Deliverable D1.1
Partial disinfection technologies for water reuse: case studies and design guidelines

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Abstract	Partial disinfection can be a cost effective and sustainable application when the chosen reuse application does not increase the risk of water-borne diseases. This report summarizes the experiences of a pilot scale investigation at WWTP Brunswick and full scale operation at WWTP El Port de la Selva for disinfection steps, performed for water reuse. Additionally results of pilot scale ozonation are presented. An economic evaluation with the defined doses is carried out and it is presented for WWTP Brunswick.

Versioning and Contribution History

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v.01	29/05/2015	Xavier Martinez	Adopted template provided to Lead Beneficiary
v.02	27/07/2015	Johan Stüber	Initial draft
v.03	03/09/2015	Raquel Iglesias	Review
v.04	15/01/2016	Johan Stüber	Revision as suggested by reviewer

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Glossary

a	Year (annum)
AC	Annual costs
BOD	Biological oxygen demand
CFU	Colony-forming units
COD	Chemical oxygen demand
DALY	Disability-adjusted life years
DBP	Disinfection by-products
DEF	Depreciation factor
DF	Discount factor
DOC	Dissolved organic carbon
DPR	Direct potable reuse
E	Specific ozone dose ($mgO_3/mgDOC$)
e.g.	Latin: exempli gratia
Etc.	Latin: etcetera
HAAs	Haloacetic acids
i	Rate of interest
IPR	Indirect potable reuse
IR	Industrial reuse
LUR	Log unit reduction
MIC	Microbial Inactivation Credit = log-credits
mio	Million (10^6)
MBR	Membrane bioreactor
MF	Microfiltration
MPN	Most probable number
n	Number of years (e.g. economic lifetime)
na	not available
NDMA	N-nitrosodimethylamine
NF	Nanofiltration
NOM	Natural organic matter
NTU	Nephelometric Turbidity Unit
Opex	operational costs
org	Organisms
PAA	Peracetic acid
PFU	Plaque forming units
p.e.	Population equivalent
PFA	Performic acid
RI	Restricted irrigation

RO	Reverse Osmosis
SE	Secondary effluent
SIB	Saltwater intrusion barrier
SRC	Sulphite-reducing clostridia
SVI	Sludge volume index
TE	Tertiary effluent
TDS	Total dissolved salts
THMs	Trihalomethanes
TOC	Total organic carbon
TSS	Total suspended solids
UF	Ultrafiltration
UI	Unrestricted irrigation
UR	Urban reuse
UV	Ultraviolet radiation
WHO	World Health Organization
$\dot{V}$	Flow (Volume per time)
WWTP	Wastewater treatment plant

Executive Summary

Water reuse is required to face the water stress situation throughout the world. Considering a sustainable approach the energy and chemical demand should be as low as possible. Therefore, partial disinfection with a lower demand for energy and chemicals is favourable wherever the reuse application allows lower water quality to be used, e.g. 100 – 2,000 CFU/100mL total coliforms, depending on the reuse application. This report shows exemplary the approach to a disinfection task at two wastewater treatment plants (WWTP), WWTP Brunswick and WWTP El Port de la Selva. Additionally, the results from pilot scale ozonation at WWTPs in Berlin are given.

At WWTP Brunswick pilot scale trials were conducted running a performic acid (PFA) and an ultraviolet radiation unit in parallel for three months. In order to achieve a water class suitable for irrigation, 2.0 g/m^3 of PFA and 35 Wh/m^3 (650 J/m^2) were defined assuring a sufficient disinfection.

Cost estimation for WWTP Brunswick is included in chapter 8. Evaluation of the specific costs for UV, PFA and chlorine-dioxide (ClO_2) showed the high dependency on the capacity utilisation, which is described by the actual utilisation divided by the maximum design capacity. Considering an utilisation of 0.53, specific costs of 2.2 cent/m^3 for ClO_2, 2.4 cent/m^3 for UV and 2.6 cent/m^3 for PFA are calculated.

At WWTP El Port de la Selva the existing tertiary treatment step including dual media filter, UV disinfection and chlorination with sodium-hypochlorite is presented.

The effects of ozonation on pathogens, E. coli and *E. cocci*, were measured within the research projects ASKURIS and IST4R. The findings showed that a log unit removal (LUR) of 2 can be achieved by applying an ozone dosage of 0.6 mgO_3/mgDOC. Nonetheless, the high capital and operation costs lead to specific costs of approximately 5.8 cent/m^3 (using 0.7 mgO_3/mgDOC).

1 Introduction

Considering the increasing water scarcity in Europe and worldwide, treated wastewater represents a valuable but not fully exploited water source. The risk of infection through water carried pathogens is the major concern with regard to the public recognition of wastewater reuse applications. On the other hand, demanding full disinfection for every reuse application will lead to high amounts of chemicals or/and energy. Evaluating disinfection technologies designed for full disinfection in a holistic way reveals an often unnecessary burden to the environment. Through quantitative microbiological risk assessment (QMRA), required disinfection levels for different applications can be defined (WHO 2006). This evaluation approach can be used to define disinfection goals balancing the effort, e.g. energy and chemicals, and the risk to public health. Waterborne diseases and their origin are summarized in Table 22 in chapter 11.

Approaching a water reuse task, disinfection is often a crucial process step, which needs to be designed in order to achieve a safe and cost effective solution. This report is based on the assumption that an existing WWTP shall be upgraded with a disinfection step. The questions at the beginning of this design process and the corresponding tasks are summarized in Figure 1 and shall serve as a guidance approaching a water reuse application. The tasks refer to chapters and sections in this report. Where possible, piloting and full scale results are given and the approach can help to get started. This decision tree helps to define a workflow targeting a technical and economical outline proposal.

In chapter 2, different applications for water reuse and the corresponding regulations are summarized. These regulations are application oriented and help to operate disinfection installation in an energy and resource efficient way. Feed water characteristics and the effect on disinfection technologies are discussed in chapter 3 (and chapter 5). Data exploitation is exemplary presented using data assessed during pilot and full scale investigations within Demoware.

A guideline to review the upstream sanitation process and potential savings for the disinfection by process optimization is summarized in chapter 4.

In chapter 5, different disinfection technologies are presented and guidelines which technology might be appropriate for the current task are given.

Evaluation of selected disinfection technologies with respect to the applied doses is presented with the data collected during pilot and full scale trials in chapter 6.

Design considerations and recommendations for process control strategies are given in chapter 7.

Using the net present value as explained in chapter 8, helps to compare different technologies and to identify the cost nature. Due to the different requirements of each technology, the net present value with respect to the actual and proposed costs for the considered site can define a break-even point between different technologies.

The disinfection technologies discussed in detail in this report were chosen due to the possibility to operate these processes with the goal of partial disinfection.

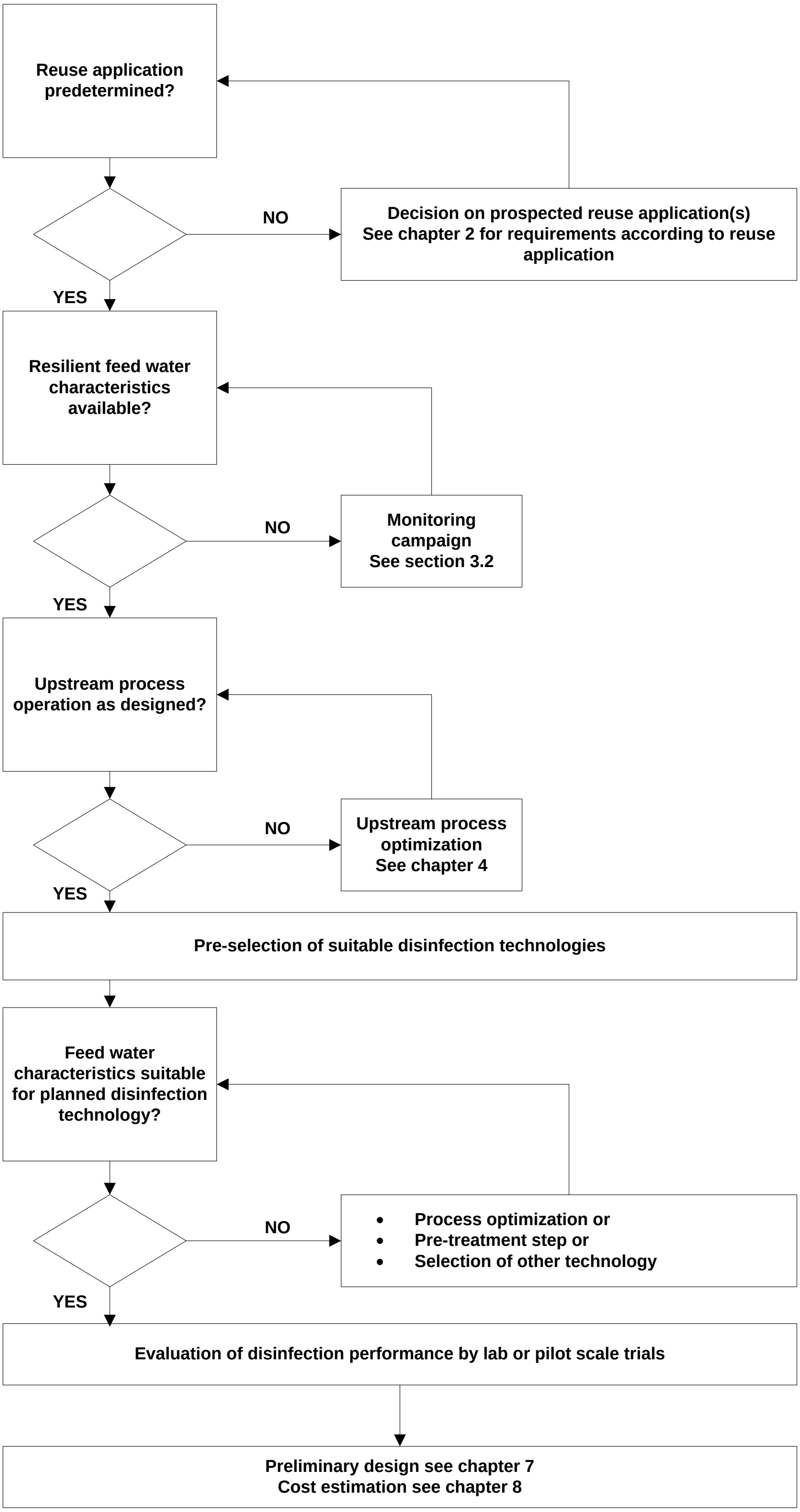

Figure 1 Decision tree and work flow

2 Selection of Reuse application – Regulatory requirements

Alcade-Sanz & Gawlik (2014) described in their report „Water Reuse in Europe“ the status quo of water reuse practice and the need for further innovations in this field. There are plenty of advantages connected to increased water reuse and the authors predict “significant economic, social and environmental benefits”. One major drawback identified in a report published by the *Water sanitation and supply Technical Platform* (WssTP 2013) is the lack of suitable regulations, which are accepted internationally. Due to the sensitive nature of the topic of water reuse, this lack of a widely accepted regulation represents a barrier to market introduction. The potential health risk for the population is a concern that needs to be addressed through active information on the safety, reliability and benefits of water reuse techniques, with remark to existing and powerful guidelines.

On the other hand, successful water reuse application can be found worldwide, among others, in Singapore (NEWater, Indirect potable reuse and industrial reuse, (PUB 2015)), Australia (e.g. agricultural), South Africa (e.g. City of Cape Town, industrial reuse (Ncube 2015)) and Israel (50% for irrigation is provided by wastewater reuse (WaterWorld 2012)). The broad range of water reuse application of these projects shows the need for adequate regulations according to the type of the reuse application.

European regulations and guidelines addressing the water reuse issue are summarized in Table 23. Exemplary definitions of water classes can be found in Table 24 and Table 25 in the Appendix.

Local, national and international regulations govern the disinfection requirements for these purposes. The World Health Organization (WHO) provides a step-by-step approach to define a health-based target of pathogens reduction (WHO 2006). This guideline is based on the precondition that the additional disease burden of water reuse should not exceed the burden defined for drinking-water: “WHO (2004) has adopted, in the third edition of the *Guidelines for drinking-water quality*, a tolerable burden of waterborne disease from consuming drinking-water of $< 10^{-6}$ DALY per person per year.”

Even though Australia has a very long history in water reuse and each state set up guidelines and regulations in order to manage risks to the population as well as to the environment, a national standardization process was established (NRMMC-EPHC-AHMC 2006; NRMMC-EPHC-AHMC 2008). This process was initiated to establish a guideline with an equivalent approach as defined prior for drinking water (NHMRC & NRMMC 2015).

Irrigation water requires different disinfection levels according to the application and two classifications are summarized in Table 1. Partial disinfection schemes are limited to applications, where a log unit removal (LUR) ≤ 3 is acceptable. Some regulations demand a specified maximal tolerable concentration of indicator organisms in the reuse water (e.g. DIN 19650 and EPA Victoria (2003)), whereas other regulation demand treatment trains with a specified LUR accredited (California Department of Public Health 2014). Other reuse applications are saltwater intrusion barrier (SIB), urban reuse (UR) and industrial reuse (IR), where different regulations apply.

Table 1 Required water class for irrigation, according to DIN19650 and EPA Victoria 2003)

	DIN19650			EPA Victoria (2003)		
	Purpose / Water class		Acceptable concentration of E. coli[1]	Purpose / Water class		Acceptable concentration of E. coli
Unrestricted irrigation (UI)	1		Non-detectable	A		<10 org/100 mL
Restricted irrigation (RI)	a) Outdoor and greenhouse crops intended for raw consumption b) School sports grounds, public parks	2	<200 org/100mL	• Agricultural: e.g. dairy cattle grazing • Industrial: e.g. wash-down water	B	<100 org/100 mL
	a) Greenhouse crops not intended for consumption b) Outdoor crops for raw consumption before fruit development or vegetables up to two weeks before harvesting c) Fruit and vegetables for preserving d) Pasture or herbage up to two weeks before mowing or grazing e) All other outdoor crops f) Other sports grounds	3	≤ 2,000	• Urban (non-potable): with controlled public access • Agricultural: e.g. human food crops cooked/processed, grazing/fodder for livestock • Industrial: systems with no potential worker exposure	C	<1,000 org/100 mL
	a) For protecting wine and fruit crops from frost b) Cultivated forests, logging sites and wet habitats c) Sugar beet, starch potatoes, oil- seed fruits, non-food plants for industrial processing and seed stock up to two weeks before harvesting (not for raw consumption) d) Cereals up to green ripeness e) Fodder for silage up to two weeks before harvesting	4	Wastewater which has passed through at least one biological purification stage	• Agricultural: non-food crops including instant turf, woodlots, flowers	D	<10,000 org/100 mL

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[1] E. coli is given as an example for a pathogen. Full requirements for the water class is given in chapter 11

3 Feed water characteristics

Partial disinfection is recommended for the purpose of irrigation and uses where the WHO health target of 10^{-6} Disability adjusted life years (DALY) per person per year can be met (WHO 2004)), considering all implemented risk reduction measures. In order to design an efficient system, considering the ecological as well as economic aspects, the feed water characteristics have to be evaluated properly. Among others, the physical and chemical characteristics influence the decision on which technology is the most appropriate for the given task. The presented technologies were chosen due to the fact that partial disinfection can be done in a cost and energy efficient way and without the burden of formation of disinfection by-products (DBPs) in high quantities.

Table 2 shows the influence of selected water parameters on disinfection technologies rating negative effect in case the parameter rises. *Negative effect* means both, lowered disinfection performance and increase of chemical and/or energy demand. A more detailed description of each disinfection technology and the impact of water constituents is given in chapter 5.

Table 2 Effect of feed water characteristic on disinfection technology, considering an increase of the parameter
(o: no negative effect; -: slight negative effect; --: medium negative effect; ---: severe negative effect)

Parameter	UV	Chlorine	ClO_2	Performic acid	Ozone
Suspended solids	- - -	- - -	- - -	- - -	- - -
Turbidity	- - -	-	-	-	-
Nitrite	o	- - -	- -	-	- -
Ammonia	o	- - -	-	o	o
UV absorption	- - -	o	o	o	o
Biological oxygen demand (BOD)	o	- - -	- - -	- - -	- - -
Dissolved organic carbon (DOC)	- -	- - -	- - -	- - -	- - -

For instance, chemical and physical disinfection technologies are affected negatively by an increase of suspended solids due to sludge run-off caused by an overload of the secondary clarifier or foaming/floating sludge, respectively. An example on how the PFA and UV disinfection units installed for pilot trials react on sludge run-off is discussed in section 6.1.4. In general, the performance of the upstream WWTP is crucial for the successful and economic operation of the disinfection unit. Measures and actions helping to identify a satisfying solution for the overall task are described in chapter 4.

In case sufficient information on the secondary effluent quality is given, data evaluation as explained in section 3.1 helps to assume the doses and installation design. Where the need for additional data collection arises, a monitoring campaign should be planned with respect to the special requirements for microbiological analysis, see section 3.2. Particularly, data on microbiological parameters for WWTP effluents are not as common as for drinking water installations.

Indicator organisms

Asano et al. (2007) summarized the ideal characteristics for indicator organisms:

1. The indicator organism must be present when faecal contamination is present.
2. The numbers of indicators organisms present should be equal to or greater than those of the target pathogenic organism.

