cd in reclaimed water). This important aspect is further discussed in the results below.

Table 3.8 Monthly water scarcity indicator AWARE (WULCA 2015)

AWARE non-agri from www.wulca-waterlca.org/project.html in [m^3 world-eq/m^3]. Values below 1 represent low water scarcity, value of 1 equals world-average in water scarcity, and values higher than 1 represent higher water scarcity.

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Le Jaunay area	0.22	0.31	0.37	0.53	0.95	3.35	100	100	3.45	0.65	0.34	0.26
La Balingue area	0.53	0.63	0.65	0.82	1.03	1.87	4.38	9.51	6.21	2.12	1.03	0.66

Table 3.9 Water quality index (WQI) for Water Impact Index

(DWTP: drinking water treatment plant) benchmark values derived from French regulations for surface water quality (MEEM 2015, MEEM 2016), **bold values determine final WQI,** shaded values are below limit of quantification (LOQ) and accounted with LOQ/2

Parameter		Bench mark (C_{ref})	Le Jaunay reservoir (summer)	Le Jaunay reservoir (winter)	La Balingue reservoir (summer)	Water reuse (EDR)	Water reuse (RO)
			Intake DWTP	Intake in quarry*	Intake DWTP	Discharge Le Jaunay	Discharge Le Jaunay
Dissolved organic carbon	*[g C/m^3]*	7	0.76	0.73	1.32	1.75	3.5
Biological oxygen demand	*[g O_2/m^3]*	6	2.05	2.35	3.12	2	2
NH_4-N	*[g/m^3]*	0.39	2.99	3.13	4.86	38.89	38.89
NO_3-N	*[g/m^3]*	10.94	12.72	3.78	1.56	12.15	9.11
Total phosphorus	*[g/m^3]*	0.2	1.58	1.58	4.36	2	2
Arsenic	*[mg/m^3]*	0.83	0.05	0.12	1.06	0.33	0.33
Cadmium	*[mg/m^3]*	0.09	0.36	0.36	0.36	0.09	0.09
Copper	*[mg/m^3]*	1	0.4	0.4	0.4	0.4	0.4
Chromium	*[mg/m^3]*	3.4	34	2.93	8.5	1.36	1.36
Lead	*[mg/m^3]*	1.2	1.52	1.02	2.63	1.2	1.2
Mercury	*[mg/m^3]*	0.05	2	2	2	1	1
Nickel	*[mg/m^3]*	4	8.89	1.6	1.6	0.8	0.8
Zinc	*[mg/m^3]*	7.8	0.99	0.45	0.85	0.33	2

* water of Le Jaunay which is stored in the quarry in winter and then released back to reservoir in summer

3.3 Results for environmental indicators (Life Cycle Impact Assessment)

All scenarios have been evaluated with the same set of environmental indicators, which are discussed in detail below using the "change" perspective defined in chapter 3.1.

Cumulative energy demand (CED) of fossil and nuclear resources

The CED for additional supply of drinking water in Vendée ranges between 30 and 76 MJ/m^3 (Figure 3.5), compared to 12 MJ/m^3 for the existing DWTP Le Jaunay. Water import and seasonal storage have comparable energy demand of 30-32 MJ/m^3, which is mostly related to water transport (more than 50% of the CED is for pumping) and secondly to water treatment. Seawater RO has the highest energy demand of 76 MJ/m^3 due to its high electricity required for the desalination process and some pumping for transport. The reuse schemes need a total of 35-39 MJ/m^3 depending on the type of tertiary treatment: the EDR process has slightly higher electricity demand than the RO process, whereas energy for chemicals is comparable between both trains. Reuse schemes need about 43-50% of the total energy for tertiary treatment, 18-20% for transport of reclaimed water to the reservoir, and the rest for the treatment of water in DWTP Le Jaunay. Disposal of sludge generated in reuse schemes requires a marginal energy demand and also generates marginal credits for nutrient valorisation. Additional infrastructure plays only a minor role in CED for all scenarios.

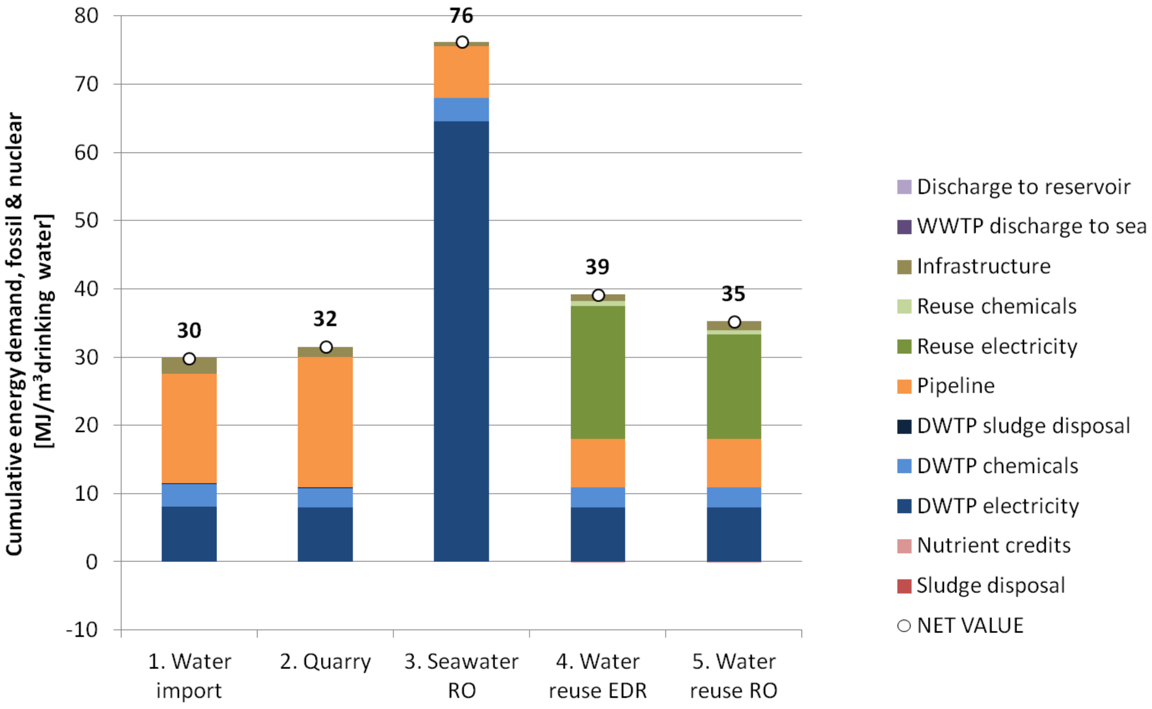

Figure 3.5 Cumulative energy demand (fossil + nuclear) per m^3 drinking water

Comparing CED for chemicals only between treatment processes, drinking water treatment and seawater desalination have distinctively higher CED for chemicals than tertiary treatment of reclaimed water (Figure 3.6). While DWTP Le Jaunay and La Balingue have higher CED due to the use of $FeCl_3$ for coagulation, PAC for trace organics removal, and CO_2 and lime for water stabilisation, seawater RO uses mainly lime and sulfuric acid for remineralisation of water and some antiscalant. In comparison, total CED for chemical demand in tertiary treatment is of reclaimed water is lower by a factor of 4-6 and is mainly contributed by activated carbon (µGAC in EDR train) or acid, caustic and membrane cleaning chemicals (RO train).

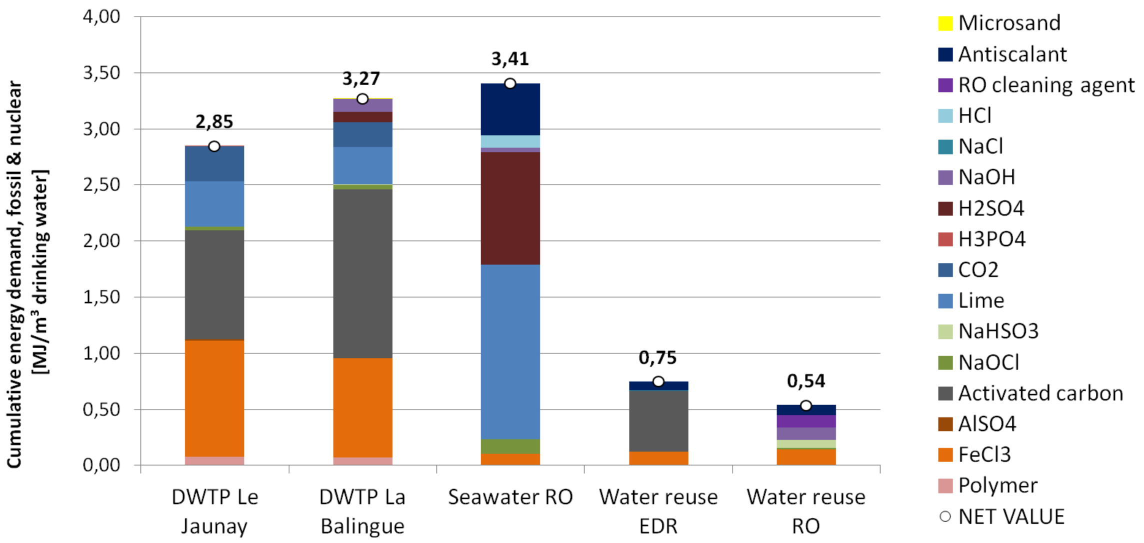

Figure 3.6 Cumulative energy demand (fossil + nuclear) for the different water treatment processes only for chemicals

Global warming potential (GWP)

In GWP, all scenarios have an impact between 0.63 and 1.05 kg CO2-eq/m³ (Figure 3.7). In general, impact of electricity demand is of less importance in GWP compared to the impact from chemicals and infrastructure due to the low carbon footprint of the French electricity mix (113 g CO_2-eq/kWh). Consequently, the scenario of seasonal storage has the lowest GWP (0.63 kg CO_2-eq/m³) as it requires only electricity for pumping and some infrastructure. Scenarios for water import (0.71 kg CO2-eq/m³) and water reuse (0.74 and 0.69 kg CO2-eq/m³ for EDR and RO trains, respectively) have a higher GWP, but are still in the same range. In parallel to CED, seawater RO has the highest GWP of 1.05 kg CO_2-eq/m³ due to high electricity and chemicals demand. Beside chemicals, infrastructure plays a more important role in GWP with a contribution of up to 21% to total GWP in water import. Material-intensive scenarios (e.g. with building of longer pipeline as in water import) have a larger impact in GWP from infrastructure than those scenarios where additional material demand for infrastructure is smaller (e.g. seawater RO). For water reuse scenarios, additional sludge production in tertiary treatment (backwash water from sand filter or UF) generates small credits for sludge disposal via nutrient valorisation.

The contribution of chemicals to GWP for each treatment process is between 0.04 and 0.32 kg CO_2-eq/m³ (Figure 3.8). Major contributions in GWP of chemicals originate from the use of activated carbon (PAC), lime, $FeCl_3$, and antiscalant. Again, the tertiary treatment of reclaimed water has a lower GWP of factor 4-8 compared to drinking water treatment or seawater RO, correlating with CED and again underlining the lower chemical demand for tertiary treatment compared to traditional drinking water production. However, chemical demand for scenarios 4 and 5 is only calculated based on the design study, whereas data for DWTP Le Jaunay and La Balingue is based on full-scale operation. Hence, estimates for chemical demand of tertiary treatment have to be validated in pilot trials to confirm this conclusion.

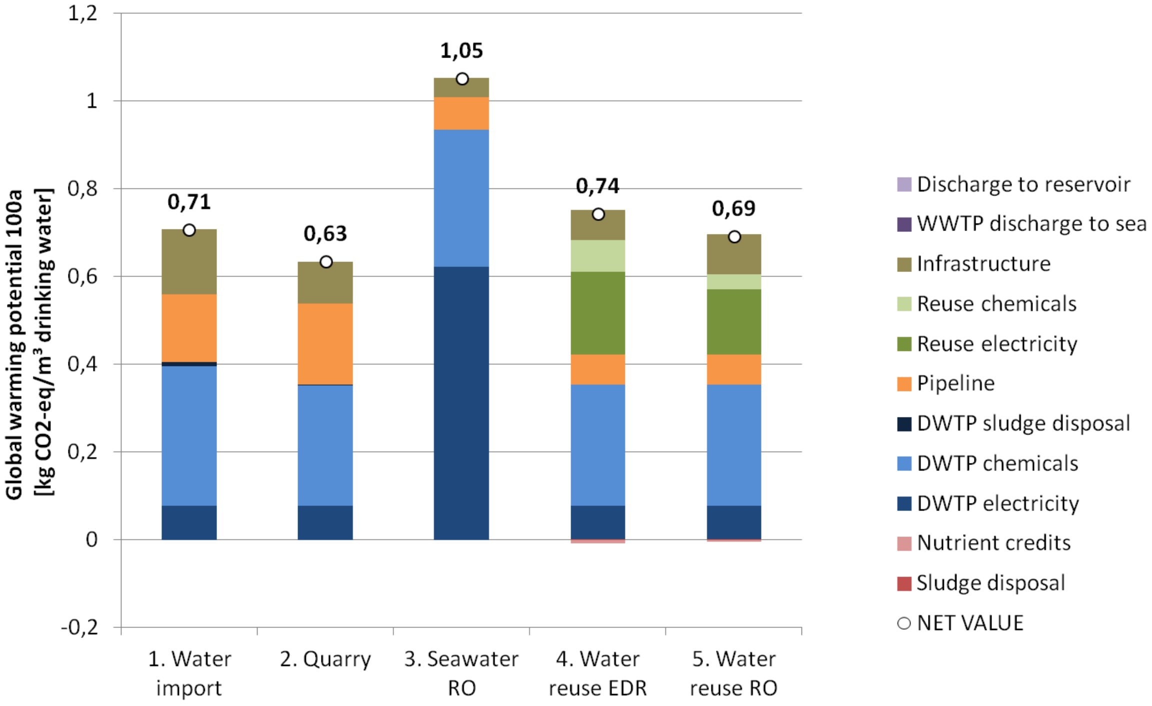

Figure 3.7 Global warming potential per m³ drinking water

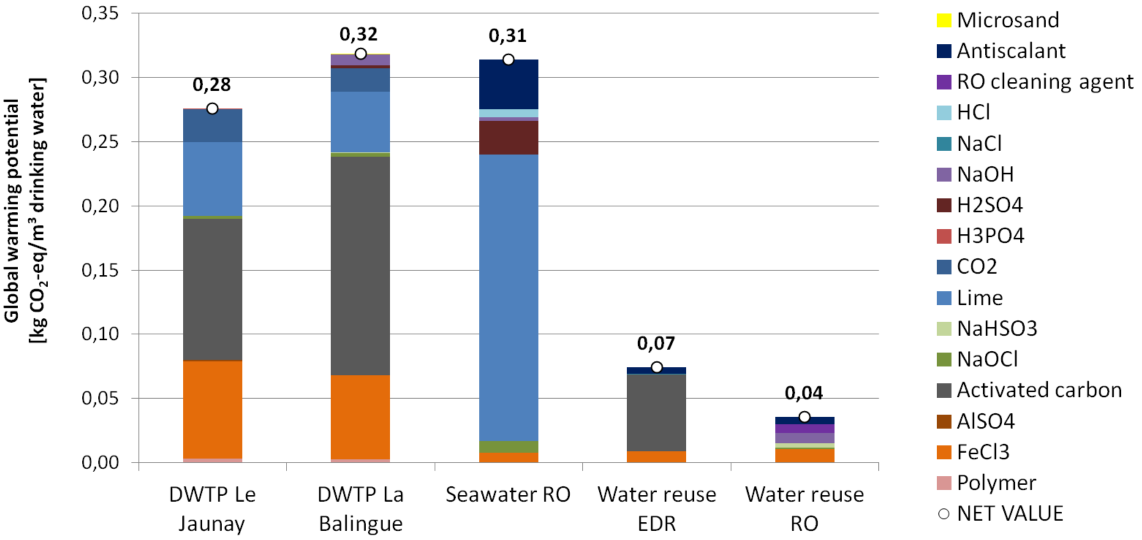

Figure 3.8 Global warming potential for the different water treatment processes only for chemicals

Terrestrial acidification potential (TAP)

TAP is between 3 and 5 g SO_2-eq/m³ for all scenarios (Figure 3.9). This indicator is dominated by the background processes and correlates strongly with the GWP, with electricity demand, but also chemicals and infrastructure playing a major role in this impact category.

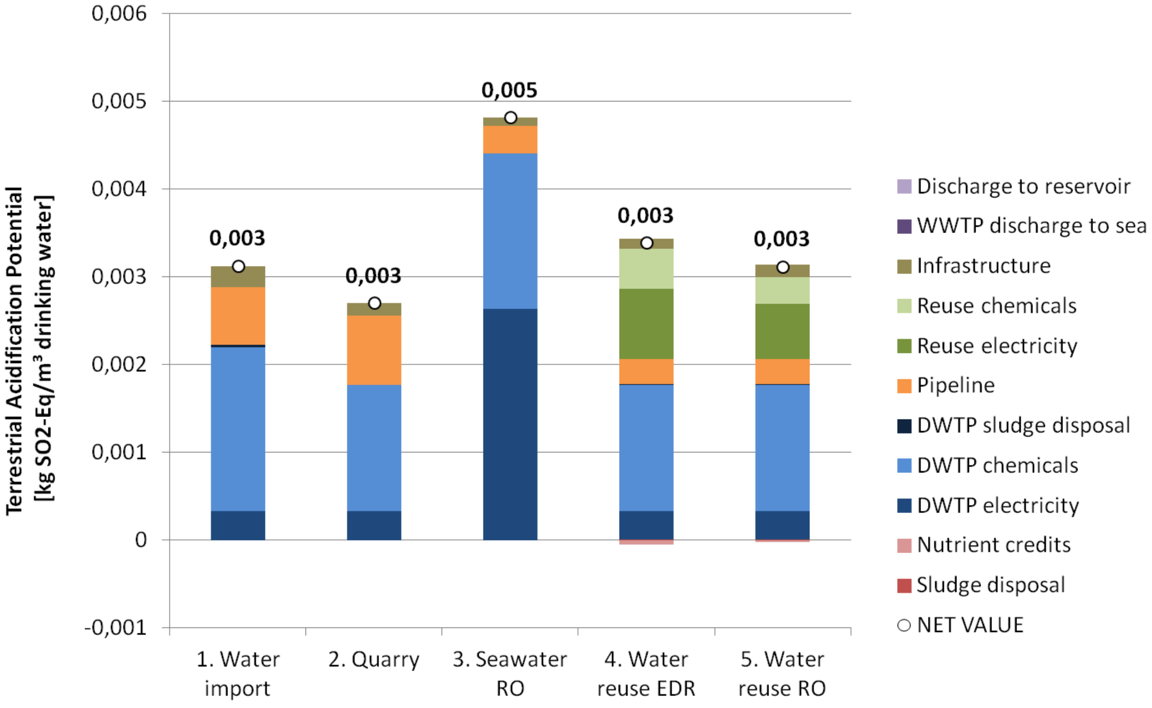

Figure 3.9 Terrestrial acidification potential per m³ drinking water

Freshwater and marine eutrophication potential (FEP and MEP)

The impacts on FEP of all scenarios illustrate a major effect using reclaimed water for refilling a natural reservoir (Figure 3.10): while water import, seasonal storage and seawater RO have only indirect effects in FEP from the background processes, the discharge of reclaimed water into the reservoir is accounted with direct effects on FEP for scenarios of water reuse. This fact is due to the residual P concentration in reclaimed water after tertiary treatment, which is relatively low (0.1 mg/L TP) but still could potentially lead to a higher risk of eutrophication in Le Jaunay reservoir.

While this potentially negative effect of water reuse is illustrated in FEP score, the global model of LCA impact assessment cannot be used to predict if this increased risk for eutrophication will be actually relevant in the reservoir. This question can only be answered by a local environmental impact assessment, which is part of the design study in D6.3 (Dupoiron, Drappier et al. 2016). The conclusion in D6.3 underlines that a potential risk for increased eutrophication cannot be excluded, as the target concentrations of TP for an oligotrophic lake are below 0.1 mg/L TP. Overall, TP emissions with WWTP effluent into the environment are also reduced in water reuse scenarios: however, WWTP effluent is discharged directly into the ocean via a deep sea outfall, and phosphorus is not taken into account as a potential factor in eutrophication for marine systems. In other words, the benefit of polishing the WWTP effluent and reducing P emissions into the ocean is not reflected in this LCA, but only the additional load of TP into the reservoir.