3. The indicator organism must exhibit the same or greater survival characteristics in treatment processes and the environment as the target pathogen organism for which it is a surrogate.
4. The indicator organism must not reproduce outside of the host organism (i.e. the culturing procedure itself should not produce a serious health threat to laboratory workers).
5. The isolation and quantification of the indicator organism must be faster than that of the target pathogen (i.e., the procedure must be less expensive and it must be easier to cultivate the indicator organisms than the target pathogen).
6. The organism should be a member of the intestinal microflora of warm-blooded animals.

Most of the regulations for water reuse in practice worldwide define the indicator organisms to be measured for permission, see Table 24 and Table 25.

3.1 WWTP data evaluation

Most WWTPs carry out a continuous monitoring of chemical and physical water characteristics for the feed and the effluent, due to legal obligations and as an internal control for the plant operation. When available, these measurements should be used. Data covering one or more years help to identify seasonal variations and shall be evaluated accordingly. For instance, suspended solids as well as transmission can be affected in a negative way during transition times in spring and fall, due to temperature change and consequently changes in the microbiological community. Additionally, the operation regime is adapted to the season and might lead to adverse effluent quality. Therefore, it is necessary to design the disinfection step with sufficient performance back-up for periods with altered water quality.

The water parameters are shown in graphs displaying a box-plot. Where possible, a timeline is also given, in order to identify seasonal variations. Figure 2 shows an exemplary box-plot indicating the meaning of the graphical elements. The box-plot displays the minimum and maximum (lower and upper end of whisker), 25 / 50 (median) / 75 percentile (box) and the mean value (square).

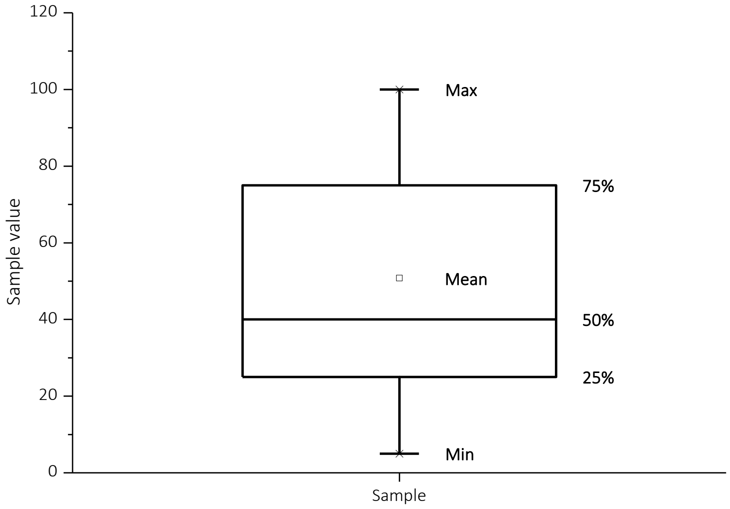

Figure 2 Example of box plot

3.1.1 WWTP Brunswick – Demoware pilot trials

The WWTP Brunswick is designed for 200,000 p.e. and equipped with biological phosphorus removal and pre-denitrification. Four secondary clarifiers are operated and primary and excess sludge are digested separately. The secondary effluent is used for irrigation either at the nearby meander for polishing or at local farms enhancing yields due to water and nutrient supply.

Physical and chemical parameters

During the pilot trials in autumn 2014, an intensive monitoring campaign was carried out and the results on physical and chemical measurements of the secondary effluent can be used for designing the disinfection step. Most of these parameters are monitored due to regulatory demands and can be used to assume the effect on different disinfection technologies. Other parameters were added, e.g. ultraviolet absorption (UV) and transmittance in order to gain all parameters affecting disinfection technologies.

Following methods were used:

• pH-value	DIN EN 38404 C5
• Temperature	DIN 38404-C04
• conductivity	DIN EN 27888 C8
• COD, filtered	DIN ISO 15705 H45
• COD homogenized	DIN ISO 15705 H45
• DOC	DIN EN 1484 H3
• Suspended solids	DIN EN 872 H33
• AOX	DIN EN 1485 H14
• Turbidity	Online turbidity probe
• Ultraviolet Absorption (UVA)	DIN 38404-C03
• Transmittance	DIN 38404-C03

In Figure 3 to Figure 6 the physical and chemical water parameters are presented for undisturbed operation. The incident of sludge run-off is discussed separately, see section 6.1.4.

The temperature fell from 21 °C to approx. 16 °C as expected towards winter season. Suspended solids covered a range of 4 – 15 mg/L with a median of 6.6 mg/L and turbidity lied between 1.9 and 7.3 NTU, with a median of 3.6. These values are in the expected range for secondary effluent and indicate that the upstream WWTP works within its designated ranges. It can also be concluded that this secondary effluent is generally suitable for the common disinfection technologies. The impact of wastewater constituents on the disinfection technologies suitable for partial disinfection is listed for each technology in chapter 5. When considering a disinfection step using chlorine (Cl_2), ammonia concentrations have to be considered, because depending on the chlorine agent to be used, present ammonia can lead to nitrosamines, which are suspected to be carcinogenic and which will increase the chlorine demand. During the pilot trials, the median concentration of ammonia-nitrogen (NH_4-N) was 4.4 mgN/L. Since ClO_2 does not react with Ammonia this chlorination agent was chosen for the economic evaluation presented in chapter 8.

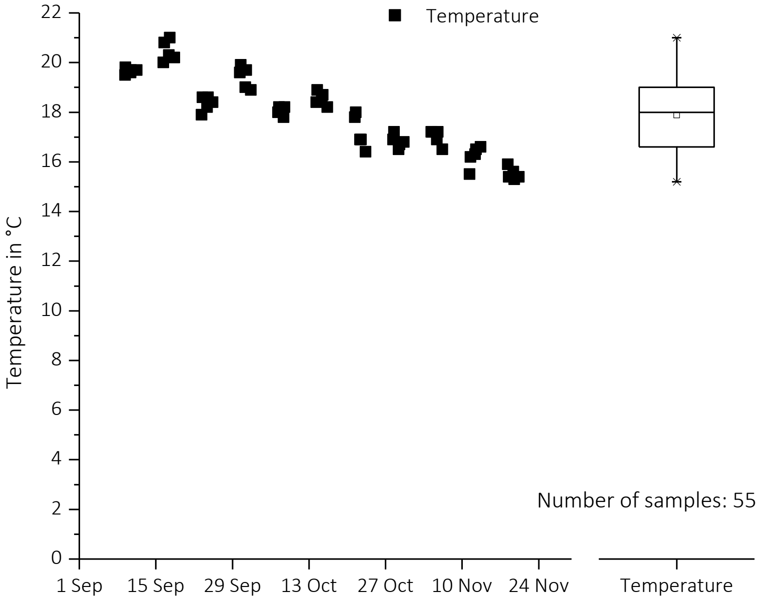

Figure 3 Temperature evolution secondary effluent WWTP Brunswick

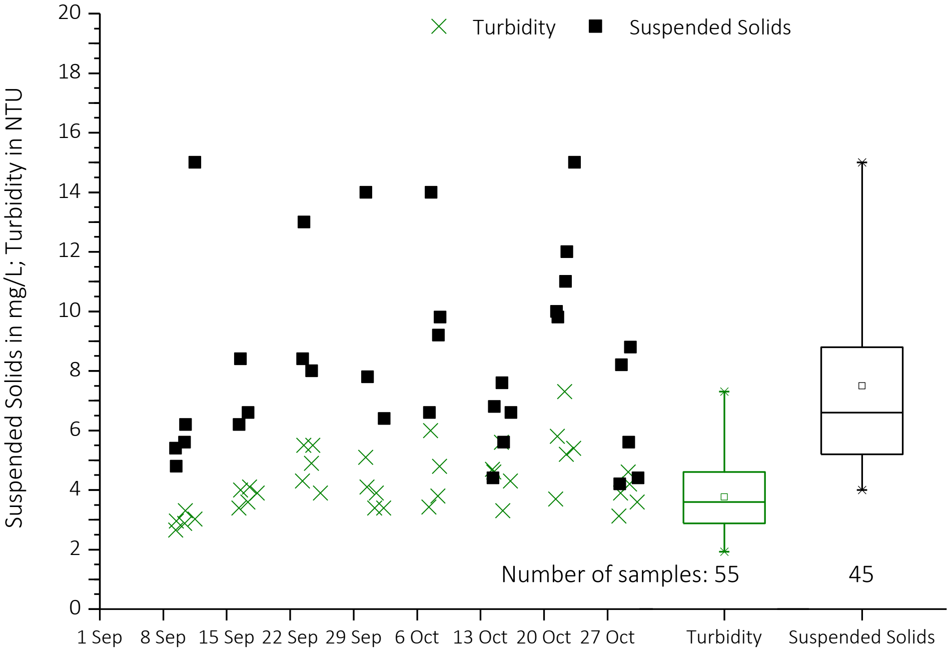

Figure 4 Suspended solids & turbidity – Secondary effluent WWTP Brunswick (without sludge run-off)

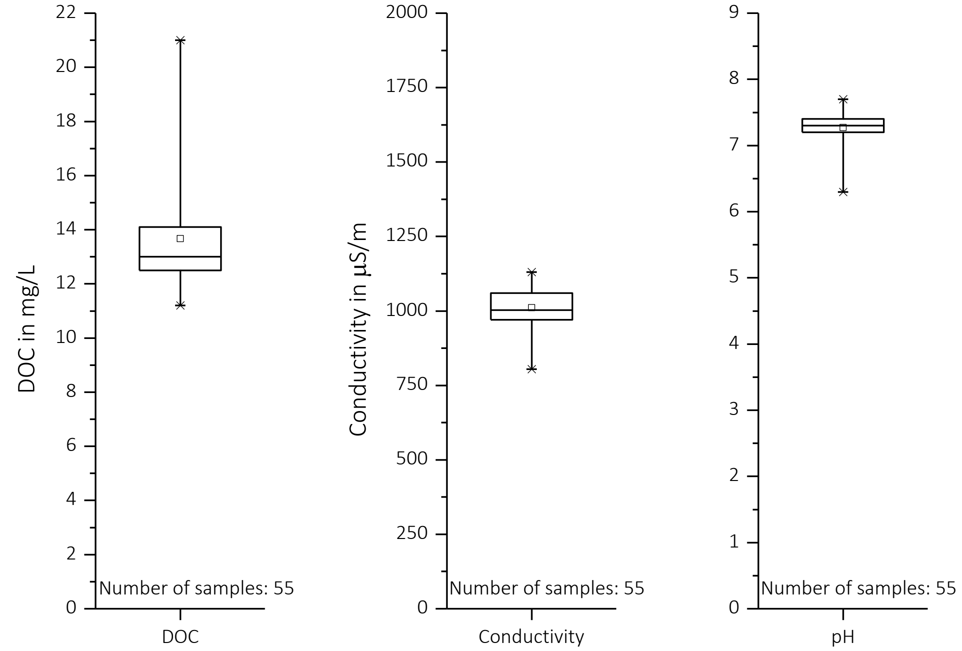

Figure 5 DOC - Conductivity - pH - Secondary effluent WWTP Brunswick

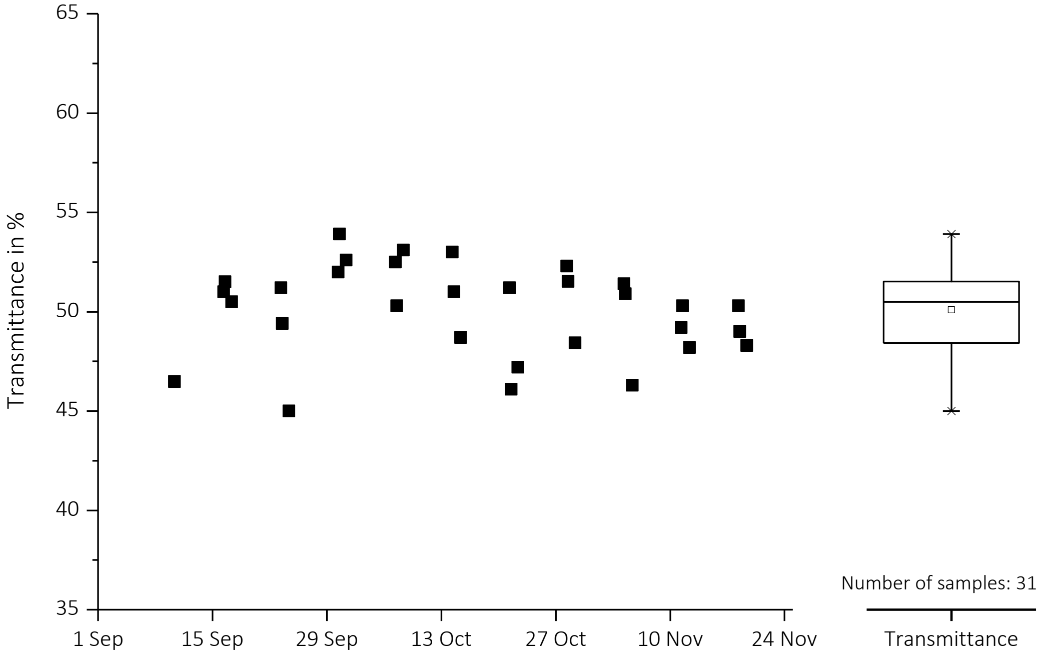

Figure 6 Transmittance - Secondary effluent WWTP Brunswick

Table 3 Summary of physico-chemical parameters of WWTP Brunswick

Parameter	Unit	Min	Max	Median	N[2]
Temperature	°C	15.2	21.0	**18.1**	58
pH	-	6.3	7.7	**7.3**	58
Conductivity	µS/cm	796	1,130	**1,002**	58
Turbidity	NTU	1.9	537	**3.6**	58
Suspended Solids	mg/L	4.0	770.0	**6.6**	58
Ultraviolet Absorption (UVA)	1/m	25.4	31.5	**27.4**	34
Specific UVA (SUVA)	L/mgm	1.2	2.5	**2.1**	34
Transmittance	%	45.0	53.9	**50.5**	31
COD	mg/L	21	840	**35**	58
COD fil	mg/L	15.0	38.0	**29.5**	57
DOC	mg/L	10.0	21.0	**13.0**	58

Microbiological parameters

Following microbiological parameters were measured regularly over the trial period:

1. E. coliE. coli	Indicator for bacteria of faecal sources	Colilert-18/Quanti-Tray;H
2. E. cocci	Indicator for faecal streptococcus group	DIN EN ISO 7899-2;H
3. *Clostridium Perfringens*	Spore forming anaerobic-persistent bacteria	DIN EN 26461-2;H
4. Somatic Coliphages	Indicator for enteric viruses	BWB-08-96

Grab samples were taken 3 – 5 times per week during three months and Figure 7 summarizes the results.

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[2] Number of samples and values are given with sludge run-off incident

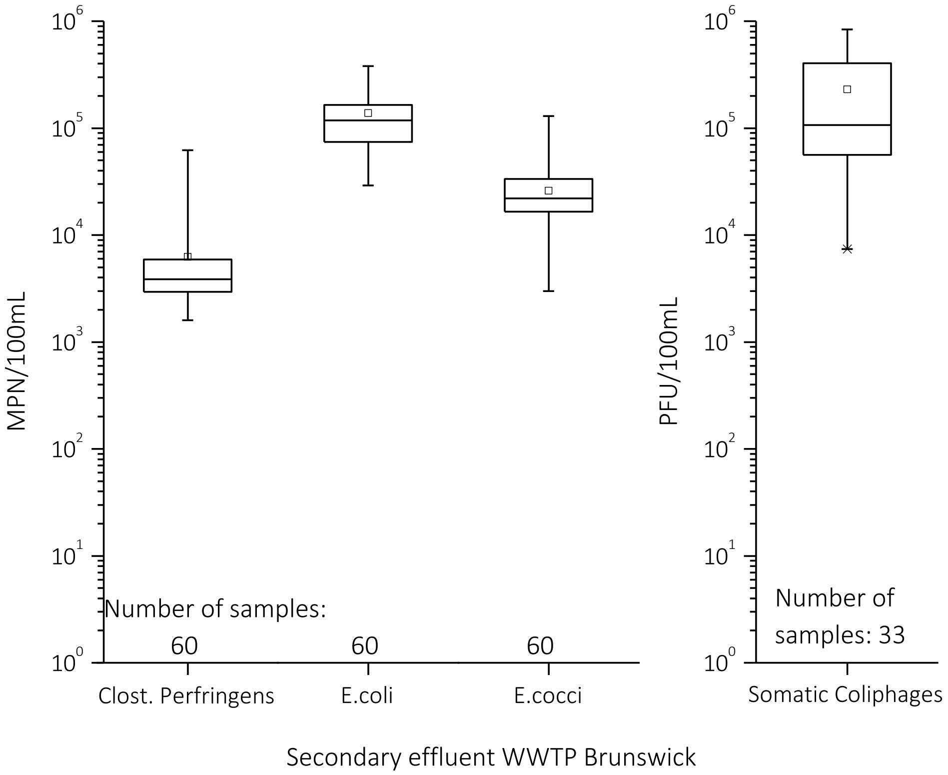

Figure 7 **Indicators present in secondary effluent WWTP Brunswick – Samples taken during pilot testing Sept. – Oct. 2014**

Sludge run-off

Practitioners in the field of wastewater treatment know several reasons for bad settling behaviour or floating sludge deteriorating the effluent water quality, especially in terms of suspended solids and turbidity. Filamentous microorganisms or delayed denitrification are just two identified causes. With suspended solids, the microbiological parameters increase, because sludge flocs incorporate the pathogens of interest (respectively their indicator organisms), among others. Even though operators work on solutions to avoid sludge run-off incidents, it is important to consider these events when designing a disinfection step and the following distribution net. A way of detection and increasing the dose to maintain the disinfection capability (if possible) should be included. Online turbidity and/or suspended solids measurement at the inlet of the disinfection step can be used for this detection. For safety issues, it is also important to detect malfunction and insufficient disinfection in order to prevent the usage of this water.