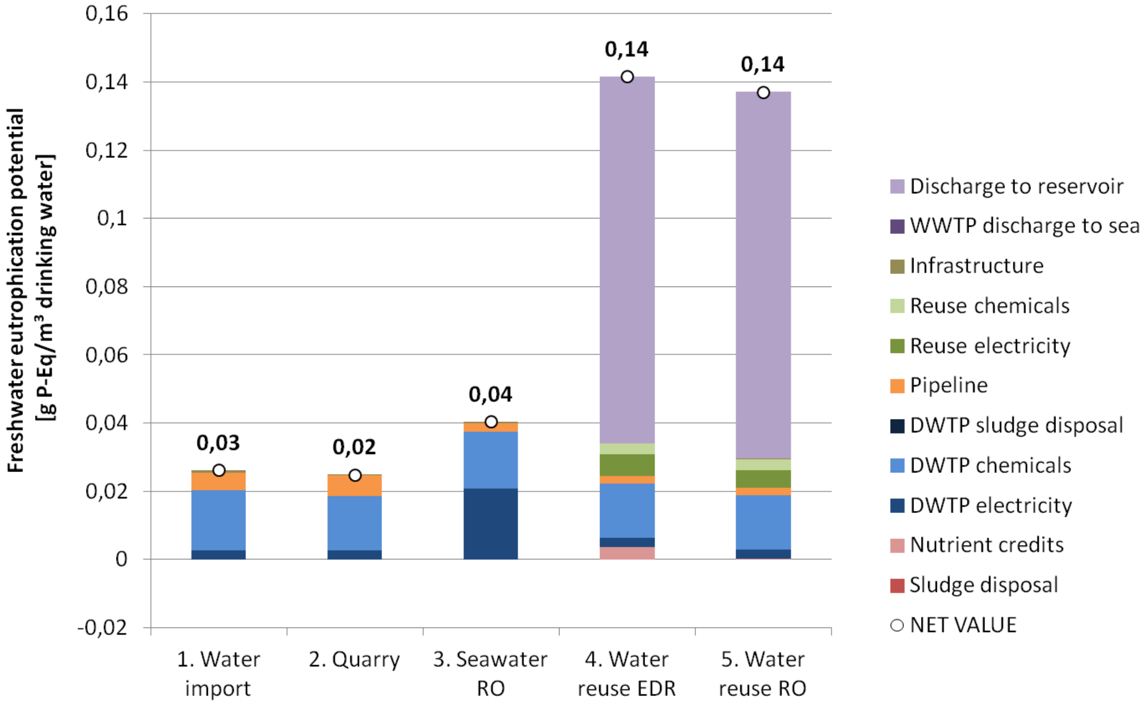

Figure 3.10 Freshwater eutrophication potential per m³ drinking water

For MEP, the situation is somewhat different: water reuse scenarios show a net decrease of eutrophication potential in marine environments (Figure 3.11). Again, MEP of the other scenarios is only coming from indirect effects in the background processes (e.g. atmospheric NOx emissions from power plants), while the reuse of secondary effluent has also direct effects on MEP due to a change of N emissions into the ocean. In fact, the polishing of secondary effluent for water reuse avoids the direct discharge of this water into the ocean, thus decreasing substantially the MEP score of the WWTP. However, part of this positive effect is off-set by the release of reclaimed water into the reservoir, from where a certain (but reduced) fraction of nitrogen can also reach the marine environment. Brine discharge from RO system into the ocean also reduces the positive effect of polishing for the RO scenario. In total, the reduction of N loads from WWTP into the ocean leads to a negative net score for MEP for the water reuse scenarios (-3.8 to -5.2 g N-eq/m³) compared to low net impacts in MEP of all other scenarios (ca. 0.1 g N-eq/m³).

The scores for FEP and MEP illustrate a major potential benefit of water reuse: the further treatment and reclamation of WWTP effluent for other uses avoids the direct discharge of this water into the environment and hence reduces pollutant and nutrient loads. Due to the situation of WWTP CCO with direct ocean discharge, this effect can be observed for nitrogen in MEP, but not for phosphorus in FEP in this study.

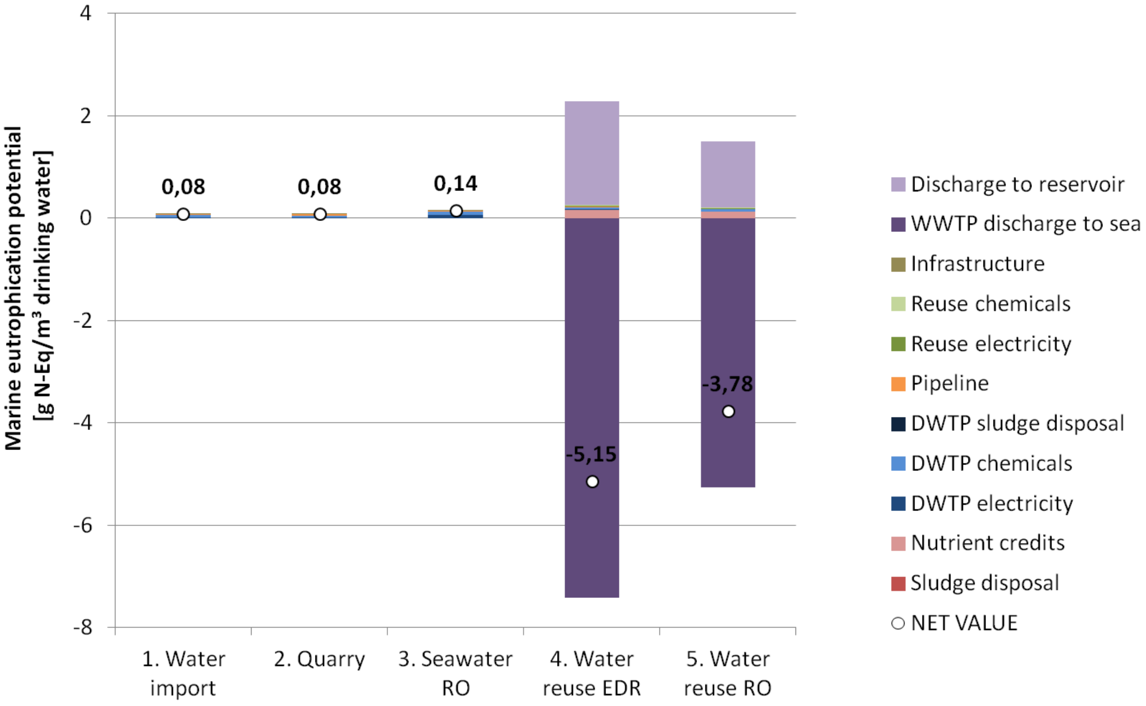

Figure 3.11 Marine eutrophication potential per m³ drinking water

Ecotoxicity (ET) freshwater and human toxicity (HT)

For both toxicity indicators, direct emissions into the environment are accounted for the discharge of WWTP effluent in ocean and discharge of reclaimed water into the reservoir in water reuse scenarios. It has to be noted that toxicity scores are generally affected with high uncertainties in related characterization factors. In addition, toxicity assessment for water flows is limited to heavy metals and excludes trace organic substances due to missing characterization factors and/or water quality data. Hence, impact of direct emissions has to be interpreted with care for this LCA. Potential impacts from drinking water consumption are also not included, as these are not accounted as emissions into the environment. A more detailed discussion of potential ecotoxic and human health impacts of water reuse in a local perspective is provided in the section on risk assessment (cf. chapter 2.1).

For ET, scores of all scenarios are between 0.23 and 1.44 CTUe/m³ drinking water (Figure 3.12). Discharge of reclaimed water into the reservoir has the highest share of ecotoxicity in the scenarios of water reuse due to residual loads of heavy metals after tertiary treatment. However, all metals except Zn are expected to be below the limit of quantification (Table 3.6), so the assessment of this emission is based on best estimates (LOQ/2) for many pollutants. ET of other scenarios originates from background processes such as electricity production and materials for infrastructure. Avoided emissions of pollutants into the ocean due to reuse of WWTP effluent are accounted in this indicator, but the credits are marginal compared to other impacts.

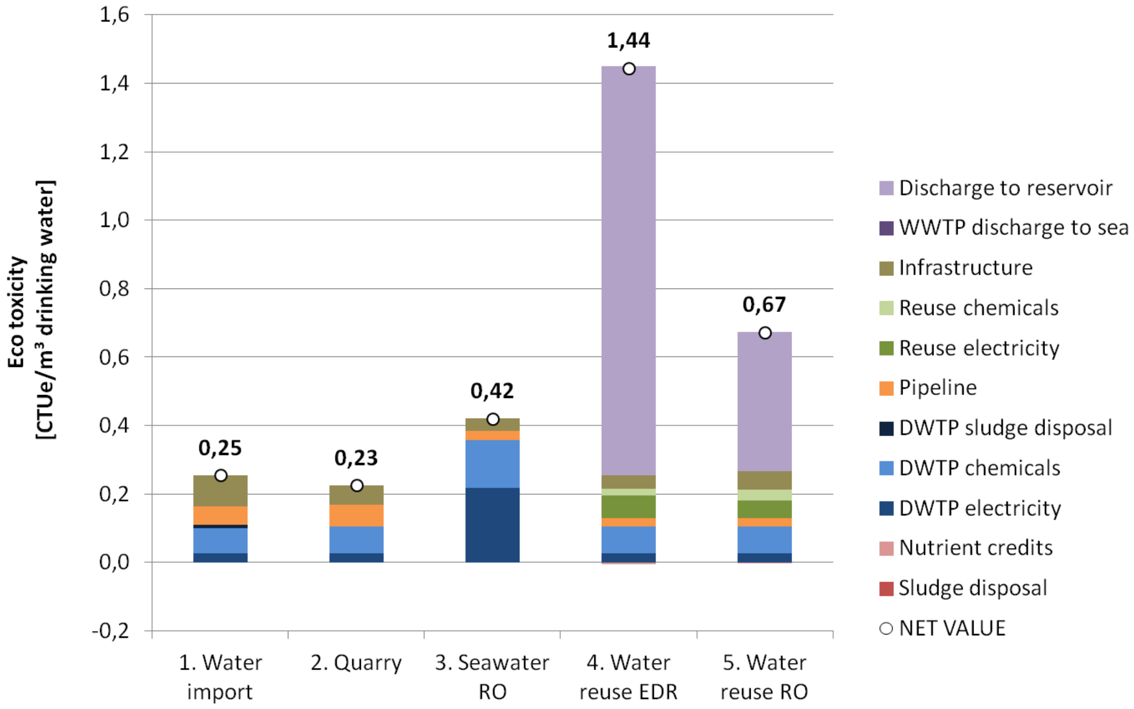

Figure 3.12 Ecotoxicity (freshwater aquatic) per m³ drinking water

Net HT of all scenarios is between 452 and 820 * 10^{-6} CTUh/m³ (Figure 3.13). Here, direct impacts from discharge of reclaimed water into the reservoir are also relevant for the total score, and lead to a higher HT for the reuse scenarios compared to the other scenarios. Again, residual heavy metals in reclaimed water are responsible for this impact in the reuse scenarios, although tertiary treatment can remove a fraction of metals from secondary WWTP effluent (cf. Table 3.6). Water quality of reuse train A is slightly worse than quality of train B, so that the HT score of 'Water reuse A' is higher than for 'Water reuse B'. For both reuse scenarios, some of the additional impacts from discharge of reclaimed water are compensated by avoided emissions with WWTP effluent into the ocean. Comparable to the nutrients, residual heavy metals in WWTP effluent are redirected from ocean to surface water, which gives them a slightly higher impact on human toxicity due to the higher potential exposure of humans to surface water.

A more detailed assessment of potential impacts of water reuse on human health is provided in the chapter on risk assessment (cf. chapter 2.4.2.5). Other impacts in HT originate from background processes, mostly from chemicals production and materials for infrastructure, but also from electricity production.

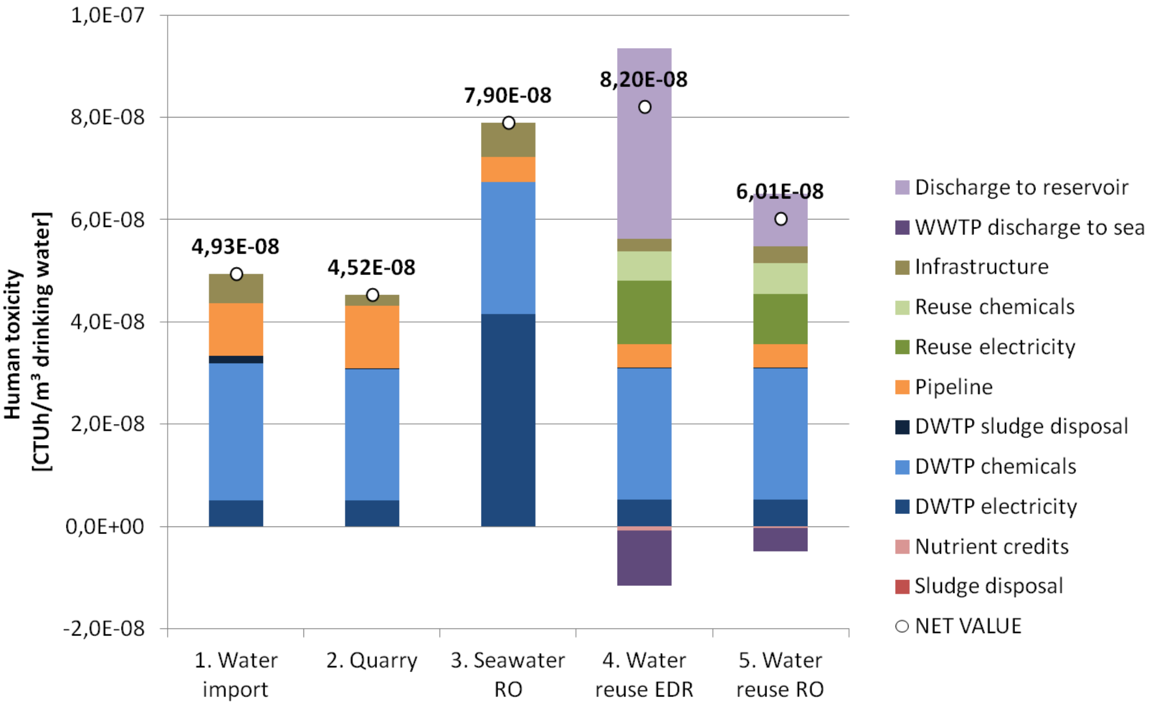

Figure 3.13 Human toxicity (total) per m³ drinking water

Water Impact Index (WIIX)

For water footprinting, the method of Water Impact Index (WIIX) is applied, which takes into account water volumes, water scarcity, and water quality for the different water flows affecting freshwater (marine water not accounted). A detailed description of the WIIX method is provided in D3.1 (Seis and Remy 2015). The local water scarcity is described with the AWARE method which takes into account local freshwater availability and local freshwater demand by humans and ecosystems, normalising the available water remaining with the world average (WULCA 2015). From the map of the AWARE index (Figure 3.14) and the related AWARE factors in Table 3.8, it can be concluded that the coastal region of Vendée is affected to higher water scarcity, in particular during the months of late summer.

Hence, the WIIX indicator evaluates both quantitative problems (= scarcity) and qualitative problems (= pollutants) at the same time, which may overlap and off-set each other and thus decrease transparency of the different aspects in the WIIX score. Therefore, a step-by-step procedure is applied here to show a) only effects of water quantity ("water availability footprint") b) only effects of water quality ("water quality footprint") and c) both effects combined ("Water Impact Index"). For the interpretation of the WIIX, it is important to notice that higher stress on the resource us reflected by a higher WIIX result.

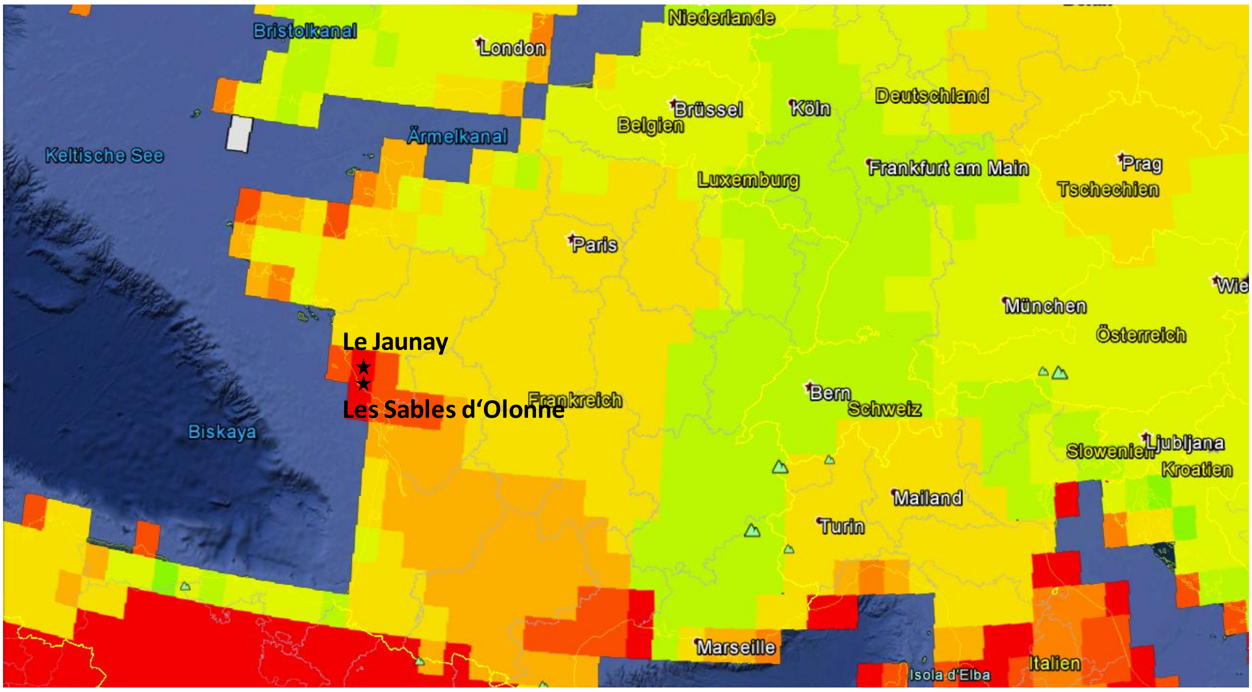

Figure 3.14 Map of AWARE index for water scarcity (Source: Google Earth with WULCA layer (WULCA 2015))

For the water availability footprint (WAF), monthly water volumes and water scarcity information (cf. Table 3.8) are taken into account, excluding indirect effects from the background processes. The results for net direct WAF show that all options for additional drinking water supply have a low WAF compared to the existing status quo of drinking water production (Figure 3.15): WAF of actual drinking water production at DWTP Le Jaunay using the reservoir water accounts for 55 m^3 world-eq per m^3, which is due to the high water scarcity in July and August in this area. In contrast, water import from La Balingue has a lower WAF of 7 m^3 world-eq per m^3 drinking water, as water scarcity is significantly lower at La Balingue area (Table 3.8). The seasonal storage in the quarry has a net WAF near neutral when assuming no net losses via evaporation from the storage surface (evaporation = rainfall): all additional water that is required for drinking water production during summer is refilled into the reservoir, so that no additional water stress is caused. Intake of this water into the quarry in winter has only a marginal WAF, as very low water scarcity is effective in this area in winter. WAF of seawater desalination is not relevant, as only seawater without scarcity is used for drinking water production. The scenarios for water reuse are also characterized by a neutral WAF, as the reservoir is refilled with reclaimed WWTP effluent which has no WAF in this study (coming from the technosphere). Of course, WWTP effluent originates from drinking water and therefore from local water sources, but this WAF is allocated to its use as drinking water and not as reclaimed WWTP effluent. Overall, WAF shows that all scenarios can provide additional drinking water without inflicting major issues of water scarcity neither in the coastal area nor in other areas.