During the trials at WWTP Brunswick, a sludge run-off appeared and Figure 8 shows the evolution of suspended solids and turbidity.

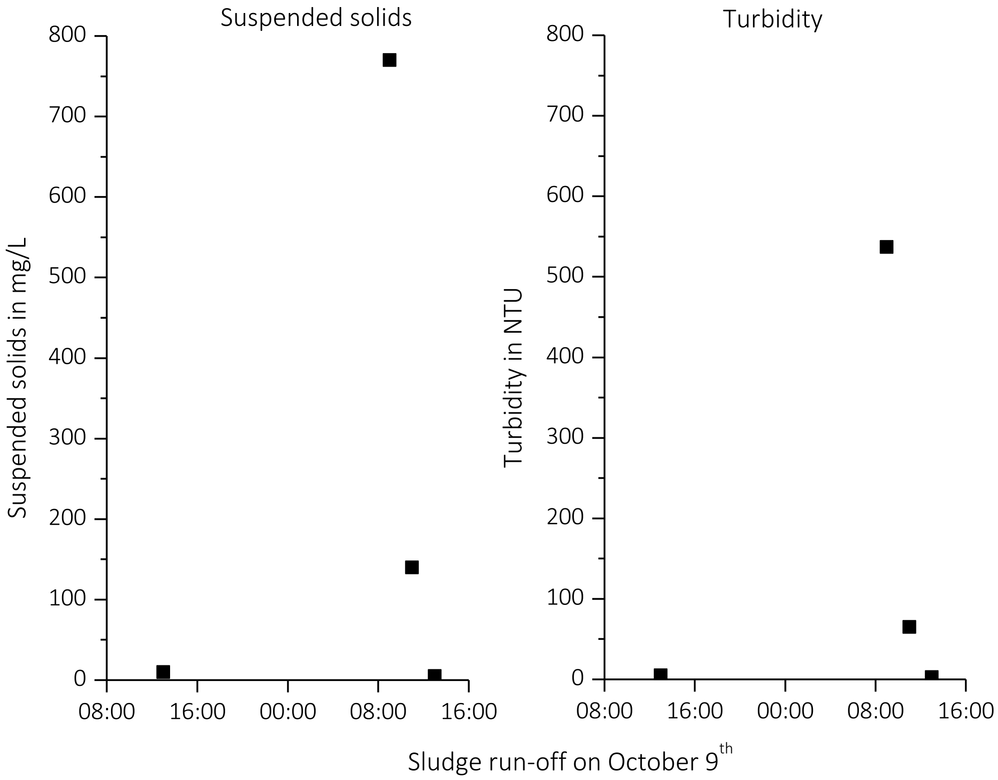

Figure 8 **Suspended solids and turbidity during sludge run-off at WWTP Brunswick on October 9th**

For comparison, the value one day before at 13:00 o'clock is also given. This rapid increase is challenging for any disinfection technology and the effect on the two tested installation, UV and PFA, is given in section 6.1.4.

3.1.2 WWTP El Port de la Selva

The second WWTP discussed here is the WWTP El Port de la Selva located at the Costa Brava at the Mediterranean Sea and it was designed for 10,500 p. e. Treating the wastewater of El Port de la Selva is challenging due to the seasonal dependency of the wastewater flow. Therefore the WWTP was designed with four contact basins, two lines with two reactors in series each, which can be operated as follows:

• One reactor	Winter operation, only one line in operation (by-passing the first reactor)
• Two reactors	One line with two reactors in operation
• Four reactors	Holyday season, two lines in operation

Each reactor is equipped with aerators and the control scheme uses oxygen and redox online measurements for alternating aerobic and anoxic conditions. Two secondary clarifiers are installed and different disposal routes for the secondary effluent are possible.

A part of the flow is furthermore treated with an additional tertiary treatment step including a two-step dual media filtration with coagulation before the first and flocculation before the second filter. Subsequently, disinfection is carried out with a UV installation and sodium hypochlorite addition in order to keep the distribution system germfree. Due the continuous operation since 2011 characterization of the secondary effluent based on regular measurements is possible. The samples were taken as grab samples once or twice a week.

In contrast to the pilot scale investigation at WWTP Brunswick, the motivation at WWTP El Port de la Selva was to optimize an existing tertiary treatment step and downstream UV disinfection. The current water reuse application includes the usage of the treated water for street cleaning and non-agricultural irrigation. In order to reduce water scarcity and to recharge ground water sources, indirect potable reuse is planned. An infiltration pond is being constructed and the tertiary effluent needs to meet more stringent requirements given by RD-1620 (2007):

< 2 NTU	(required for private irrigation)
< 35 mg/L suspended solids	(required for aquifer recharge)
< 10 mg/L Nitrogen-N for 90 % of time – No samples above 15 mg/L Nitrogen-N	
< 1,000 E. coli/100mL	

These goals have to be achieved by upstream process adaptation, e.g. nitrogen removal, as well as optimization of the tertiary treatment step, e.g. turbidity.

Physical and chemical parameters

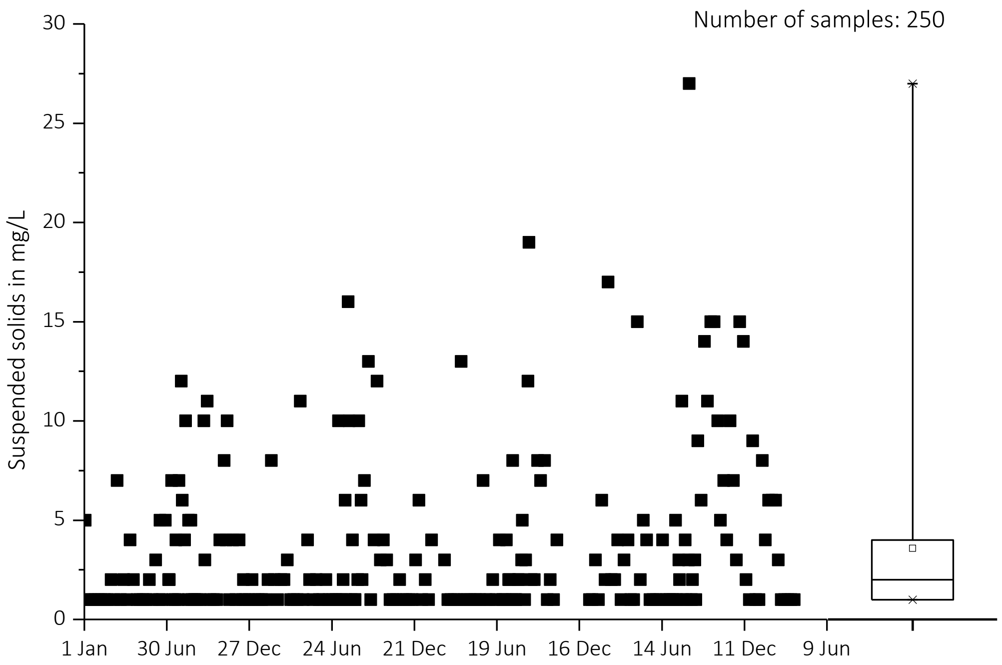

Figure 9 **Suspended solids of secondary effluent WWTP El Port de la Selva - 2011 to March 2015**

As seen in Figure 9, the suspended solids are comparably low with a median of 2 mg/L and a mean value of 3.6 mg/L. Nonetheless, peak values above 10 mg/L occur regularly.

Turbidity of the secondary effluent is shown in Figure 10. The median of 1.7 NTU is comparably low and would fulfill the requirements of < 2 NTU for indirect potable reuse as planned at this demonstration site. But the regulation also demands that 90 % of all values shall be below 2 NTU and the 90 % percentile of

3.9 NTU is clearly above that goal. Therefore, the tertiary treatment step includes the filtration through a series of two dual media filters.

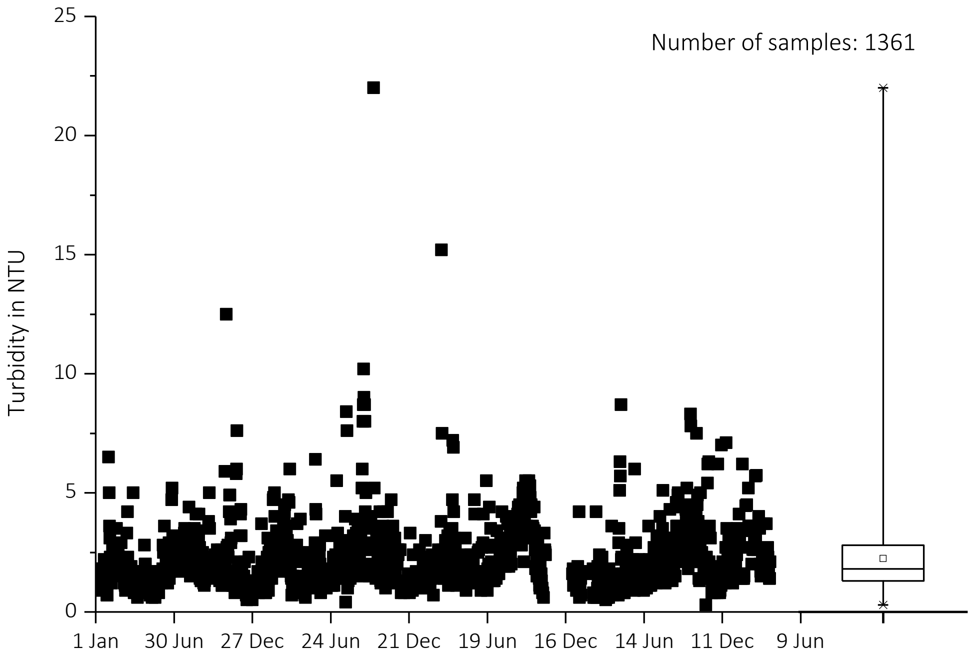

Figure 10 Turbidity secondary effluent WWTP El Port de la Selva - 2011 to March 2015

Besides removal of suspended solids and further reduction and stabilization of turbidity, the transmittance is of special interest, as it influences the effectiveness of the disinfection via ultraviolet radiation. The transmittance after the filtration is shown in Figure 11. The median is 64.5 % and the 75 percentile lies at 73 %, indicating a water quality appropriate for UV disinfection, see chapter 5.

Since this demonstration site is located at the Mediterranean Sea the goal for water reuse is not only indirect potable reuse but also to build up a saltwater intrusion barrier. Due to storm weather incidents pushing sea water towards the coast and upstream the river infiltration into the canalisation, conductivity shows a high fluctuation and needs to be monitored. Figure 12 displays the conductivity of the tertiary effluent. The median of 1.1 mS/cm lies in an acceptable range, but in the winter period high values up to 6 mS/cm can occur. Especially when these high values cover a longer period of time, the water reuse requirements are not met and infiltration of this water is not permitted according to the regulation. Therefore, an online conductivity measurement was installed and will be used as a control device before infiltration can be carried out.

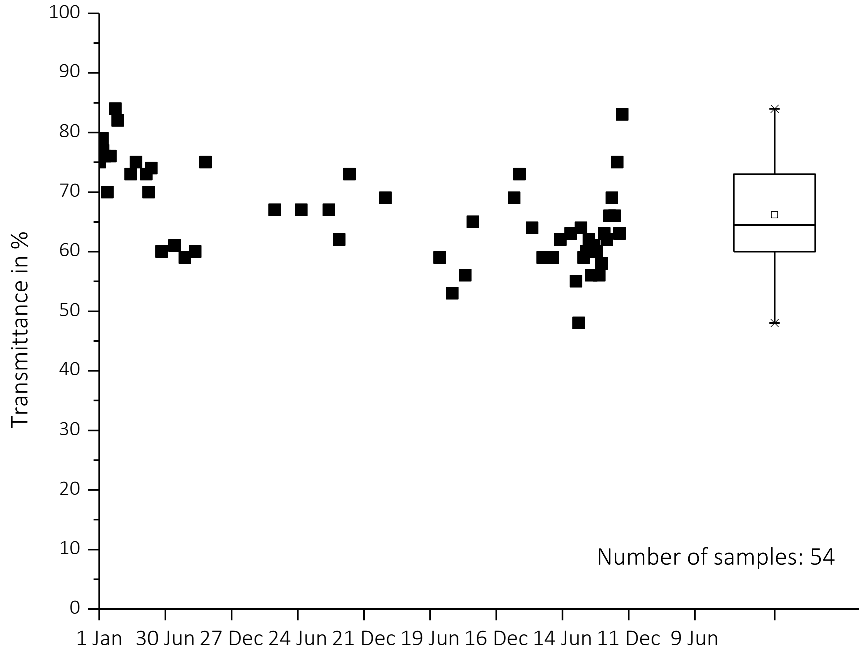

Figure 11 Transmittance tertiary effluent – 2011 to March 2015

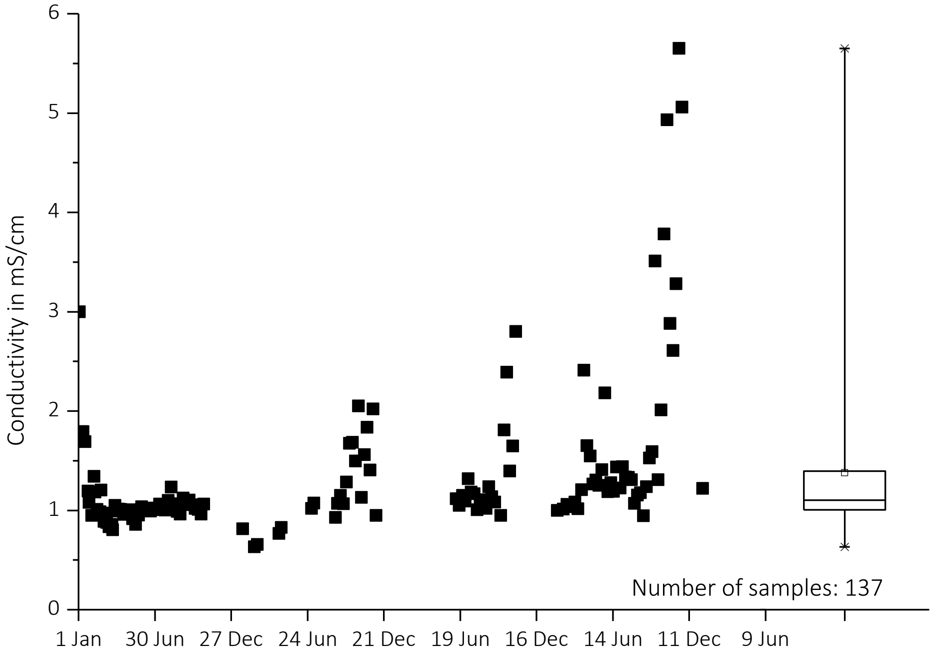

Figure 12 Conductivity tertiary effluent at WWTP El Port de la Selva - 2011 to March 2015

Microbiological parameters

At WWTP El Port de la Selva, four microbiological indicator organisms are measured on a regular basis:

- E. coli
- Sulphite-reducing clostridia (SRC)
- Aerobic bacteria
- Somatic coliphages

In Figure 13 the box-plots for these indicators are given and the obtained values can be compared to the secondary effluent of WWTP Brunswick, see section 3.1.3.

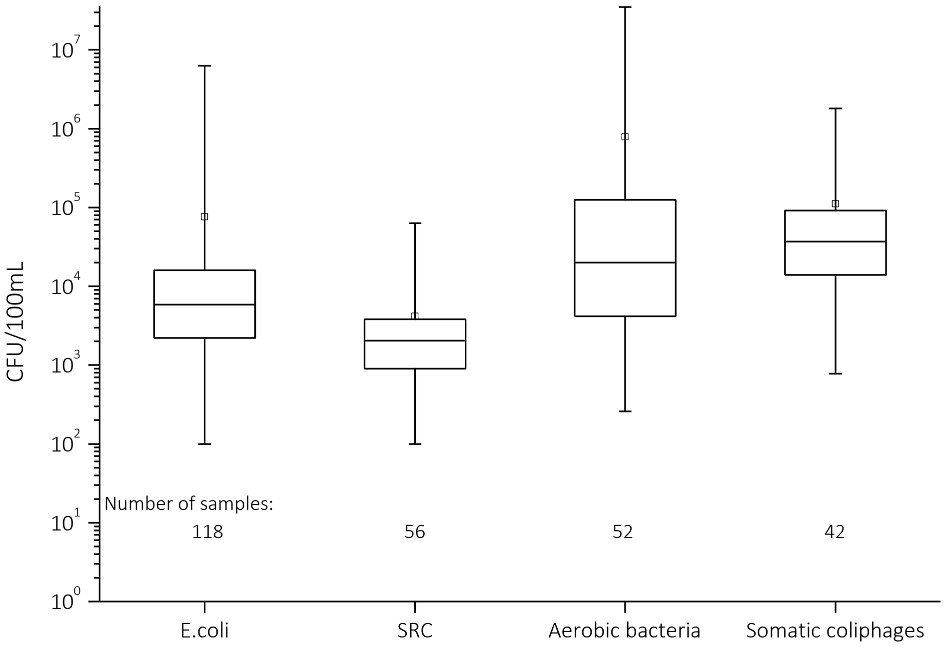

Figure 13 Pathogens present in secondary effluent WWTP El Port de la Selva – Samples taken 01/2011 to 12/2015

3.1.3 Summary water parameters

Table 4 summarizes and compares the collected water parameters of the two tested WWTPs. It has to be kept in mind that the presented data was collected over different periods of time, 3 months for WWTP Brunswick and over 5 years for WWTP El Port de la Selva. The outliers of WWTP El Port de la Selva seem therefore more extreme. Nonetheless a disinfection step has to be capable to handle extreme values either by maintaining the disinfection goal or by detecting the upstream malfunction and act accordingly, e.g. by-passing until the operation is within certain boundaries again.

Table 4 Water parameters WWTP Brunswick and WWTP El Port de la Selva – Secondary effluent

Parameter	Unit	WWTP Brunswick		WWTP El Port de la Selva	
		Median	Min/Max[3]	Median	Min/Max[3]
Suspended solids	mg/L	6.6	15[4]	2	27
Turbidity	NTU	3.6	7.3[5]	1.8	22
Transmittance	%	50.5	45[6]	71	18
Conductivity	mS/cm	1.0	1.13	1.1	5.65[7]
Indicator organisms					
E. coli	MPN/100mL	118,000	380,000	5,850	6,300,000
Somatic coliphages	CFU/100mL	107,000	1,120,000	25,000	1,800,000
E.cocci	CFU/100mL	22,000	130,000	na	na
Clostridia perfringens	CFU/100mL	3850	62,000	na	na
Aerobic bacteria	CFU/100mL	na	na	24,000	34,900,000
Sulphite-reducing clostridia	CFU/100mL	na	na	2050	63,000

3.2 Monitoring campaign secondary effluent

In case no data is available, data collection is necessary and a monitoring campaign should be initiated. Due to the set up and processes operated and the WWTP of interest, the water quality can be estimated. This can give a start for consideration on the treatment technology suitable for the goal of partial disinfection.

A monitoring campaign should cover a representative period of time, including times of lower water quality in terms of suspended solids, turbidity and/or transmittance. This is often the case during transition

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[3] Min or Max values depending on which has a negative influence on the disinfection step

[4] Without sludge run-off incident - Sludge run-off was 770 mg/L

[5] Without sludge run-off incident - Sludge run-off was 537 NTU

[6] Without sludge run-off incident - No value for sludge run-off collected

[7] Most likely due to sea water intrusion

times in spring or autumn, when changing temperatures and adaptation of the biological operation, e.g. change of sludge age, takes place.

Besides the physical and chemical water parameters, the indicator organisms are of special interest. Therefore, the planned reuse application and the corresponding local regulations have to be considered when planning the sampling and analysis campaign. Sampling can be done either with grab-, time-proportional or volume-proportional samples. Since the handling of microbiological samples is more demanding in terms of storage temperature and time, grab samples often give more precise and sufficient results. In cases where a load has to be calculated volume-proportional sampling is mandatory. The following aspects need to be considered before the sampling campaign is planned:

- Sampling points

  Is the sampling point representative? Is complete mixing given? In case several treatment trains are operated, is it useful to measure each treatment train? Is it possible to withdraw samples without contaminating the sample? Is it helpful to measure the disinfection efficiency of the upstream treatment process?

- Sample volume

  Sample volume should be sufficient for the tests planned, but easy to handle. Usually sterilized bottles of 250 mL can be used.

- Sample temperature

  Cooling to 4°C should be done directly after sampling; at this temperature, biological activity is haltered to a minimum and with respect to concentrations of indicator organisms neither growth nor decay falsifies the analysis. On the other hand freezing the samples is only permitted when no effect on the measurement method or the indicator organism is expected.

- Transport/storage time

  In order to minimize effects of growth and decay the samples shall not be stored and transported for more than 24h. Additionally exposure to light should be minimized.

- Water quality parameters

  What should be measured additionally to the pathogens? As discussed before, suspended solids, turbidity, transmittance or ammonia can affect a disinfection step adversely. Scaling propensities should be monitored, because this can severely impact the operation of UV disinfection installations.

- Indicator organisms

  Which indicator organisms should be measured? Local regulations and guidelines have to be considered here. Analysis of microbiological parameters should be done in a certified laboratory and the measurement method should be evaluated and discussed prior.

4 Upstream process evaluation / optimization

As discussed before, the water quality influences the disinfection step to a great extent and can cause additional costs due to higher chemical doses and energy costs see tables in chapter 5. Therefore it is necessary to evaluate the performance of the upstream processes. A review can help to decide whether upstream optimization or adaptation of the disinfection technology is more efficient. Expectable water qualities according to the prior treatment are summarized in Table 5.

Table 5 Expected water quality according to the prior treatment adapted from Asano et al. (2007)

Process	Total Suspended solids	Turbidity	Ammonia-N
	mg/L	NTU	mgN/L
Primary effluent	131	88	21
Secondary effluent	9.8	14	5 - 10
Tertiary effluent	1.3	0.5	5 - 10

Reddy & Pagilla (2009) summarized in detail the review process in order to identify and optimize existing wastewater treatment plants. Data evaluation and monitoring of the peak flows and loads respectively are of special interest and a desktop study reviewing the design assumptions is recommended as a first step. Afterwards, the current treatment facility should be evaluated identifying different parameters for each treatment step e.g. Total Suspended Solids (TSS), Total Kjeldahl Nitrogen (TKN), Biological Oxygen Demand (BOD). In order to minimize efforts in terms of chemicals and/or energy, partial disinfection is mostly located at the end of the treatment train and therefore sludge parameters are of special interest. Bad settling behaviour or a hydraulic overload of the secondary clarifier results in high amounts of suspended solids and correspond water qualities and will affect the disinfection in a negative way.

This chapter is a brief summary what should be looked at when upgrading an existing WWTP with a disinfection step in order to decide for a cost effective system. It can be more reasonable to optimize the WWTP operation and install a smaller disinfection step than sizing the disinfection step according to lower water quality.

The following key factors should be considered when troubleshooting an existing plant:

- Denitrification

  Incomplete denitrification leads to build up of small gas bubbles in the secondary settling tank and consequently to flotation.

- High Sludge blankets

  A high sludge blanket may lead to high suspended solids concentrations in the secondary effluent. The sludge blanket is determined by the settling behaviour of mixed liquor, influent flow rate and return activated sludge flow rate. When measuring the flows it should be noted that each settling tank has to be evaluated separately.

- Ratio of dissolved suspended solids (DSS) and flocculated suspended solids (FSS)

  Poor flocculation can cause high concentrations of suspended solids in the effluent and one measure to identify the cause is the relationship between DSS and FSS. Reddy & Pagilla (2009) name following reasons: Bioflocculation problem, excessive turbulence or not enough flocculation time, hydraulic problems and high sludge blanket and the combination of bioflocculation and hydraulic problems.

- Phosphorus release

  In nutrient removal activated sludge systems, a phosphorus release within the secondary settling tank can lead to poor effluent qualities and therefore the phosphorus dynamic should be measured. Here, an adaptation of the control regime, optimizing retention times and sludge blanket level can lead to the desired effluent quality.

The sludge volume index (SVI) is a key characteristic for evaluating the overall process. This parameter should therefore be measured in standard as well as in peak load conditions. Seasonal variations can be expected and adaptation of sludge age and solid retention times, respectively, will alter this value. Therefore, the measurement should be carried out consistently throughout the whole year.

5 Selection of disinfection technology

Disinfection technologies can be classified according their mechanism: Chemical or physical. In the following sections three chemical and two physical disinfection technologies are briefly discussed. Performic acid (PFA) is presented, because this chemical disinfection agent does not form by-products in considerable amounts. Chlorination is the most widely implemented disinfection technology, even though disinfection by-products (DBPs) are of increasing concern. Disinfection with chlorine-dioxide (ClO_2) does not show this drawback. Additionally, processes for on-site production of PFA and ClO_2 improved recently, considering safety and economic aspects. Ozone is discussed, as water treatment with ozone can achieve two major goals in wastewater treatment: disinfection and trace organic removal. Membrane filtration developed over the last decades and is worldwide installed for various purposes, e.g. membrane bioreactors (MBRs) or pretreatment for desalination. No formation of DBPs besides the high effluent quality in terms of suspended solids and turbidity are further reasons which make this technology attractive. Ultraviolet (UV) radiation is described, due to the increasing number of installations as recent developments in production and energy requirements lead to economical competitive installations.

More detailed descriptions on these technologies can be found in (Asano et al. 2007; Tchobanoglous et al. 2014).

Disinfection in water and wastewater treatment processes can be attributed to one of the following mechanisms (Asano et al. 2007):

- Damage to cell wall
- Alternation of cell permeability
- Alteration of the colloidal nature of the protoplasm
- Alteration of the organism DNA or RNA
- Inhibition of enzyme activity

5.1 Chemical disinfection technologies

All chemical disinfection technologies can be assessed through the *Ct approach.* Chick (1908) published the relationship between the dose and the contact time referring to the lethality rate of the measured micro-organisms. Watson (1908) used the data gathered by Chick and others to formulate the mathematical description of dose-contact time relationship, which is now known as the Chick-Watson law:

$$\ln\left(\frac{N}{N_0}\right) = \Delta_{CW}\, C^n\, t$$

- $ln\left(\frac{N}{N_0}\right)$ is the survival ratio for the microorganisms being killed
- Δ_{CW} is the Chick-Watson coefficient of specific lethality
- C is the concentration of the disinfection
- t is the contact time

The Ct concept describes the relative effectiveness of a specific aqueous disinfectant against different microorganisms under specific conditions. Using the Ct-approach disinfection technologies can be compared and evaluated against each other.

Evaluation of the Ct values for one organism can be used to calculate the corresponding Ct values for other organisms when a sufficient data base is given, assuming that the correlation of the LURs at a given Ct between two organisms is the same. This can be necessary in cases where measurement of the organisms of interest is impossible or very cost intensive. For the case study of Brunswick, this approach helped to identify the necessary dose for the desired LUR of Rota- and Noroviruses without measuring these organisms each time. This concept is further explained in section 6.1.

5.1.1 Chlorination and disinfection with chlorine dioxide

Chlorination is the most widespread disinfection technology and has been further developed for various applications over the last decades. Following chlorine agents are used in wastewater disinfection:

- Free chlorine gas
- Sodium chloride
- Combined chloride
- Chlorine dioxide

Due to a long evolution of disinfection by chlorine, it is a-well established process and especially where reliable and quick-in-action technologies are required, chlorine is often installed. Among others the possibility to provide residuals for a network-disinfection is often emphasized when discussing the possible process steps. The main disadvantages of chlorine are, beside the laborious handling due to safety reasons, the possible formation of by-products, e.g. trihalomethanes (THMs), *N*-nitrosodimethylamine (NDMA), and haloacetic acids (HAAs). When chlorine dioxide is used, the formation of chlorite and chlorate has to be kept in mind and a maximum concentration of chlorine needs to be respected (Asano et al. 2007; Crittenden et al. 2012). Where residual chlorine is unwanted, dechlorination has to be designed and operated.

In order to form residual free chlorine breakpoint chlorination is necessary. The required chlorine dosage depends on the water quality, because formation of chloro-organic and chloramine compounds takes place. High concentrations of ammonia lead to higher formation of chloramines and consequently to a higher chlorine demand.

Chlorine-dioxide (ClO_2) has the advantage that no reaction with ammonia occurs and therefore is adequate for secondary effluents with higher ammonia concentrations. It was also reported that no halogenated organic compounds are formed in concerning concentrations, which is another advantage over other chlorine agents (Asano et al. 2007; DVGW 2008). On the other hand, due to the way of production by reaction of chlorine-chlorite, chlorite-hydrochloric acid, or chlorite-peroxodisulfate reaction trace amounts of chlorite and chlorate are present in the dosing solution and are further formed during reaction in the water (DVGW 2008; Höll 2002). The formation of these DBPs can be limited by an effective management of the production process. This includes severe monitoring of the precursors and the product concentration. Due to these considerations ClO_2, was chosen for the economic evaluation for the disinfection step at WWTP Brunswick.

It has to be noted, that the disinfection mechanism imposed by ClO_2 is due to oxidation and thus differs from other chlorine agents.

Table 6 gives the impact of water constituents on the use of chlorine for disinfection.

Table 6 **Impact of wastewater constituent on the use of chlorine for wastewater disinfection, adapted from (Asano et al. 2007) (without ClO_2)**

Water constituent	Effect
BOD, COD, and TOC	Organic compounds comprised within BOD and COD can increase the chlorine demand. The degree of interferences depends on their functional groups and their chemical structure
Natural organic matter (NOM)	Reduces effectiveness of chlorine by forming chlorinated organic compounds that are measured as chlorine residual, but are not effective for disinfection
Oil and grease	Can exert the chlorine demand
Total suspended solids (TSS)	Shield embedded bacteria
Alkalinity	No or minor effect
Hardness	No or minor effect
Ammonia	Combines with chlorine to form chloramines / Not for ClO_2
Nitrite	Oxidized by chlorine, formation of N-nitrosodimethylamine (NDMA)
Nitrate	Chlorine dose is reduced because chloramines are not formed. Complete nitrification may lead to the formation of NDMA due to the presence of free chlorine. Partial nitrification may lead to difficulties in establishing the proper chlorine dose
Iron	Oxidized by chlorine
Manganese	Oxidized by chlorine
pH	Affects distribution between hypochlorous acid and hypochlorite ion
Industrial discharges	Depending on the constituents, may lead to a diurnal and seasonal variations in the chlorine demand

5.1.2 Performic acid (PFA)

In contrast to chlorination, performic acid for disinfection is not widely established yet. The precursor of this agent (peracetic-acid (PAA)) formed adsorbable organic halogens (AOX) in wastewater applications. By switching to performic–acid, this disadvantage was no longer detected. In comparison to chlorination and ozone, PFA leads to less harmful products. Formic acid, O_2, CH_4, CO_2, and H_2O are formed during the reaction of performic acid with wastewater constituents, which are considered not toxic in the concentrations typically encountered (Tchobanoglous et al. 2014).

Due to its instable nature, PFA has to be produced on-site by the reaction of formic acid and hydrogen-peroxide. The company Kemira provides a reaction unit where performic acid is produced with a concentration of approx. 13.5 % in the dosing solution. Due to the relatively low investment costs for the reactor and the comparably easy implementation in existing wastewater treatment plants this process is more and more considered as an alternative to ultraviolet radiation and chlorination. This process was tested for different applications including advanced primary effluent, storm water treatment, and secondary effluent (Falsanisi et al. 2008; Gehr et al. 2009; Karpova et al. 2013). A full scale installation is operated at WWTP Ruhleben by Berliner Wasserbetriebe and the results are summarized by Gnirrs et al. (2015).

The pilot scale investigations at WWTP Brunswick therefore included performic acid, and the economic comparison shown in section 8 highlights the key circumstances when this novel process is favourable. Table 7 gives the impact of some water constituents present in wastewater to be disinfected on the use of PFA. Because this novel process is not widely implemented yet, data on the impact of physical and chemical water constituents is limited in comparison to the other disinfection technology.

Table 7 Impact of wastewater constituent on the use of PFA for wastewater disinfection

Water constituent	Effect
BOD, COD, and TOC	Organic compounds comprised within BOD and COD can increase the PFA demand.
NOM	Affects the rate of PFA decomposition and the demand
Oil and grease	Can exert the PFA demand
TSS	Shield embedded bacteria

5.1.3 Ozone

Ozone is widely used for disinfection in drinking water applications and becomes more and more an alternative process in wastewater treatment. Among others the advantage of ozone is a high efficiency in inactivating viruses, spores, cysts, and oocysts in comparison to chlorine (Asano et al. 2007). With lower contact times required another practical advantage are the smaller reaction tanks. Since ozone is discussed for trace organic removal in water and wastewater treatment, a synergic effect can be deployed.

Drawbacks are the higher measurement and control efforts as well as the safety issues, e.g. handling, off-gas treatment, ambient control probes. Due to its instability, ozone cannot be stored and transported and the on-site production is energy consuming. In addition, ozone requires comparably high maintenance and operation efforts which increase the operation costs.

For secondary effluent, the required doses given by Asano et al. (2007) are as follows:

- 3 - 5 mg/L → coliform count < 1,000 MPN/100mL
- 5 - 7 mg/L → coliform count < 200 MPN/100mL
- 12 – 16 mg/L → coliform count < 23 MPN/100mL
- 20 – 30 mg/L → coliform count < 2.2 MPN/100mL

These values shall serve as a rough estimation and further tests on site are required in order to precisely estimate the required dosage for a specific application. The given dosages in mg/L do not account for the high reactivity of ozone with organic compounds and can therefore be misleading. In order to be able to evaluate ozonation processes at different locations, the DOC concentration shall be used for calculation of the specific ozone dose. This calculation is further explained in chapter 6.3 where the disinfection results for the ozonation pilot trials are presented.

Table 8 gives the impact of wastewater constituents on the use of ozone for disinfection.