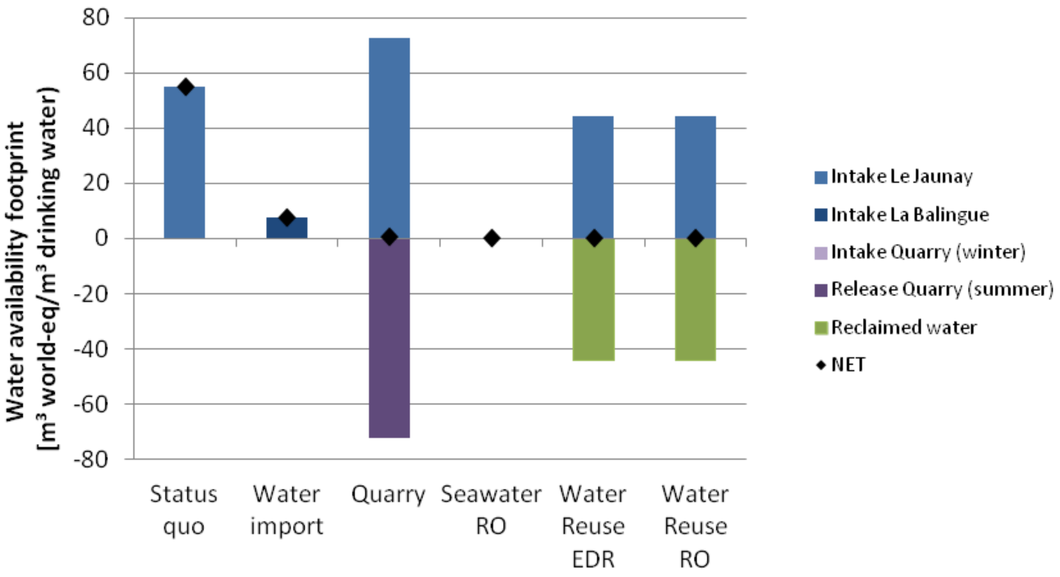

Figure 3.15 Water availability footprint per m³ drinking water
(footprint accounts for water volumes and local water scarcity with AWARE index, no indirect effects included)

For the water quality footprint (WQF), water flows and water quality index (cf. Table 3.9) are accounted, again focusing on the direct effects on freshwater resources and excluding indirect water flows in the background processes. Net WQF of all options for drinking water supply shows that water sources of different quality are used (Figure 3.16): WQF of the status quo is quite low due to the low quality index of Le Jaunay water in summer, mainly originating from the high level of As in the reservoir. In contrast, WQF of the imported water from La Balingue is significantly higher due to higher quality index at this reservoir. Seasonal storage of water in the quarry transfers water with higher quality index from winter into summer, assuming no change in water quality during storage and thus resulting in a net WQF which is comparable to the status quo. Seawater desalination has no WQF, as seawater is not accounted in this indicator. In the water reuse scenarios, the reservoir is refilled with reclaimed water which has a higher quality index (0.09) than the reservoir water itself (0.05) (Table 3.9), which gives a negative WQF in this calculation.

However, it has to be underlined again that the quality index calculation for the WQF is dependent on the concentration of only two metals (As and Cd) for all water flows in this study, with the data for Cd being below limit of quantification (Table 3.6) in La Balingue and reclaimed water. Hence, the results of the WQF have to be interpreted with care and should be seen in the light of methodological short-comings of this approach (cf. discussion of the WIIX in D3.2 (Kraus, Seis et al. 2016)). If for example the strict As benchmark of 0.83 µg/L is raised to 10 µg/L (= drinking water standard), the WQF results would change the comparison between all scenarios significantly (cf. Figure 6.1 in the annex).

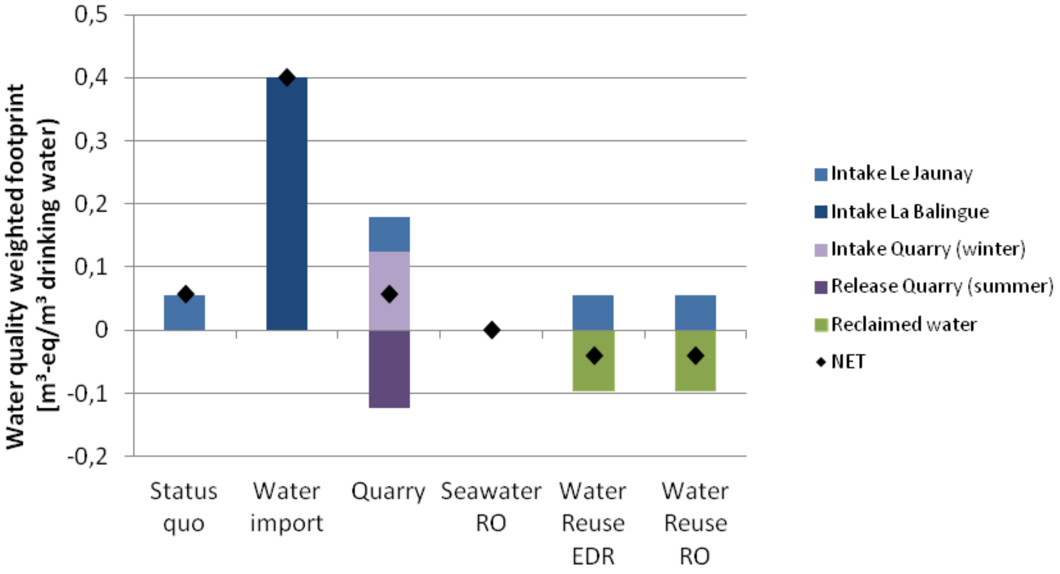

Figure 3.16 Water quality footprint per m³ drinking water
(footprint accounts for water volumes and water qualiy index WQI, no indirect effects included)

Finally, the WIIX combines both aspects of water scarcity and water quality information and calculates a net water footprint for all scenarios, including also the indirect water use in background processes (Figure 3.17). The results show that WIIX is dominated by direct effects of water withdrawal and discharge in all scenarios, while the contribution of indirect water use is only marginal. Combining effects of water quality and quantity, WIIX scores for status quo and water import are comparable: whereas water with high scarcity but lower quality is used from Le Jaunay reservoir, water from La Balingue is characterized by low scarcity but higher quality. Finally, both options have a net WIIX of 2.8-2.9 m³ world-eq/m³ of drinking water.

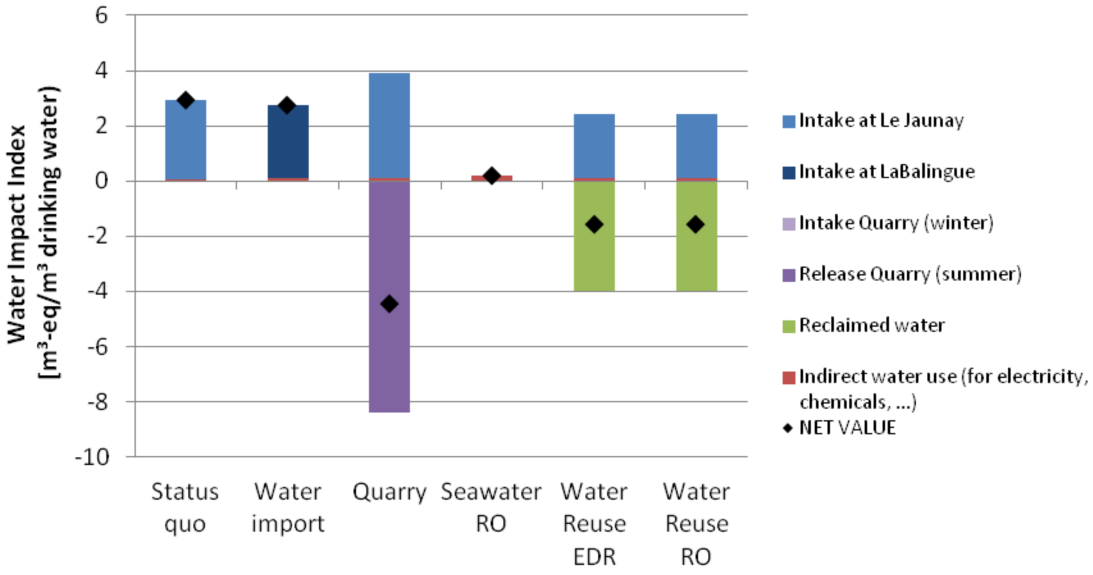

Figure 3.17 Water Impact Index (WIIX) per m³ drinking water
(WIIX accounts for water volumes, water qualiy index WQI and local water scarcity with AWARE index)

Net WIIX of the seasonal storage in the quarry is the lowest of all scenarios: while no additional water stress is imposed, water with higher quality is transferred from winter into summer, accounting with high credits for refilling the reservoir especially in water-scarce summer months. The same effect can also be seen for the water reuse scenarios, which refill the reservoir with surplus water of high quality and without imposing additional water stress on local resources. The storage option is slightly better than the reuse system due to the higher water quality (lower WQI) of stored water, and the operation of storage "refilling" during times of highest water scarcity (Jul-Sept) compared to the reuse system operated in a longer period (Jun-Oct). For seawater desalination, WIIX is near neutral as seawater is not accounted in the WIIX, but only accounts for indirect water use in this scenario.

Overall, water footprinting in this study illustrates the following aspects:

- All alternatives to the status quo can provide additional drinking water without increasing the local water stress at Le Jaunay reservoir. Water import partially shifts the water stress to another region, while water reuse, storage, and seawater desalination do not cause additional water stress in Vendée.
- Quality of Le Jaunay reservoir water is impaired by high As concentration, especially in summer. However, drinking water standards are safely and constantly met for all contaminants, including As. Nevertheless, water quality in the reservoir should be monitored closely to control potential risks from this chemical.
- Both seasonal storage and water reuse refill the reservoir with water of high quality and without additional water stress, which is reflected by additional credits in Water Impact Index for these options.
- Seawater desalination has a neutral water footprint, as it is based on marine resources without scarcity.
- Indirect water use for drinking water production (e.g. water consumed in the production of electricity, chemicals, infrastructure) has only a marginal impact on water resources compared to the direct handling of water flows.