Table 8 **Impact of wastewater constituent on the use of ozone for wastewater disinfection, adapted from (Asano et al. 2007)**

Water constituent	Effect
BOD, COD, and TOC	Organic compounds comprised within the BOD and COD can increase the ozone demand. The degree of interferences depends on their functional groups and their chemical structure
NOM	Affects the rate of ozone decomposition and the ozone demand
Oil and grease	Can exert an ozone decomposition and increase the ozone demand
TSS	Increase ozone demand and shielding of embedded bacteria
Alkalinity	No or minor effect
Hardness	No or minor effect
Ammonia	No or minor effect, can react at high pH
Nitrite	Oxidized by ozone
Nitrate	Can reduce effectiveness of ozone
Iron	Oxidized by ozone
Manganese	Oxidized by ozone
pH	Effects the rate of ozone decomposition
Industrial discharge	Depending on the constituents, may lead to a diurnal and seasonal variations in the ozone demand
Temperature	Effects the rate of ozone decomposition

5.1.4 Summary Ct values for chemical disinfection technologies

Table 9 and Table 10 summarize Ct values obtained in several experimental studies and shall serve as a general guide. Due to the nature of these experimental studies and the evolving analytical techniques the results may differ from other publications.

Table 9 **Ct[8] values for chemical disinfection technologies for secondary effluent in mg * min * L^{-1} (adapted from (Tchobanoglous et al. 2014))**

	Chlorine dioxide	Chlorine (free)	Ozone
	Ct in mg*min*L^{-1}	Ct in mg*min*L^{-1}	Ct in mg*min*L^{-1}
Bacteria	Total Coliform	Total Coliforms	Total Coliform
2-log	0.8 – 1.2	0.8 – 1.2	0.01 – 0.02
3-log	1.2 – 1.8	1.2 – 1.8	0.015 – 0.03
4-log	1.6 – 2.4	1.6 – 2.4	0.02 – 0.04

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[8] pH ca. 7.5, ca. 20°C

Virus			
2-log	5 – 5.5	1.5 – 1.8	0.25 – 0.3
3-log	9 – 10	2.2 – 2.6	0.35 – 0.45
4-log	12.5 – 13.5	3 – 3.5	0.5 – 0.6
Protozoan Cysts			
2-log	235 – 260	45 – 55	8 – 8.5
3-log	700 – 100	70 – 80	1.43

Table 10 Examples of Ct values for 99 % (2-log) inactivation of various microorganisms by disinfectants[1,2,3]

	Ct Values (mg * min * L^{-1})			
Microorganism	Free Chlorine	Preformed Chloramine	Chlorine Dioxide	Ozone
Escherichia coli	<1 (10-15°C)	95-180	0.4-0.75	0.02
Enteric viruses	5.4 (15°C)	428 (15°C) (for viruses in general)	5.6	0.6
Giardia	60 (15°C)	1,000 (15°C)	17	0.5-0.6
Cryptosporidium[4]	7,200 (25°C)	7,200 (25°C) (4)	357 (15°C)	32

Notes: (1) Temperature is 5°C unless stated.

(2) pH is within range of 6-9 unless stated.

(3) See individual information sheets for references for quoted values

(4) The Ct value for *Cryptosporidium* is for a 1 log reduction

5.2 Physical disinfection technologies

5.2.1 Membrane filtration

Membrane filtration represents a physical barrier and can therefore withhold all organisms and particles exceeding the pore size, see Table 11. Due to this, membrane filtration acts as a disinfection technology depending on the size and shape of the microorganism.

Table 11 Nominal pore size membrane filtration

Microfiltration (MF)	Ultrafiltration (UF)	Nanofiltration (NF)	Reverse Osmosis (RO)
100 – 200 µm	10 – 20 nm	5 nm	Dense membrane

Integrity is a key pre-condition for disinfection by membranes and a proper monitoring system needs to be prepared (for further information see D2.2 Demoware). In case the filtrate/permeate is rich in nutrients, biofilm formation and, in consequence, a recontamination with microorganisms in the downstream network is possible. Monitoring tools and in case of positive indication, actions against recontamination have to be planned.

Besides significant capital costs, operational costs for membrane filtration are high compared to other disinfection technologies, due to the pressure that has to be applied in order to maintain a certain flow. Membrane fouling is still a burden and membrane cleaning and/or replacement increase the expenditures for this process. On the other hand, membrane filtrate is of the highest quality and where solid free and low turbidity process water is required, membrane filtration presents an important option.

Membrane installations will not be further discussed in the following sections because it is not suitable for partial disinfection. Installations with side stream full disinfection by membranes, followed by blending with non-disinfected water may lead to a partial reduction of pathogens and is technical possible, but will not be further described, since economic considerations result in a comparable high price.

5.2.2 UV radiation disinfection

The wavelength considered to be ultraviolet lies in the spectrum of 100 and 400 nm (Tchobanoglous et al. 2014). Ultraviolet radiation harms the DNA sequences of organisms under exposure. The range is divided into three sections, where the UV-C (between 220-320 nm) is the range showing the highest germicidal effectiveness. The relative DNA absorbance peaks at 260 nm. The different lamp technologies and their characteristics are summarized in Table 12.

Table 12 Characteristics of UV lamps - adapted from Tchobanoglous et al. (2014)

	Unit	Low pressure – Low intensity	Low pressure – High intensity	Medium pressure – High intensity
Lamp output at 254 nm	W	25 - 27	60 - 400	
Efficiency	%	30 - 40	25 - 35	10 - 12
Temperature	°C	35 - 45	90 - 150	600 - 800
Pressure	mmHg	0.007	0.001 - 0.01	100 – 10,000

There are three ways to assume the necessary UV dose for a specified disinfection target:

- Point sources summation
- Computational fluid dynamics (CFD)
- Bioassay - Collimated Beam Test

Point source summation was used during early stages of UV disinfection applications. Due to insufficient results, predicting the necessary dose for a disinfection target and limited use for full scale design, this method is generally considered obsolete. With the increasing computing capacity over the last decade, CFD is more and more capable to estimate the UV dose. Nonetheless, the standard procedure is the collimated beam test requiring equipment and trained personnel. For this analysis, water samples of the respective WWTP effluents are tested with laboratory equipment (Tchobanoglous et al. 2014). In order to confirm the outcomes and to reduce the risk of inadequate design, pilot scale tests are recommended, see chapter 6.

Table 13 Impact of wastewater constituent on the use of UV for wastewater disinfection, adapted from Asano et al. (2007)

Water constituent	Effect
BOD, COD, and TOC	No or minor effect. Unless humic materials comprise a large portion of the BOD
NOM	Strong absorbers of UV radiation
Oil and grease	Can accumulate on quartz sleeves of UV lamps, can absorb UV radiation
TSS	Absorption of UV radiation, can shield embedded bacteria
Alkalinity	Can impact scaling potential. Also effects solubility of metals that may absorb UV light
Hardness	Calcium, magnesium and other salts can form mineral deposits on quartz tubes especially at elevated temperatures
Ammonia	No or minor effect
Nitrite	No or minor effect
Nitrate	No or minor effect
Iron	Strong absorber of UV radiation, can precipitate on quartz tubes, can adsorb on suspended solids and shield bacteria by adsorption
Manganese	Strong absorber of UV radiation
pH	Can affect solubility of metals and carbonates
Total dissolved solids (TDS)	Can impact scaling potential and the formation of mineral deposits
Industrial discharges	Depending on the constituents (e.g. dyes), may lead to a diurnal and seasonal variations in the transmittance

6 Evaluation of disinfection performance of selected technologies

Within the Demoware project, pilot scale investigations at WWTP Brunswick gave the opportunity to operate two disinfection plants, ultraviolet radiation and performic acid, in parallel. Additionally, one project goal is optimization and adaptation of WWTP El Port de la Selva. Current treatment at WWTP El Port de la Selva consists of primary treatment, biological nutrient removal followed by a secondary settler. Tertiary treatment with dual media filters, UV disinfection and downstream treatment with sodium hypochlorite (NaOCl) is operated and shall be enhanced for indirect potable reuse by set up of an infiltration pond. Dosage of NaOCl has to be stopped for infiltration so the water requirements have to be met after UV disinfection.

Piloting and full scale operation, respectively, enable the evaluation of a comprehensive set of data.

6.1 Piloting example Brunswick

The secondary effluent of WWTP Brunswick is currently used for irrigation of energy crops or is discharged into a meander system. The current water quality of the secondary effluent was presented in detail in section 3 and according to DIN 19650 can be attributed to water class 4. In order to achieve a higher water quality class allowing further reuse applications a disinfection step is necessary. The outcomes of a quantitative microbiological risk analysis (QMRA) carried out during the research project CoDiGreen (Seis 2012) suggested that a further reduction of Noro- and Rotaviruses by 1.5 log is necessary to reduce the risk for field workers as defined by the WHO. Therefore this case study is highly appropriate for a partial disinfection application. The goals of these trials were to define the doses achieving the water class 3.

The direct measurement of viruses is still timely and cost intensive, so the following widely accepted indicator organisms were chosen: E. coli, E.Cocci, Clostridium Perfringens, and somatic coliphages. A correlation between the indicator organisms and the pathogens was calculated based on data published by Hijnen et al. (2006). With this correlation the following LUR were assumed to be equivalent to 1.5 LUR of rotaviruses:

Table 14 Target LUR of indicator organisms assumed to be equivalent to 1.5 LUR of viruses

Indicator organism	Target LUR
E. coli	3.17 LUR
E.Cocci	1.77 LUR
Clostridium Perfringens	0.32 LUR

Considering that norovirus is more sensible to UV radiation than rotavirus it is assumed that achieving the 1.5 LUR for rotavirus means consequently an equal or higher removal for norovirus.

6.1.1 Pilot plant set up

Ultraviolet radiation

The UV disinfection reactor was manufactured by Xylem-Wedeco and the system was a “LBX 10” designed for a maximum flow of 15 m^3/h. During the trials a flow between 5 and 8.1 m^3/h was tested. Equipped with wipers for mechanical cleaning this system is suitable for secondary effluent. The wipers frequency was set to once per hour. The three low-pressure UV-C lamps were operated approximately for one year prior to the presented investigations, so the disinfection results can be assumed as representative in terms of lamp ageing. New lamps achieve higher disinfection rates in the beginning, possibly leading to an overestimation of the disinfection capacity. With a reactor volume of 13 L the retention time lied between 5 and 10 s. Figure 14 shows the basic flow sheet for the UV disinfection plant.

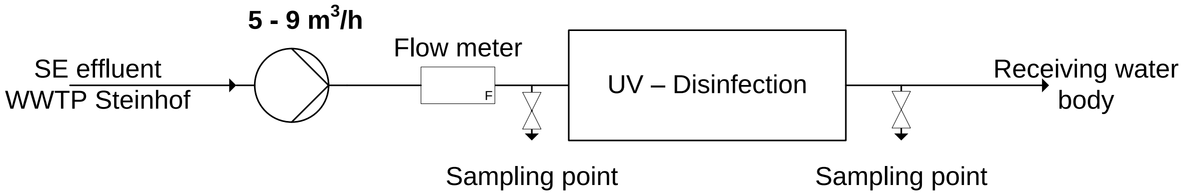

Figure 14 **Basic flow sheet UV disinfection**

UV lamps cannot be controlled individually in term of power output; therefore, the fluence and the specific energy consumption, respectively, are set by controlling the flow, see Table 15. Within in the first trial phase, three specific energy consumptions were tested: 27, 32 and 44 Wh/m^3. After a first evaluation of the disinfection results with respect to the defined goals, a specific energy consumption of 35 Wh/m^3 was recommended.

Table 15 **Flow and correspondent specific energy consumption and fluence**

Flow in m^3/h	Dose equivalent in J/m^2	Specific energy consumption in Wh/m^3
8.1	500	27
7	600	32
6.3	650	35
5	800	44

Performic acid (PFA)

A pilot plant to produce performic acid on site was rented out by Kemira. The plant “DEX 3” is designed with a flow proportional reaction and dosing system, so that the planned concentration in the water stream can be achieved for different flows. The pilot scale installation was designed for a water flow of 50 – 100 m^3/h and a dosing range of 0.5 to 3 g/m^3 PFA. A 20 m^3 reactor was used to maintain a retention time of 12 – 24 min, see Figure 15.

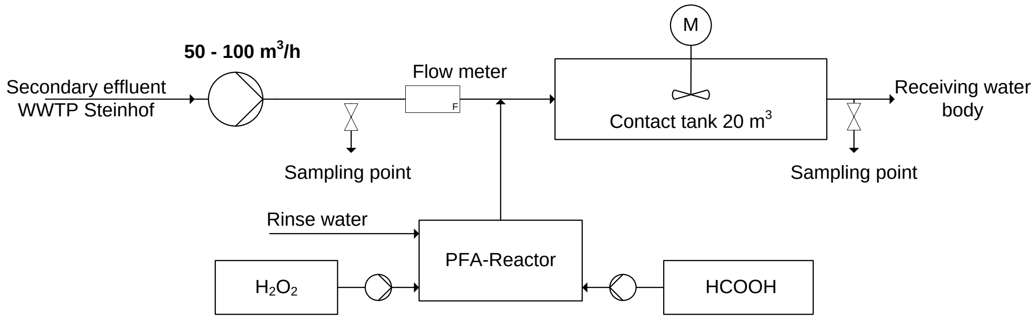

Figure 15 **Basic flow sheet PFA pilot plant WWTP Brunswick**

During the trial period in 2014 the flow was kept constant at 50 m^3/h whereas three concentrations of PFA were tested: 1.4, 2.0 and 2.7 g/m^3. The outcomes of the first trial phase were used to conclude the following statements:

- UV and PFA show similar effectiveness on indicator organisms
    - ➢ Target LUR of 1.77 for E. cocci is also valid for PFA

Therefore a PFA dose of 2 g/m^3 is recommended for the goal of 1.5 LUR of rotavirus and 3.17 LUR for E. coli.

6.1.2 Results pilot scale investigations

In order to allow a complete data evaluation the data is presented in total, including the first trial phase and the results obtained with the recommended doses.

Figure 16 and Figure 17 show the disinfection capacity on E. coli for both pilot plants. The different specific energy demand and PFA dose, respectively, are indicated and the mean LURs are given. The mean LURs are calculated using the LUR of each data pair. E. coli is known to be sensitive to UV radiation what is clearly shown in Figure 16.

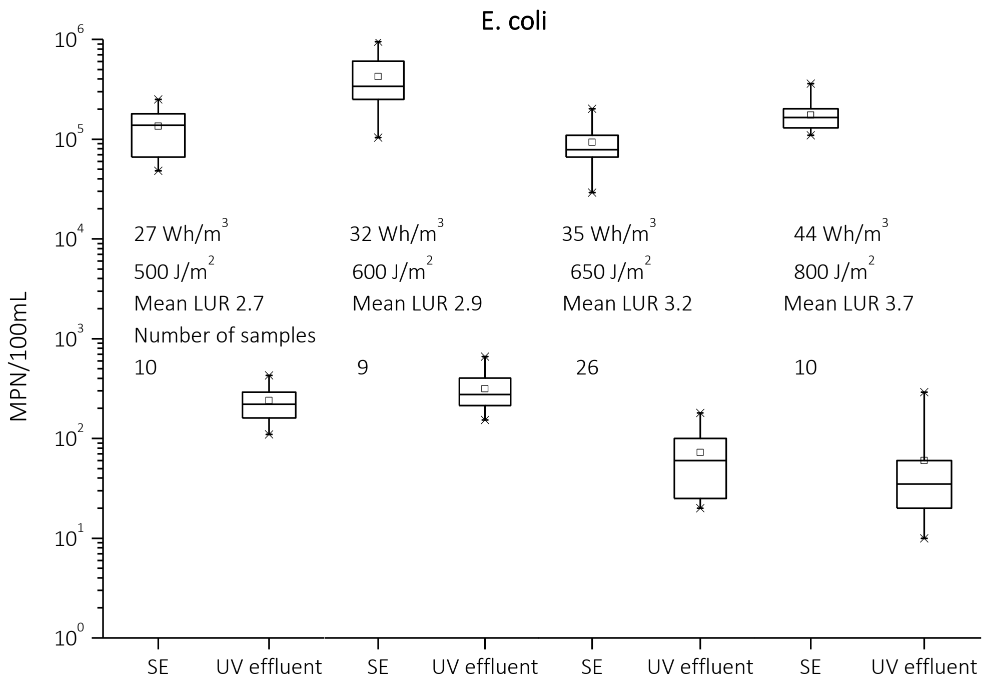

Figure 16 Disinfection results - E. coli - UV radiation

The LUR rises from 2.7 to 3.7 by increasing the specific energy consumption from 27 (~500 J/m^2) to 44 Wh/m^3 (~800 J/m^2). With respect to the targeted LUR of 3.17 for E. coli the recommendation is a specific energy consumption of 35 Wh/m^3 (~650 J/m^2).

For the PFA, a similar result was obtained, a clear sensibility of E. coli to the disinfection agent, see Figure 17. The higher the dose is, the higher the LUR. But the goal of 3.17 LUR was not achieved, in contrast to the assumption that a similar sensitivity correlation between E. coli and viruses for UV and PFA exists.

During the trials it was shown that the minimal retention time after dosing was significantly below the targeted 10 min. This and the corresponding consequences are further explained in section 6.1.3.