Summary of all indicators: environmental profile

An overview of all net indicator results of this LCA is provided below (Figure 3.18). The following conclusions can be drawn from the environmental profile:

- All scenarios for alternative water supply can reduce the local water stress, which is illustrated by the decrease in WIIX. Seasonal storage and water reuse refill the reservoir with water of high quality and low/no scarcity footprint, resulting in credits for water footprint. Water import has a comparable footprint than the existing system, as it uses water with lower scarcity but higher quality for drinking water supply.
- All options for alternative water supply are more energy-intensive than the existing scheme at Le Jaunay. Whereas water import, seasonal storage and water reuse increase energy demand of drinking water production by a factor 3-4, seawater desalination is by far the most energy-intensive process with +600% compared to DWTP Le Jaunay.
- Consequently, greenhouse gas emissions and other air pollutants associated with drinking water production increase significantly with alternative supply options. From this point of view, use of alternative water resources should be minimized to keep excessive resource use and associated air pollution low. Indeed, Vendée Eau is committed to minimize the use of alternative water resources only when truly necessary to secure adequate water supply safety in the region.

- Tertiary treatment and reclamation of secondary WWTP effluent will decrease N loads to the marine environment, but also increases input of nutrients N and P and other potentially hazardous substances into the reservoir. Resulting risks of freshwater eutrophication or ecotoxicity from water reuse should be evaluated with a local impact study to control negative effects on water quality from pollutants (cf. chapter 2.1) and nutrients (cf. D6.3 (Dupoiron, Drappier et al. 2016)).
- Overall, water reuse is competitive to other options of water supply in its environmental profile and can bring additional positive effects for the marine environment. Local effects of reclaimed water on the quality of the reservoir water should be monitored closely and evaluated in a local risk assessment with a focus on human health and ecosystems.

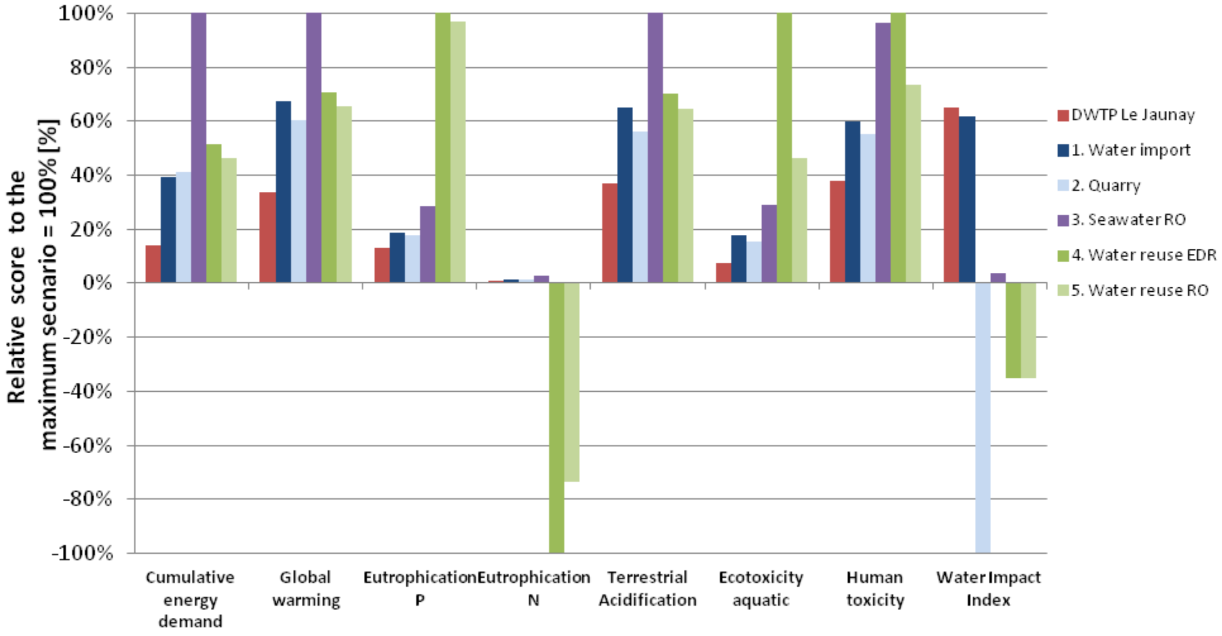

Figure 3.18 Overview of all indicators per scenario
(scenario with maximum/minimum score is set to 100%)

Normalisation of all indicators to the European average citizen

Scores of all environmental indicators (except WIIX) can be normalised to the annual footprint per citizen in the EU25 (population equivalent or pe). This perspective reveals those categories of environmental impact where the systems have a higher or lower contribution, giving a first indication about the relevance of this indicator in the overall environmental profile. Normalisation factors are listed in DEMOWARE D3.2 (Kraus, Seis et al. 2016).

Normalised scores show that all indicator results are in the same range (< 0.06%) compared to the annual footprint per pe. While CED has the highest contribution, GWP, TAP, ET and HT are all <0.02% after normalisation for all scenarios. Nutrient emissions of P and N are somewhat higher for the reuse scenarios, indicating the impact of WWTP effluent and its transfer from ocean discharge to reservoir. Overall, normalisation shows that the supply of 1 m³ additional drinking water is associated with around 0.01 to 0.06% of the total environmental footprint of an average EU citizen. When assuming an annual drinking water demand of 50-70 m³ per person and year, related environmental impacts for drinking water supply amount to 0.5-4% of the annual footprint per person.

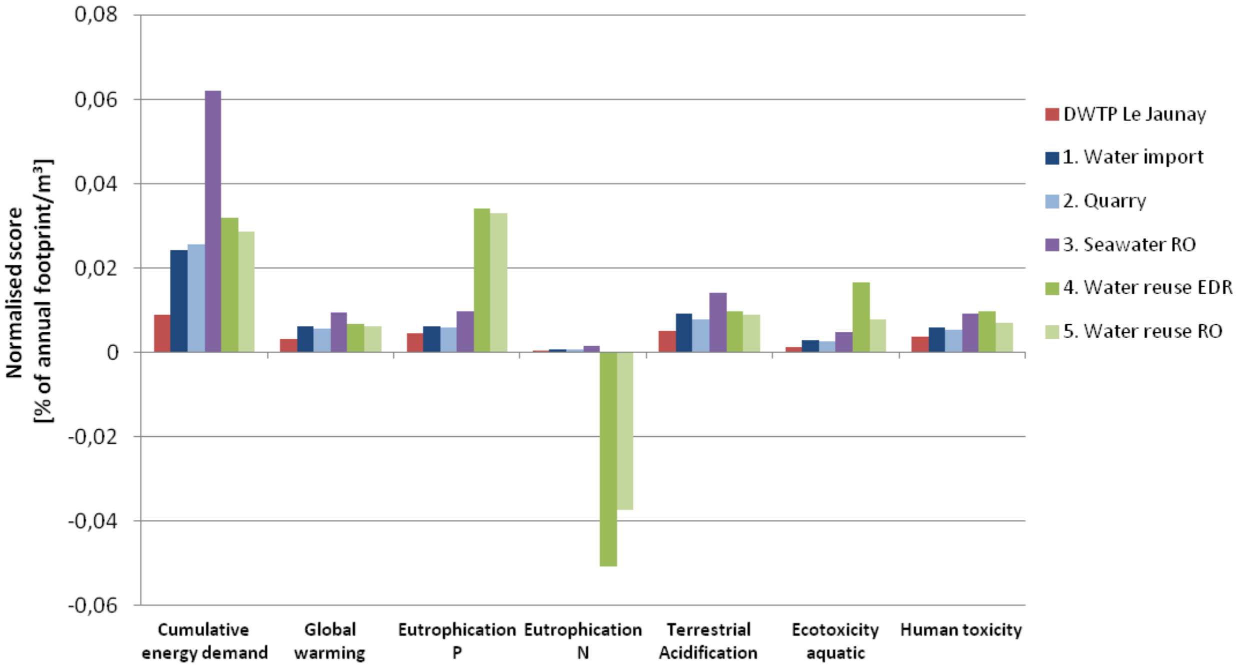

Figure 3.19 Normalised indicators per scenario
(normalisation to EU25 population equivalent = footprint per person and year)

3.4 Interpretation and conclusions

The relative net environmental impacts of drinking water supply for all scenarios are listed in relation to the scenario with maximum effect. In detail, the following conclusions can be drawn:

- Alternative options for water supply in Vendée during the summer period are water import, seasonal storage, seawater desalination, and water reuse.
- All these options can supply additional drinking water without causing higher local water stress at Le Jaunay reservoir. Water import has a comparable water footprint than the existing scheme, as it relies on water resources with lower scarcity, but higher quality of water. Seasonal storage exploits available water in winter with very low scarcity and refills the reservoir in summer with good quality, while both seawater desalination and water reuse exploit water resources without scarcity (seawater or WWTP effluent). All latter options have a considerably lower water footprint than the existing drinking water treatment scheme.
- Supply of additional drinking water is associated with higher energy demand and associated environmental impacts (e.g. greenhouse gas emissions) than the existing treatment process at Le Jaunay. Water transport and treatment cause an increase by a factor of 3-4 for water import, seasonal storage and water reuse, while seawater desalination increases energy demand per m^3 water by 600%. Hence, use of alternative options for water supply should be restricted to times of high water scarcity to minimise use of resources and associated impacts.
- Use of reclaimed water from secondary WWTP effluent for refilling of the reservoir decreases negative impacts of WWTP discharge on the marine environment (N emissions). However, water

reuse also increases input of nutrients and other pollutants into the reservoir, indicating potential risks for eutrophication or ecosystem and human health. These potential risks for human health have been separately assessed with methods of risk assessment (cf. chapter 2).

- Overall, water reuse is competitive to water import or seasonal storage in energetic efforts and superior to seawater desalination. While water reuse can have positive impacts for the marine environment (less WWTP discharge), potential negative effects on water quality in the reservoir should be closely monitored and evaluated in a local risk assessment (cf. chapter 2.1) to control hazards for ecosystems or human health. If potential risks are managed effectively, water reuse is recommended from an environmental point of view based on the results of this LCA.