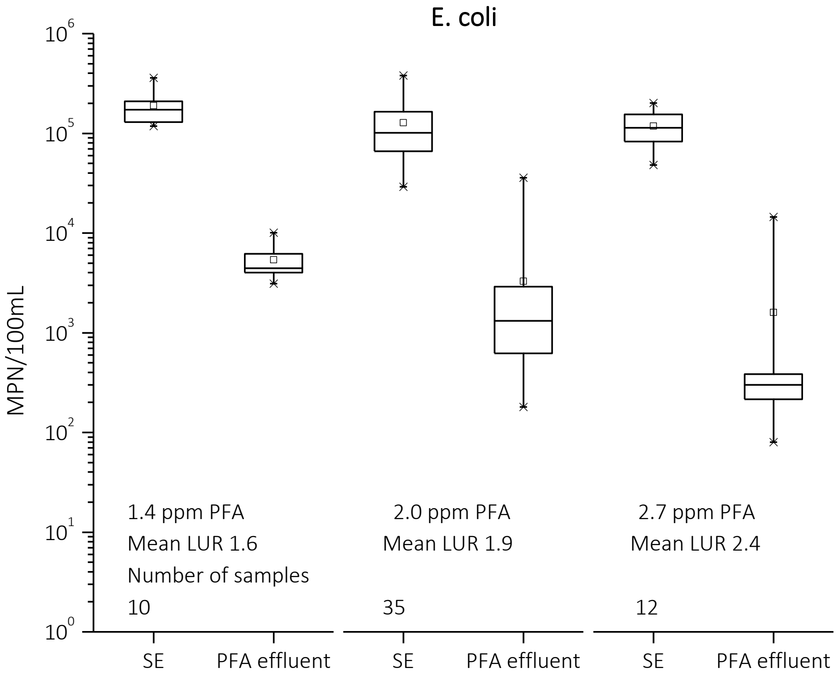

Figure 17 Disinfection results - E. coli – Performic acid (PFA)

The targeted LUR of 1.77 for E.Cocci was achieved even with a lower specific energy consumption of 32 Wh/m^3 (600 J/m^2), see Figure 18. Nonetheless, the maximum concentration exceeded 100 organisms/100mL as required by the DIN 19650 to achieve water class 2.

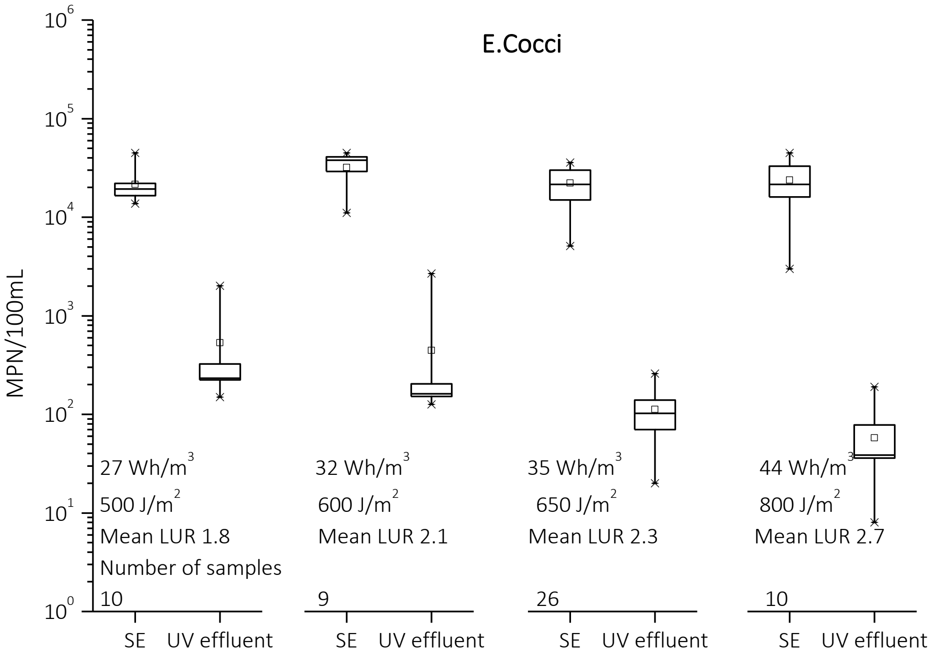

Figure 18 Disinfection results - E.Cocci - UV radiation

A dose of 2.0 g/m^3 of PFA achieved a mean LUR of 1.8 for E.Cocci which is higher than the targeted 1.77 LUR. The high maximum value indicated by the upper whisker points out to measurements exceeding the concentration limit.

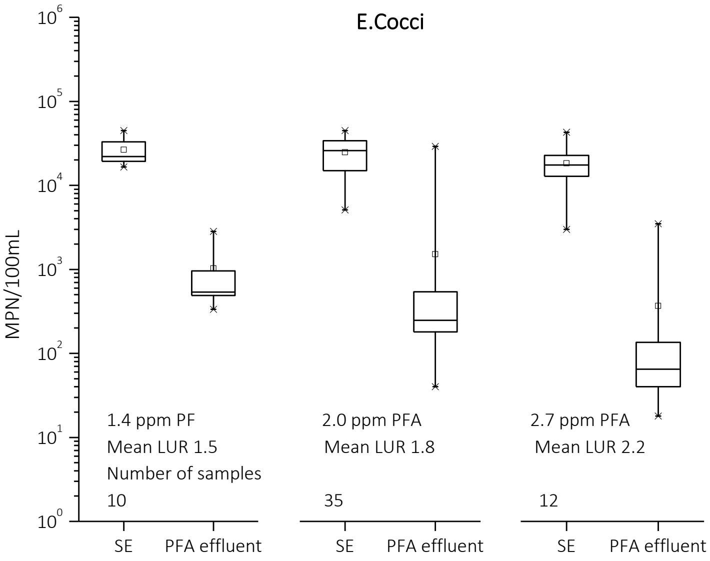

Figure 19 Disinfection results - E.Cocci – Performic acid (PFA)

Figure 20 and Figure 21 show the results for Clostridium Perfringens. The low LURs for both treatment technologies and all doses showed an overall high resilience of the indicator organism.

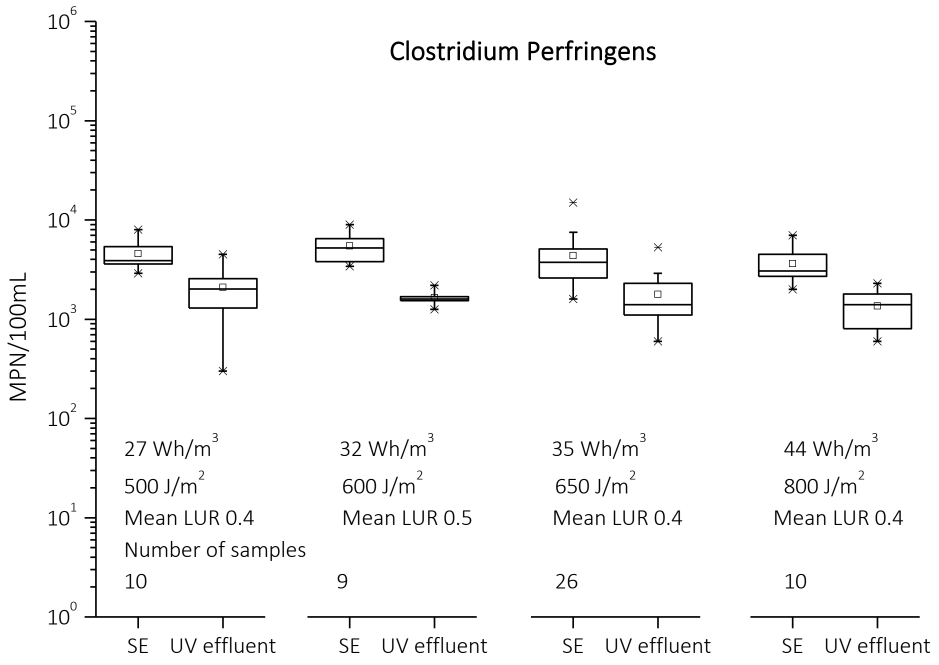

Figure 20 **Disinfection results - Clostridium Perfringens - UV radiation**

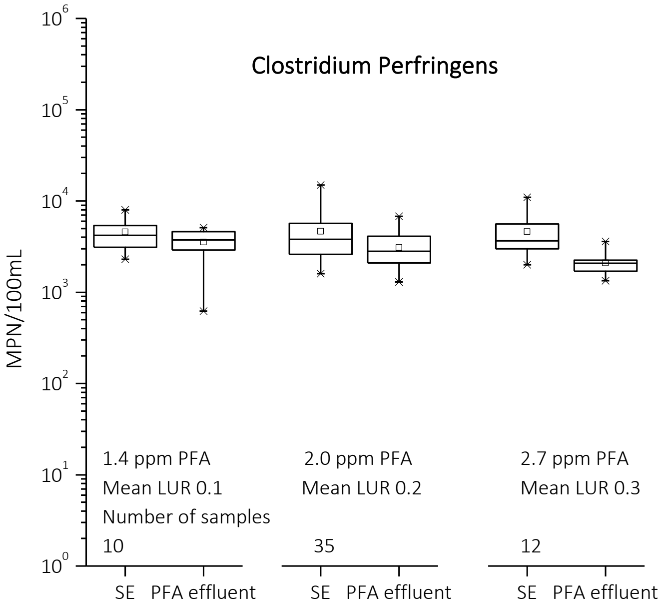

Figure 21 **Disinfection results - Clostridium Perfringens - Performic acid (PFA)**

Somatic Coliphages show a high sensitivity to UV radiation and the LUR applying 27 Wh/m^3 (500 J/m^2) was > 3. Increasing the specific energy consumption further led to LURs above 4.0. Only the LUR for the highest specific energy consumption decreased in comparison, which can be explained by the already high LURs. In this case the mean value is biased by the maximum value.

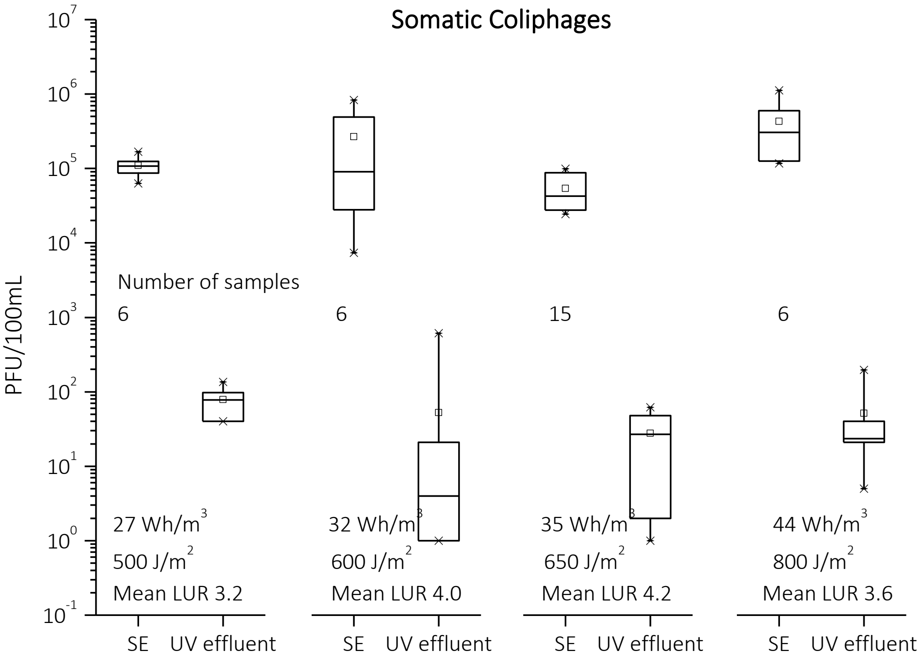

Figure 22 **Disinfection results - Somatic Coliphages - UV radiation**

As shown in Figure 23 PFA is effective against somatic coliphages. But increasing the dose from 1.4 to 2.7 g/m^3 does not increase the LUR to the same extent. In this case the indicator organism somatic coliphages does not show similar sensitivities for UV and PFA. Nonetheless, a LUR > 2.0 can be satisfying for water reuse applications where partial disinfection is sufficient.

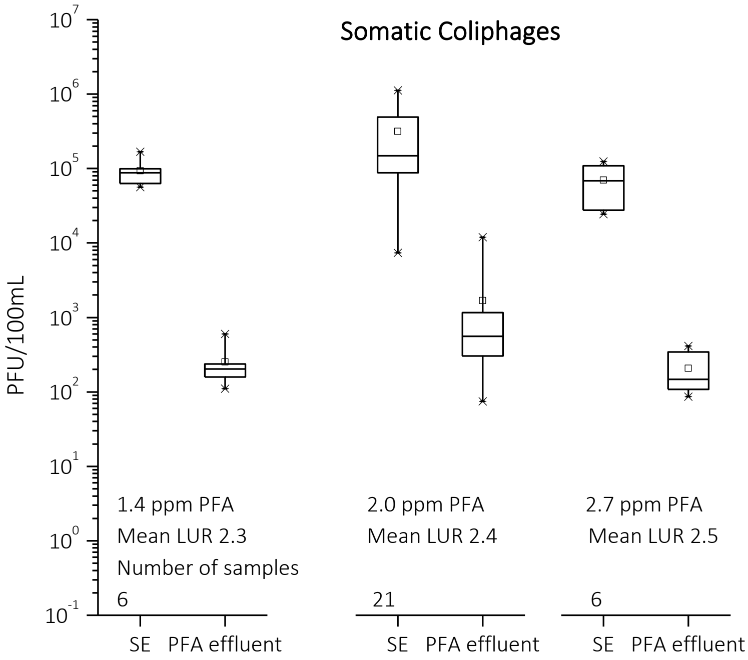

Figure 23 Disinfection results - Somatic Coliphages - Performic acid (PFA)

6.1.3 Retention time PFA reactor

A minimum retention time of 10 min is recommended for the PFA reaction by the manufacturer. Therefore a contact tank with 20 m^3 was installed for piloting. A plug flow contact basin is the ideal reactor for chemical disinfection technologies, neglecting the possibility of short cuts leading to poor disinfection results. Since for piloting the construction of such a contact basin was too cost intensive and due to limiting space, a lying tank was set up. The design with a length to height ratio of 2.5 was considered to result in mostly plug flow-like conditions. As this tank was manufactured for different purposes, the inlet as well as the outlet were on the bottom. Even though the piping was designed in order to maintain and control the water level in the tank, thus the theoretical reaction volume, the position of the connections would have led to a constant short circuit. Therefore a mixer was installed in the middle of the tank, aiming at increasing the mean retention time. The mixer was more effective than expected and tracer tests were performed implying a minimum retention of 3.4 min and long tail indicating higher retention times.

In order to evaluate the impact of the comparatively short reaction time, sampling was performed without quenching reactant (Sodiumthiosulfate STS) in the sampling bottles. Considering the time for storage and transportation to the laboratory (3-7 h), a complete reaction can be assumed representing an ideal designed reaction basin. Additionally samples with the quenching reactant were taken in parallel enabling a direct comparison. Figure 24 shows the mean removal results for E. coli, E.Cocci and Clostridium Perfringens with and without quenching. The results prove that the previously presented results underestimate the disinfection performance for the PFA. Table 16 compares the median LURs with and without quenching.

Bearing this in mind, the recommendation dose of 2.0 g/m^3 for WWTP Brunswick can be considered sufficient. The impact of the dose on the economic evaluation will be discussed in Section 8 where different dosage and energy costs are evaluated.

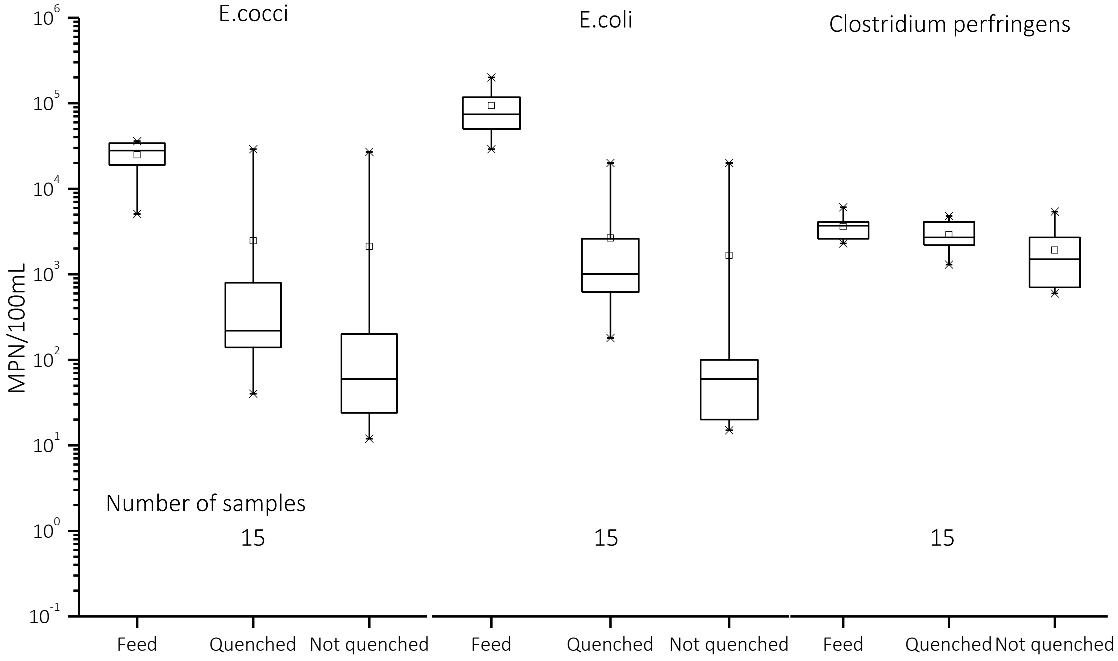

Figure 24 Comparison results for 2 g/m^3 PFA - with and without quenching

Due to the maximum value obtained during this measurement campaign, the mean values for all three indicator organisms lie in the same range. Nonetheless, the median is clearly lower for samples not quenched for E. coli and E.Cocci. This backs the assumptions that the reaction was not completely ended. The maximum values show outliers for the PFA, which could not be explained during evaluation of the trials.

Table 16 Comparison of median LURs with and without quenching

	E. coli	E.Cocci	Clostridium Perfringens
With quenching	1.95	2.02	0.08
Without quenching	3.06	2.62	0.46

6.1.4 Sludge run off incident

Malfunctions in the upstream operation may lead to a significant impact of the water quality for short periods of time and the capability of the disinfections step to handle this can help in the decision which technology should be installed. During the pilot scale trials at WWTP Brunswick, an incident of sludge run-off took place, see section 3.1.1. The impact on the microbiological indicators is shown in Figure 25.

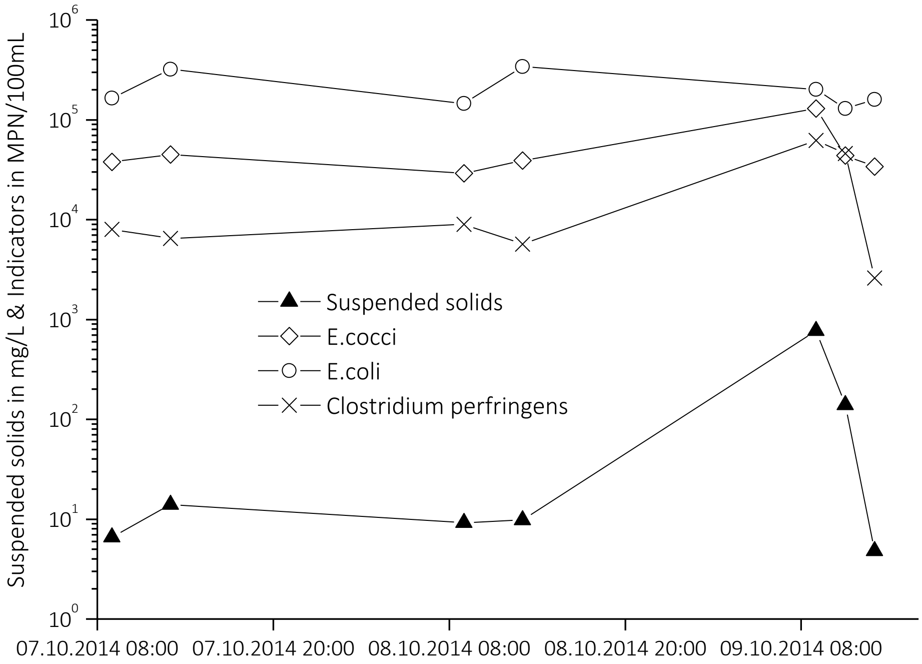

Figure 25 Indicator organisms and suspended solids during sludge run-off - secondary effluent - PFA 2 g/m³, UV 32 Wh/m³ (600 J/m²)

While E. coli concentration can be correlated with suspended solids, the impact on E.Cocci and Clostridium Perfringens is not obvious. Correlating the log unit removal of both disinfection technologies it is shown that the removals of E. coli and E.Cocci are highly dependent on the concentration of suspended solids, whereas the removal of Clostridium Perfringens shows no direct correlation. Due to the fact that the LUR for both technologies are not remarkably high even with low suspended solids concentration, an impact cannot be observed with three sample values.

The rising LUR for both technologies with the suspended solids decrease, shows the capability of both systems to recover automatically. The systems react almost with the same speed to the alteration of this water quality parameter.

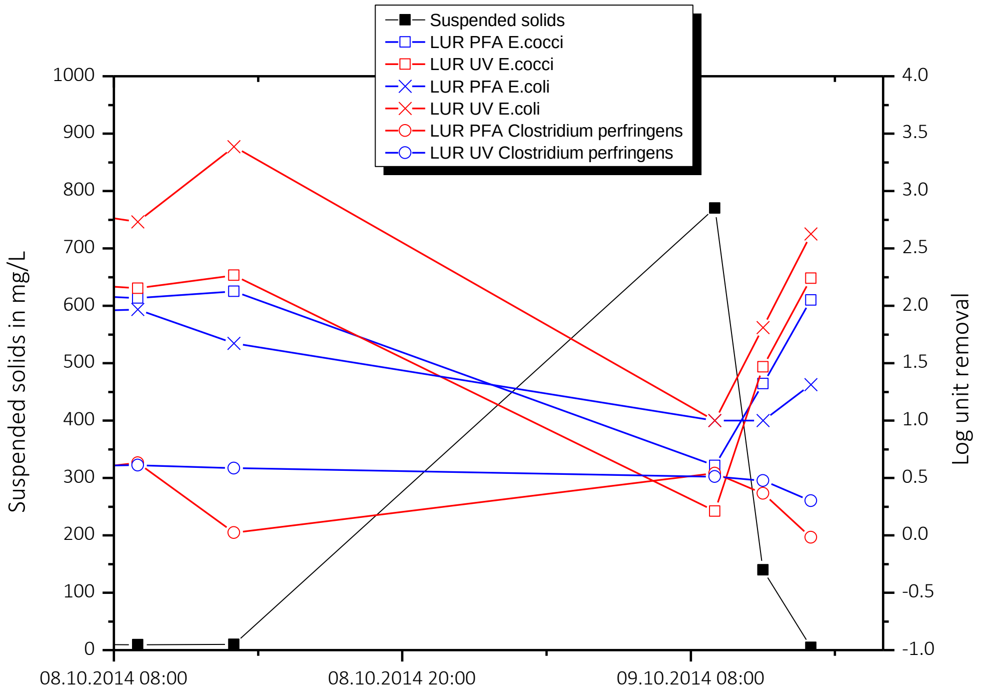

Figure 26 Suspended solids and LUR for PFA and UV during sludge run-off

6.1.5 Summary Pilot trials WWTP Brunswick

After piloting for three months testing four different microbiologic parameters with 3 – 4, doses the disinfection performance for UV radiation and performic acid can be compared for WWTP Brunswick. Considering the impact of the retention time for the reaction with performic acid, 2 g/m^3 PFA and 35 Wh/m^3 is the recommendation in order to increase the water class from 3 to 2, according to DIN 19650. The correspondent LURs are given in Table 17. These dosages proved to be sufficient as mean/median values, but run-away values, caused by sludge run-off, lead to high values and based on the grab sample value the disinfection result is not appropriate. Therefore it has to be kept in mind, that different the regulations might require different sampling procedures and different quantification of limit values. E.g. either median values or 90 % of all measured values.

Table 17 Comparison disinfection results Brunswick – Mean LURs

Parameter	UV 27 Wh/m^3 500 J/m^2	UV 32 Wh/m^3 600 J/m^2	UV 35 Wh/m^3 650 J/m^2	UV 44 Wh/m^3 800 J/m^2	PFA 1.4 g/m^3	PFA 2.0 g/m^3	PFA 2.0 g/m^3 Without quenching (median)	PFA 2.7 g/m^3
E coli	2.7	2.9	**3.2**	3.7	1.6	1.9	**3.1**	2.4
E. cocci	1.8	2.1	**2.3**	2.7	1.5	1.8	**2.6**	2.2
Clostridium Perfringens	0.4	0.5	**0.4**	0.4	0.1	0.2	**0.5**	0.3
Somatic coliphages	3.2	4.0	**4.2**	3.6	2.3	2.4		2.5

6.2 El Port de la Selva

6.2.1 Set up tertiary treatment system

At WWTP El Port de la Selva, a running disinfection unit is operated downstream a dual media filter. The final step of the disinfection system combines UV radiation and chlorination with sodium-hypochlorite in order to stop re-contamination of the distribution system. Figure 27 shows a flow scheme of the disinfection step at WWTP El Port de la Selva.

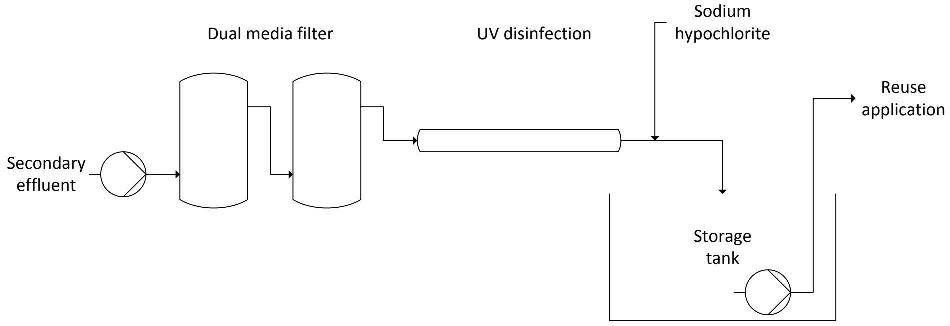

Figure 27 Tertiary treatment including disinfection by UV and Sodium-hypochlorite at WWTP El Port de la Selva

The UV system was designed for a dose of approximately 400 J/m^2 considering a transmission of 40 %. As seen in chapter 3.1.2 the median transmission is 71 % and therefore the actual dose is higher. A very rough estimation based on simple calculation tools provided by UV manufacturer results in a dose of 800-820 J/m^2 considering a transmission of 70 %. This figure is only an estimation and the actual dose has to be determined on-site with further testing.

Subsequently, 10 – 12 mg/L of sodium hypochlorite (15 % dosing solution) are dosed.

6.2.2 Disinfection results

Operation of the UV disinfection was unstable and UV effluent concentrations as high as 12,000 MPN/100mL were detected. This could be explained by a run-out of the UV lamps and therefore the operators changed the lamps in March 2014. The data on the disinfection results are divided into these two periods.

In Figure 28, the values for E.coli are given after the secondary settler, after the UV system and after chlorination. Samples with no detectable concentration of E. coli were set to 1 cfu/100 mL for further evaluation and calculations. After installation of the new UV lamps the median concentration of E.coli is as low as 1 cfu/100 mL and the disinfection efficiency are higher compared to the period before. Due to the fact that the tertiary treatment system shall feed into an infiltration pond, a concentration below 1,000 E. coli per 100 mL must be reached according to the Spanish reuse regulation (RD-1620 2007). This requirement is not always met, 4 out of 42 samples exceeded 1,000 E.coli/100mL. In order to assure the limit of 1,000 E.coli/100mL, it is recommended to reduce the flow into the UV system when infiltration is operated.

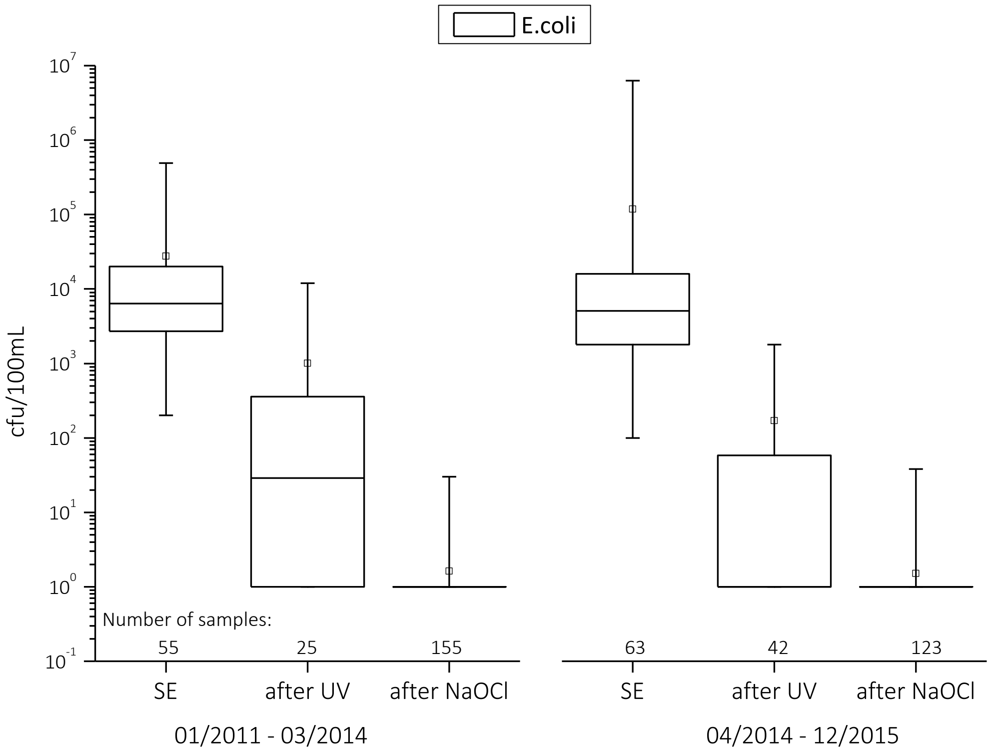

Figure 28 E. coli - secondary effluent - UV effluent – after NaOCl - WWTP El Port de la Selva

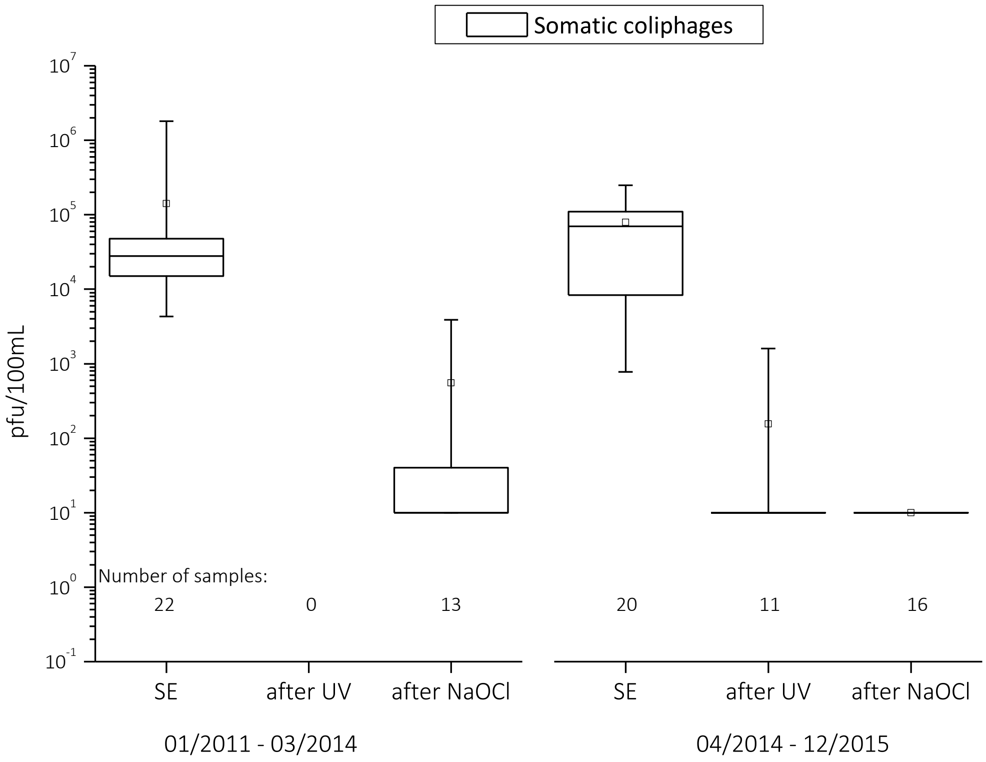

Figure 29 Somatic coliphages - secondary effluent - UV effluent – after NaOCl - WWTP El Port de la Selva

The detection limit for somatic coliphages is 10 pfu/100mL and this value is used when no organisms could be detected for further calculations. The new UV lamps increased the removal efficiency and after UV radiation the concentration was except one outlier (1,600 pfu/100 mL) below detection limit, see Figure 29.

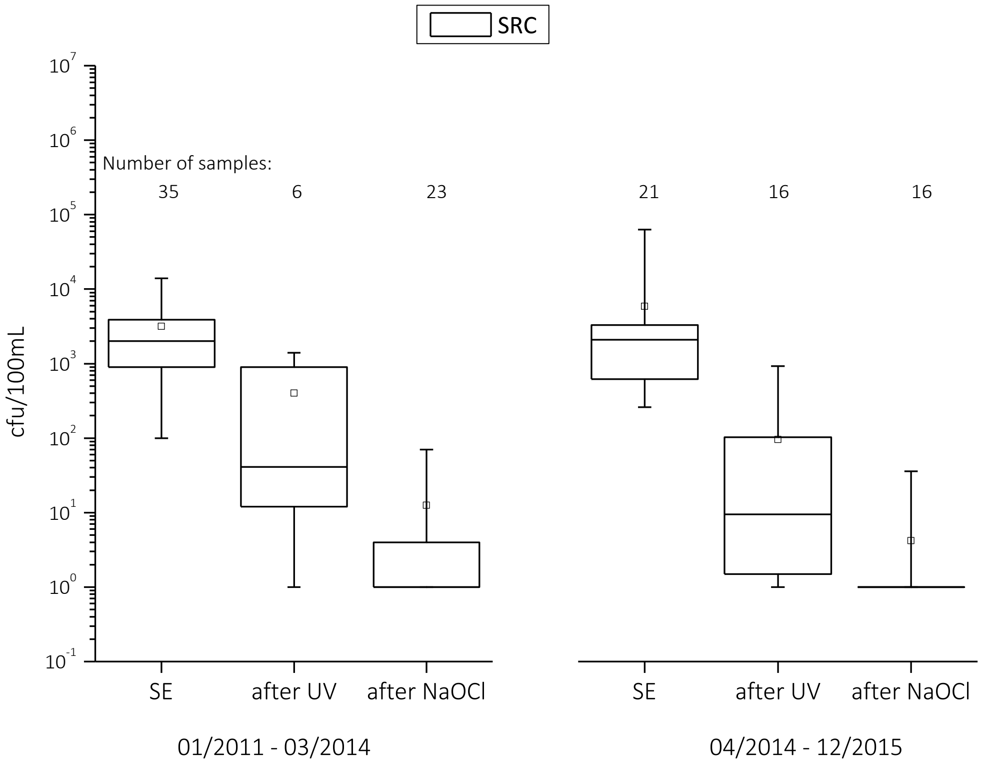

Figure 30 **Sulphite-reducing clostridia - secondary effluent - UV effluent – after NaOCl - WWTP El Port de la Selva**

The results for sulphite-reducing clostridia are shown in Figure 30. For SRC a removal can be seen for each disinfection step and after NaOCl more than 50 % of samples the detection limit.