Table 3.10 Summary of net environmental impacts for each scenario per m³ drinking water
(100% is defined as maximum or minimum score in each indicator and printed in bold red or green)

Indicator	0. Status quo	1. Water import	2. Mining quarry	3. Seawater RO	4. Water reuse (EDR)	5. Water reuse (RO)
Cumulative energy demand	14%	39%	41%	**100%**	51%	46%
Global warming potential	34%	67%	60%	**100%**	71%	66%
Freshwater eutrophication potential	13%	19%	18%	29%	**100%**	97%
Marine eutrophication potential	1%	2%	1%	3%	**-100%**	-73%
Terrestrial acidification potential	37%	65%	56%	**100%**	70%	65%
Ecotoxicity (freshwater aquatic)	7%	18%	16%	29%	**100%**	47%
Human toxicity (total)*	38%	60%	55%	96%	**100%**	73%
Water Impact Index	65%	62%	**-100%**	4%	-35%	-35%

* Potential risks for human health also assessed in risk assessment (cf. chapter 2)

4 Summary and outlook

This report presents methods, input data and results of risk assessment and LCA for the water reuse scheme at Le Jaunay reservoir in the Vendée region. Drawing on the particular conclusions of the assessment methods, this part summarizes major outcomes of this study.

The following outcomes can be summarized for risk assessment:

- Quantitative assessment of microbial risk from IPR has shown that **no unacceptable additional risk for the produced drinking water at Le Jaunay** is expected from pathogen concentrations in the secondary effluent after tertiary treatment and drinking water treatment.
- For recreational activities in the reservoir, potential hazards from IPR are well below acceptable risk levels defined in the EU Bathing Water Directive, knowing that bathing is prohibited in the reservoir.
- Although the presence of trace organic compounds cannot be excluded completely, chemical risk assessment of 130 monitored substances has revealed that **out of the measured substances none is expected to cause an unacceptable risk for human health given the methods applied in this study**
- **Gabapentin and EDTA** should be checked as they was not included in the monitoring program and are known to be highly persistent as well as highly recalcitrant against many water treatment technologies.
- After tertiary treatment, some chemicals still pose a potential risk for ecosystems, which should be further analysed in future studies.
- In general, the level of uncertainty in risk assessment is still high due to the small set of available monitoring data. It is recommended to continue risk assessment in future studies based on more frequent monitoring and a demonstrator pilot trials of tertiary treatment.
- Effect based monitoring is recommended for including mixture effects low doses of chemicals

The following outcomes can be summarized for Life Cycle Assessment:

- All options for additional drinking water supply require higher energy demand and associated emissions than the current drinking water treatment at Le Jaunay.
- **Water reuse is comparable in energy demand and greenhouse gas emissions with water import** from another reservoir (La Balingue) **or seasonal water storage** in a mining quarry. The two options for tertiary treatment (EDR/µGAC and RO) are comparable in their environmental profile. Seawater desalination requires twice as high energy input and causes an increase of 40% in greenhouse gas emissions compared to water reuse.
- **Water reuse provides additional drinking water without posing additional water stress to local resources**, having a significant lower water footprint than drinking water production at Le Jaunay or La Balingue.
- Use of reclaimed water for IPR reduces emissions into the marine environment, but may cause additional risk of eutrophication in the reservoir.
- If potential risks are effectively managed, water reuse can be recommended from an environmental point of view.

Overall, both methods show that the implementation of a scheme for indirect potable reuse at Le Jaunay reservoir does not pose unacceptable risks for human health and is beneficial from an overall environmental point of view compared to water import or seawater desalination. However, input data from design of tertiary treatment and monitoring of water quality should be validated in further studies (e.g. demonstrator, more frequent monitoring) to support the conclusions of this study and strengthen the arguments for a safe and environmentally friendly operation of IPR at Vendée. In particular, selected substances of potential concern (e.g. Gabapentin, EDTA) should be monitored to confirm the acceptable level of risk reduction that was stated in this study. Effect based monitoring should be considered as complementary monitoring strategies. In addition, local stakeholders and regulators should analyse the presented approaches for deriving benchmark values for risk assessment and agree on a common method of accepted “residual risk” which is then to be applied in future studies.

5 References

Bayart, J. B., S. Worbe, J. Grimaud and E. Aoustin (2014). "The Water Impact Index: A simplified single-indicator approach for water footprinting." International Journal of Life Cycle Assessment **19**(6): 1336-1344.

Dorevitch, S., S. Panthi, Y. Huang, H. Li, A. M. Michalek, P. Pratap, M. Wroblewski, L. Liu, P. A. Scheff and A. Li (2011). "Water ingestion during water recreation." Water Research **45**(5): 2020-2028.

Dupoiron, B., A. Drappier and V. Jauzein (2016). DEMOWARE D6.3: Reuse scheme design and impact assessment for the greenfield demo site, IRH Ingenieur Conseil and Vendee Eau.

EC (2001). Pollutants in Urban Waste Water and Sewage Sludge.

Ecoinvent. (2014). "Ecoinvent data v3.1, ecoinvent reports No. 1-26, Swiss Center for Life Cycle Inventories, www.ecoinvent.org."

EPA (2010). Treating Contaminants of Emerging Concern: A Literature Review Database.

EPA, U. (2012). 2012 Edition of the Drinking Water Standards and Health Advisories. U. S. E. P. A. (EPA).

Etchepare, R. and J. P. van der Hoek (2015). "Health risk assessment of organic micropollutants in greywater for potable reuse." Water Research **72**: 186-198.

Goedkoop, M. J., R. Heijungs, M. A. J. Huijbregts, A. De Schryver, J. Struijs and R. Van Zelm (2009). ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level; First edition Report I: Characterization, http://www.lcia-recipe.net.

Haas, C. N., J. B. Rose and C. P. Gerba (1999). Quantitative Microbial Risk Assessment, John Wiley & Sons, Inc.

Havelaar, A. H. and J. Melse (2003). Quantifying Public Health Risk in the WHO GDWQ.

Hernando, M. D., M. Mezcua, A. R. Fernández-Alba and D. Barceló (2006). "Environmental risk assessment of pharmaceutical residues in wastewater effluents, surface waters and sediments." Talanta **69**(2 SPEC. ISS.): 334-342.

IHCP (2003). Technical Guidance Document on Risk Assessment. E. C. Bureau. Italy, European Commission Joint Reasearch Centre.

ISO 14040 (2006). Environmental management - Life Cycle Assessment - Principles and framework. Geneva, Switzerland, International Standardisation Organisation.

ISO 14044 (2006). Environmental management - Life cycle assessment - Requirements and guidelines. Geneva, Switzerland, International Standardisation Organisation.

ISO 14046 (2014). Environmental Management - Water Footprint - Principles, Requirements and Guidelines. Geneva, Switzerland, Inernational Standardisation Organisation.

Kimura, K., S. Toshima, G. Amy and Y. Watanabe (2004). "Rejection of neutral endocrine disrupting compounds (EDCs) and pharmaceutical active compounds (PhACs) by RO membranes." Journal of Membrane Science **245**(1–2): 71-78.

Kounina, A., M. Margni, J. B. Bayart, A. M. Boulay, M. Berger, C. Bulle, R. Frischknecht, A. Koehler, L. Milà I Canals, M. Motoshita, M. Núñez, G. Peters, S. Pfister, B. Ridoutt, R. Van Zelm, F. Verones and S. Humbert (2013). "Review of methods addressing freshwater use in life cycle inventory and impact assessment." International Journal of Life Cycle Assessment **18**(3): 707-721.

Kraus, F., W. Seis, C. Remy, M. Rustler, I. Jubany i Güell, J. J. Espi and F. Clarens (2016). DEMOWARE D3.2 Show case of the environmental benefits and risk assessment of reuse schemes, Kompetenzzentrum Wasser Berlin gGmbH.

Kresimir Kosutic and B. Kunst (2001). "Removal of organics from aqueous solutions by commercial RO and NF membranes characerized porosities." Desalination.

Lee, Howe and Thomson (2009). State of Knowledge of Pharmaceutical, Personal Care Product, and Endocrine Disrupting Compound Removal during Municipal Waste Water Treatment. New Mexico, USA, The University of New Mexico;.

LfULG (2009). Untersuchungen zur Eliminierung bestimmter gefährlicher Stoffe in kommunalen Abwasserbehandlungsanlagen. Germany, Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie.

Luo, Y., W. Guo, H. H. Ngo, L. D. Nghiem, F. I. Hai, J. Zhang, S. Liang and X. C. Wang (2014). "A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment." Science of The Total Environment **473–474**: 619-641.

Mailler, R., J. Gasperi, Y. Coquet, A. Buleté, E. Vulliet, S. Deshayes, S. Zedek, C. Mirande-Bret, V. Eudes, A. Bressy, E. Caupos, R. Moilleron, G. Chebbo and V. Rocher (2016). "Removal of a wide range of emerging pollutants from wastewater treatment plant discharges by micro-grain activated carbon in fluidized bed as tertiary treatment at large pilot scale." Science of the Total Environment **542**: 983-996.

MEEM (2015). Arrêté du 27 juillet 2015 modifiant l'arrêté du 25 janvier 2010 relatif aux méthodes et critères d'évaluation de l'état écologique, de l'état chimique et du potentiel écologique des eaux de surface pris en application des articles R. 212-10, R. 212-11 et R. 212-18 du code de l'environnement. Paris, Ministère de l'Environnement, de l'Énergie et de la Mer.

MEEM (2016). Guide relatif à l'évaluation de l'état des eaux de surface continentales (cours d'eau, canaux, plans d'eau). Paris Ministère de l'Environnement, de l'Énergie et de la Mer de la France.

NRMMC-EPHC-AHMC (2006). National Guidelines for Water Recycling: Managing Health and Environmental Risks. Canberra, Environment Protection and Heritage Council, the Natural Resource Management Ministerial Council and the Australian Health Ministers' Conference.

Petrie, B., R. Barden and B. Kasprzyk-Hordern (2015). "A review on emerging contaminants in wastewaters and the environment: Current knowledge, understudied areas and recommendations for future monitoring." Water Research **72**: 3-27.

Petterson, S., R. Signor and A. Ashbold (2006). "QMRA methodology." Report MICRORISK.

Remy, C. (2010). Life Cycle Assessment of conventional and source-separation systems for urban wastewater management, Technical University.

Rodriguez-Mozaz, S., M. Ricart, M. Köck-Schulmeyer, H. Guasch, C. Bonnineau, L. Proia, M. L. de Alda, S. Sabater and D. Barceló (2015). "Pharmaceuticals and pesticides in reclaimed water: Efficiency assessment of a microfiltration-reverse osmosis (MF-RO) pilot plant." Journal of Hazardous Materials **282**: 165-173.

Rosenbaum, R. K., T. M. Bachmann, L. S. Gold, M. A. J. Huijbregts, O. Jolliet, R. Juraske, A. Koehler, H. F. Larsen, M. MacLeod, M. Margni, T. E. McKone, J. Payet, M. Schuhmacher, D. van de Meent and M. Z. Hauschild (2008). "USEtox-the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment." International Journal of Life Cycle Assessment **13**(7): 532-546.

Schriks, M., M. B. Heringa, M. M. E. van der Kooi, P. de Voogt and A. P. van Wezel (2010). "Toxicological relevance of emerging contaminants for drinking water quality." Water Research **44**(2): 461-476.

Seis, W. and C. Remy (2015). DEMOWARE D3.1 Appropriate and user friendly methodologies for Risk assessment, Life Cycle Assessment, and Water Footprinting, Kompetenzzentrum Wasser Berlin gGmbH.

Sudhakaran, S., S. Lattemann and G. L. Amy (2013). "Appropriate drinking water treatment processes for organic micropollutants removal based on experimental and model studies — A multi-criteria analysis study." Science of The Total Environment **442**: 478-488.

Taheran, M., S. K. Brar, M. Verma, R. Y. Surampalli, T. C. Zhang and J. R. Valero (2016). "Membrane processes for removal of pharmaceutically active compounds (PhACs) from water and wastewaters." Science of The Total Environment **547**: 60-77.

Teunis, F. M., C. L. Moe, P. Liu, S. E. Miller, L. Lindesmith, R. S. Baric, J. Le Pendu and R. L. Calderon (2008). "Norwalk Virus: How infectious is it?" Journal of Medical Virology **80**: 1468-1476.

VDI (2012). VDI-Richtlinie 4600: 2012-01: Kumulierter Energieaufwand - Begriffe, Berechnungsmethoden (VDI guideline 4600: 2012-01: Cumulative energy demand - Terms, definitions, methods of calculation). Berlin, Germany, Beuth Verlag.

WHO (2006). Guidelines for the safe Use of Wastewater, Excreta and Greywater. Wastewater use in agriculture. **2:** 222.

WHO (2011). Guidelines for Drinking-water Quality. FOURTH EDITION, WHO**:** 564.

WULCA (2015). AWARE factors for water scarcity, http://www.wulca-waterlca.org/project.html.

6 Annex

6.1 Data for risk assessment

Table 6.1 Substances selected from 130 analysed substances

Group	CAS Number	Substance
Group 1	1066-51-9	Aminomethylphosphonic acid (AMPA)*
	41859-67-0	Bezafibrate
	298-46-4	Carbamazepine
	81103-11-9	Clarithromycin
	15307-86-5	Diclofenac
	330-54-1	Diuron
	114-07-8	Erythromycin
	120068-37-3	Fipronil
	1071-83-6	Glyphosate
	66108-95-0	Iohexol*
	78649-41-9	Iomeprol*
	73334-07-3	Iopromide*
	37350-58-6	Metoprolol
	604-75-1	Oxazepam
	525-66-6	Propanolol
	723-46-6	Sulfamethoxazole
	738-70-5	Trimethoprime
	14798-03-9	Ammonium
	58-08-2	Caffeine
	53-16-7	Estrone
	94-74-6	MCPA
	62-53-3	Aniline
Group 2	1912-24-9	Atrazine
	80-05-7	Bispehenol A
	94-75-7	2,4-D
Group 3	54910-89-3	Fluoxetine
	60166-93-0	Iopamidol
	91-20-3	Naphtalene
	80214-83-1	Roxithromycin*
	108--88-3	Toluene
Group 4: Additional compounds	29122-68-7	Atenolol
	119-61-9	4-benzophenone
	95-14-7	Benzotriazole
	30485-87-1	EDTA
	60142-96-3	Gabapentin

Group	CAS Number	Substance
	58-55-9	Theophylline

6.2 Data for LCA

Table 6.2 Background datasets from ecoinvent database (Ecoinvent 2014)

Product/process	Dataset	Remarks
Electricity	market for electricity, medium voltage [FR]	
H_2SO_4	market for sulfuric acid [GLO]	
HCl	market for hydrochloric acid, without water, in 30% solution state [RER]	
H_3PO_4	market for phosphoric acid, industrial grade, without water, in 85% solution state [GLO]	
NaOH	market for sodium hydroxide, without water, in 50% solution state [GLO]	
NaOCl	sodium hypochlorite production, product in 15% solution state [RER]	
$NaHSO_3$	market for sodium hydrogen sulfite [GLO]	
Polymer	market for acrylonitrile [GLO]	0.75 kg acrylonitrile + water = 1 kg polymer
$FeCl_3$	market for iron (III) chloride, without water, in 40% solution state [GLO]	
$AlSO_4$	market for aluminium sulfate, powder [GLO]	
Lime	market for lime, hydrated, packed [GLO]	
CO_2	market for carbon dioxide, liquid [RER]	
NaCl	market for sodium chloride, powder [GLO]	
Antiscalant	Mixture of H_3PO_4, market for citric acid [GLO], and market for acrylic acid [GLO]	Estimate: 20% H3PO4, 10% citric acid, 10% acrylic acid
RO cleaning agent	Mixture of citric acid, NaOH, and cyanoacetic acid (market for cyanoacetic acid [GLO])	Estimate: 40% cyanoacetic acid, 30% NaOH, 30% citric acid
Powdered activated carbon	Dataset based on raw material (hard coal briquettes production [RoW]), consumptives (steam production, in chemical industry [RoW], electricity, high voltage, production mix [CN] and heat production, natural gas, at industrial furnace low-NOx >100kW [RoW]), and transport (truck and ship (transport, freight, sea, transoceanic ship [GLO])), including emissions from activation of hard coal	5 t hard coal briquettes, 100 kWh electricity, and 3.5 t steam per t virgin PAC plus 19000 km per ship and 300 km per truck transport
Granular activated carbon		Reactivation: 120 kWh electricity, 140 Nm^3 gas, and 350 kg steam per t GAC, +10% virgin AC as make-up
Transport by truck	transport, freight, lorry 16-32 metric ton, EURO5 [RER]	Chemicals + materials: 200 km, except concrete/sand: 50 km

Disposal of DWTP sludge	treatment of inert waste, inert material landfill [RoW]	Transport: 20 km
Disposal of WWTP sludge	Composting + fertilizer substitution (market for nitrogen fertiliser, as N [GLO] and market for phosphate fertiliser, as P2O5 [GLO])	20% of N and 80% of P are accounted as fertilizer substitution; Transport: 60 km, Emission factors for composting: (Remy 2010)
Concrete	market for concrete, for de-icing salt contact [GLO]	
Reinforced steel	reinforcing steel production [RoW]	
Low-alloyed steel	steel production, low-alloyed, hot rolled [RoW]	
Stainless steel	steel production, electric, chromium steel 18/8 [RoW]	
Cast iron	cast iron production [RoW]	
Copper	copper production, primary [RoW]	
PE	polyethylene production, low density, granulate [RER	
Sand	silica sand production [DE]	
Excavation	excavation, hydraulic digger [RER]	
UV lamps	Mixture of flat glass production, uncoated [RER], steel production, low-alloyed, hot rolled [RER], copper production, primary [RER], and market for mercury [GLO]	1 UV lamp (4 kg) is made of 96% glass, 2% steel, 2% copper, and 12 mg Hg

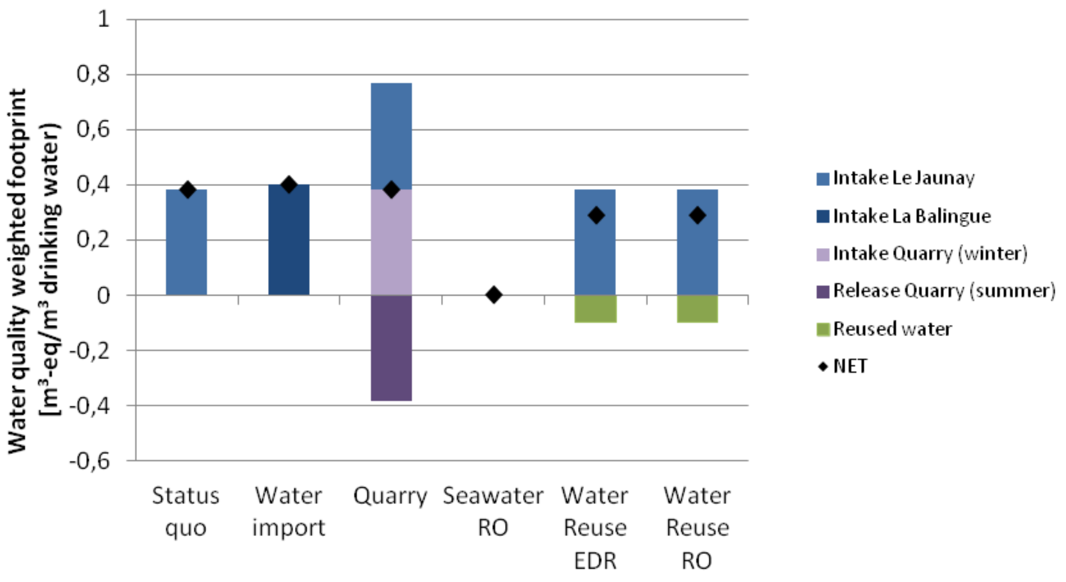

Figure 6.1 Water quality footprint per m^3 drinking water
(footprint accounts water volumes and water quality index WQI with higher As benchmark of 10 µg/L As)