6.3 Ozonation pilot trials

Within the research projects ASKURIS (2015) and IST4R (2015) ozonation of secondary effluent of two municipal WWTPs was carried out at pilot scale. Besides the main focus on trace organics, disinfection through ozonation was studied. In addition the costs were calculated for a WWTP treating 132,000 m3/d, see section 8.2.

6.3.1 Set up pilot plants

Figure 31 shows the flow diagram of the used ozonation units. A counter stream bubble column was used for the trials in the frame of Askuris (picture on the left A)), whereas a venturi cone introducing the ozone into a side stream was used within the research project IST4R.

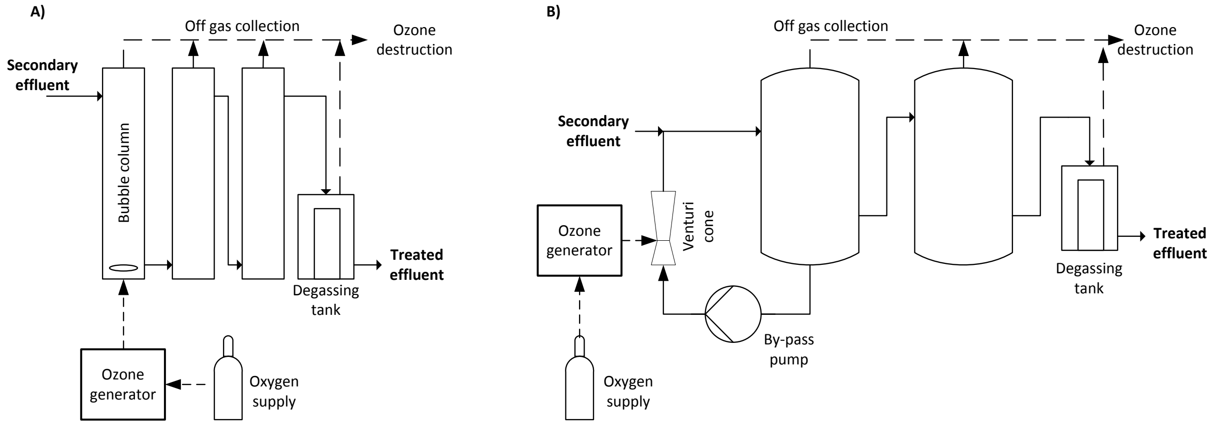

Figure 31 Ozone contactors - A) Bubble column as used in ASKURIS - B) By-pass system with venturi cone as used in IST4R

The DOC specific ozone dosage E is used for evaluation and this value allows a comparison between different installations treating waters with varying water qualities. To be able to calculate the transferred amount of ozone precisely, an off gas measurement is necessary. The following equation applies here:

$$d = \left(c_{O_3,\ in} - c_{O_3,\,out}\right) * \frac{\dot{V}_{Gas}}{\dot{V}_{H_2O}}$$

Division of d by the the DOC concentration in the water gives the specific dose E_{DOC}. When nitrite is present the dose can be corrected with regards to the ozone consumed by nitrite, see section 6.3.2. This value is given as $E_{DOC,\,corr}$.

6.3.2 Results

As mentioned in section 5.1.3, nitrite has to be taken into account, because the additional ozone consumption by nitrite (3.43 mg O_3/mg N) reduces the amount of ozone which is available for disinfection. Jekel et al. (2015a) showed that the disinfection efficiency decreases, if nitrite is spiked into the influent of the ozonation to simulate concentrations of up to 1 mg N/L. Without consideration of nitrite, a range of about 2 log in E. coli reduction can be seen at an applied ozone dose of 0.6 mg O_3/mg DOC. If the applied ozone dose is corrected for the ozone consumption of nitrite, a correlation of the E. coli reduction with an increasing applied ozone dose appears (Figure 32). In order to achieve a more stable disinfection, the applied ozone dose has to be adapted to the varying water quality at the secondary effluent. A possible process control for the operation of the ozonation can be an open-loop process control based on the online measurement of DOC and nitrite at the influent of the ozonation. Another option could be a closed-loop process control based on the reduction of the UV absorbance at 254 nm due to the ozonation, which was primarily used at an ozonation stage to eliminate trace organic contaminants (Stapf & Miehe 2015). An advantage of such a closed-loop process control is the indirect consideration of ozone consuming substances like nitrite.

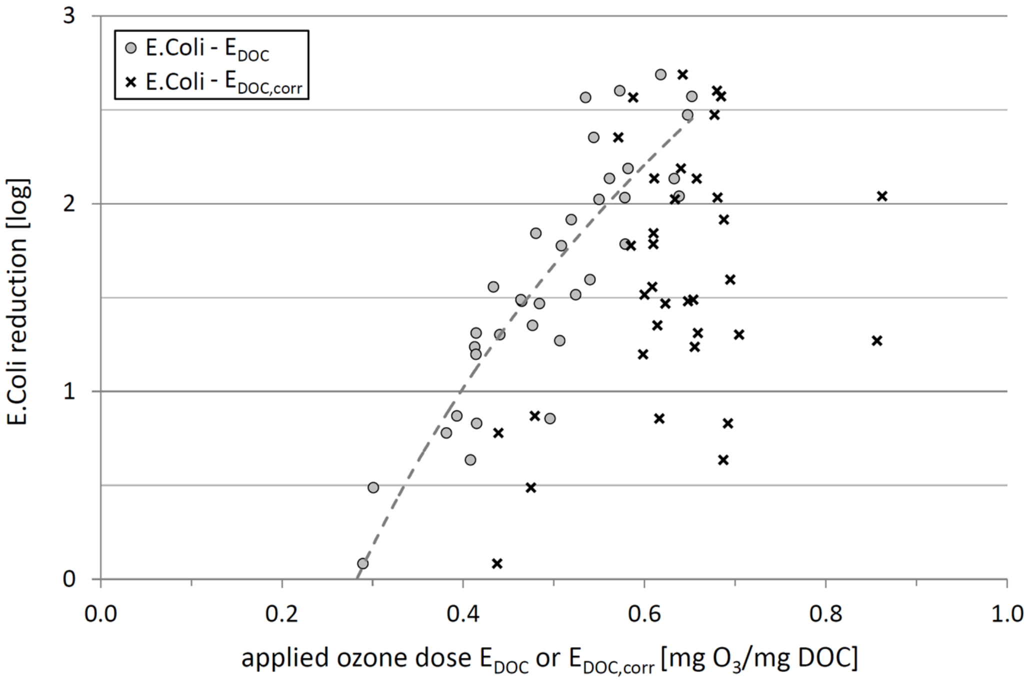

Figure 32 **Log reduction of E. coli due to ozonation of a secondary effluent at pilot scale versus DOC specific ozone dose with (grey points) and without (black cross) consideration of the additional ozone consumption by nitrite. Adapted from (Jekel et al. 2015a), mean DOC concentration was 12.9 mg/L.**

Achieved reductions of E. coli and *E. cocci* due to ozonation by pilot plants at two different municipal wastewater treatment plants in Berlin (Germany) are shown in Figure 33 (Jekel et al. 2015a; Jekel et al. 2015b). At a median of E. coli at the secondary effluent of $3*10^4$ MPN/100 ml and $5*10^3$ MPN/100 ml for *E. cocci*, respectively, reductions of 2 to 3 log could be achieved for both parameters with applied ozone doses >0.6 mg O_3/mg DOC. A further reduction of up to 1-log can be achieved with a post filtration like coagulation and dual media filtration which is used for phosphorous removal (Jekel et al. 2015a).

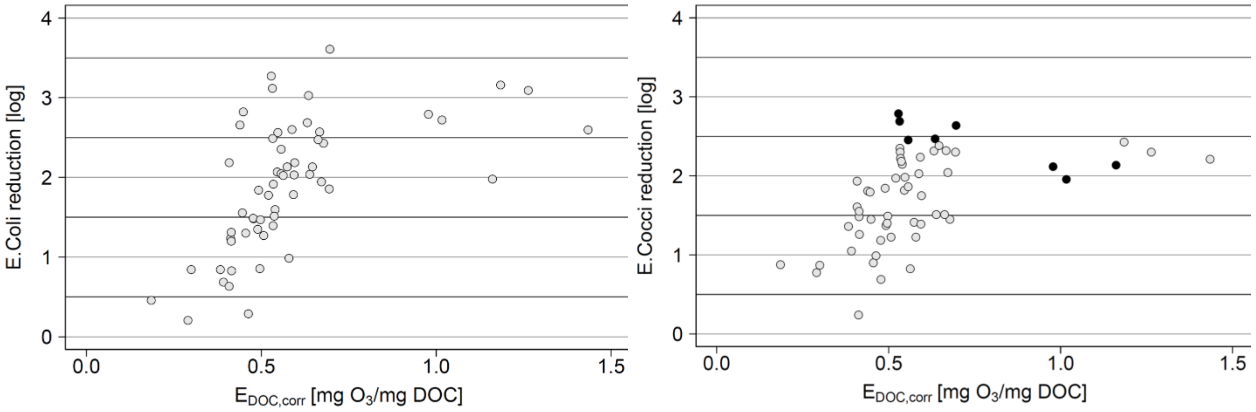

Figure 33 **Reduction of** E. coli **(left) and *E. cocci* (right) due to ozonation of a secondary effluent of a municipal wastewater treatment plant.**

Black points indicate that *E. cocci* concentrations at the ozonation effluent were below the LOQ of 15 or 38 MPN/100 ml.

7 Design guidelines partial disinfection

The previous chapters give an overview of possible technologies as well as results of pilot/full scale trials. The experience gained during these trials and the guidelines published internationally are used to give recommendations in the following sections.

Disinfection of treated wastewater is usually done in separate reactors or departments, (Asano et al. 2007; Tchobanoglous et al. 2014). For the chemical disinfection technologies, a complete mixing into the water stream is required. Afterwards a plug-flow is the ideal condition to maintain the retention time without any short circuits, which would lead to a reduction of disinfection efficiency. Long pipelines or serpentine reactors with submerged baffles serve this goal, see 7.1 & 7.2.

Ozone can be introduced in the water stream by either using a diffuser installed in a counter current set-up or by using a by-pass system where a part of the water stream is oversaturated with ozone using a venture-injector, see 7.3.

UV disinfection can be either designed as open channel reactors or as closed in-line reactors. Special care on the hydraulic design of open channel rectors is necessary because the retention time is comparably low, therefore the hydraulic design needs to assure a sufficient distribution of the UV radiation. Closed in-line reactors are designed for a specific flow range, within this range the UV distribution is thought to be sufficient, see 7.4.

Table 18 shows key parameters for technologies suitable for partial disinfection. The costs given shall help as a rough guidance, because the costs depend strongly on local conditions and the economic evaluation needs to be done for each case. Cost estimation for the case of Brunswick using the net present value is included in chapter 8.

Table 18 Comparison of technologies suitable for partial disinfection, adapted in part from Asano et al. (2007), Tchobanoglous et al. (2014), and Crittenden et al. (2012)

	Chlorination	Performic acid	Ozone	Ultraviolet radiation
Mechanism	Chemical	Chemical	Chemical	Physical
By-products	Chlorine gas and sodium hypochlorite: • Trihalomethanes (THM) • Haloacetic acids (HAA) Chlorine dioxide: • Chlorite • Chlorate	None known in measureable concentrations	Bromate	None known in measurable concentrations
Safety concern	Depending on agent: • Sodium hypochlorite: Moderate to low • Chlorine gas: High • Chlorine dioxide: High	Moderate	Moderate	Low
	Costs			
Capital	Low	Low	High	High
Operation	Moderate	High	Moderate	Moderate

7.1 Chlorination and disinfection with chlorine dioxide

Chlorination is worldwide applied for disinfection tasks and the effectiveness and availability made it the most common technology. With respect to the high potential to form harmful disinfection by-products (DBPs) as well as safety considerations, alternatives become more and more important (Whitby & Scheible 2004). Nonetheless, for partial disinfection application it is still an option, because the processes involved are well known and online measurement devices help to make this process safer and reliable.

7.1.1 Reactor design

A complete mixing of the disinfection agent with the water to be treated is the first process step for chemical disinfection technologies. Creating high turbulences at the point of dosing is necessary to ensure a sufficient mixing. This can be done by static mixers, in-line mixers, injector pumps, or using a bypass with an extra pump introduces a stream with high velocities at the point of dosing. Further examples are given in (Asano et al. 2007; Tchobanoglous et al. 2014). In Figure 34 this step is termed “mixing device”.

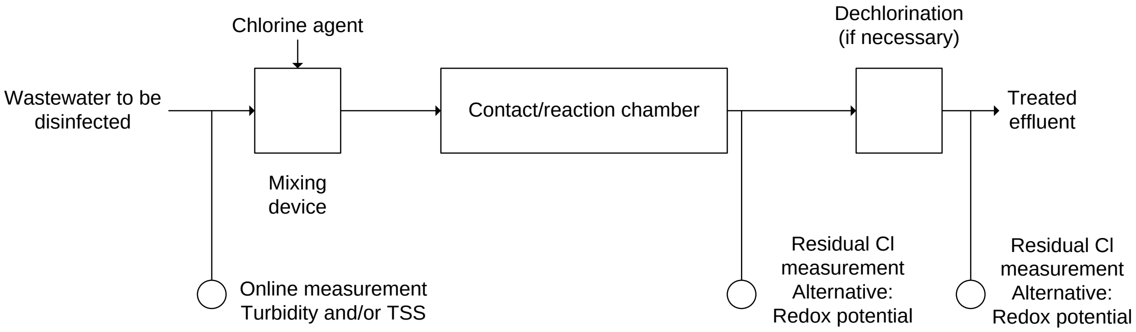

Figure 34 Process flow sheet - chlorination

One cannot over emphasize the importance to minimize short circuits for chlorination processes (and for disinfection processes in general). So the reaction chamber has to be designed accordingly. Figure 35 shows examples for contact basins which were installed assuring a close to plug-flow operation. These and further examples are given by Asano et al. (2007).

Figure 35 Examples for chlorine contacts basins: left serpentine plug-flow basin, right with rounded corners; adapted from Asano et al. (2007) – Design can be adapted for PFA contact basins

Where necessary a dechlorination step is included to avoid discharge of toxic substances and odour issues. Dechlorination agents serve as reducing compounds and sulfur-dioxide (SO_2) is most commonly used. Other agents are sodium bisulfite ($NaHSO_3$), sodium sulphite (Na_2SO_3), sodium metasulfite ($Na_2S_2O_2$), and sodium thiosulfate ($Na_2S_2O_3$). An alternative to these agents is the adsorption to activated carbon and subsequent reaction to harmless compounds.

7.1.2 Control strategy

With reliable online-measurement techniques, chlorination for water reuse can be designed with a permanent detection of malfunctions and correspondent actions can be implemented in the control system. The previously presented sludge run-off incident (see section 6.1.4) can be detected by a TSS or turbidity measurement in the inlet of the system. Together with the back-loop control cycle using the residual Cl concentration, a control scheme can be designed minimizing the chance for undetected failure and usage of insufficiently disinfected water.

For chlorination processes residual Cl measurement is implemented in order to control the free and combined residual chlorine. Depending on the circumstances, a certain concentration is targeted in order to protect the distribution network from regrowth and contamination.

Figure 34 shows a basic process flow sheet for a chlorination process and where it is recommended to install online measurement techniques.

7.2 Performic acid

As discussed before, PFA processes were developed recently and only few full scale installations are running. Due to the similar constraints for mixing and reactor design as chlorine, the experiences gained over the last decades operating and optimizing chlorine installations can be used for PFA reactors, see Figure 35.

TSS and turbidity online measurement techniques should be used in the inlet of the PFA disinfection step to enhance process reliability. These measurements are often already implemented at WWTPs effluents or can be easily installed, and can therefore be used to determine whether the water can be disinfected with PFA or not.

Implementation of a reliable online detection of micro-organisms will help to optimize the PFA dosage, and thus will significantly reduce the operating costs. Direct measurement of PFA in the effluent would be another way to minimize operating costs, but up to now this kind of online analysis is not available.

7.3 Ozone

7.3.1 Reactor design

Ozone is introduced either by by-pass systems or by counter current bubble columns. Figure 36 shows the scheme of a four compartment contact chamber (Asano et al. 2007). On the right, hand side an ozone contactor for the treatment of up to 10 m^3/h is shown (Stüber & Godehardt 2013). The first column is the bubble column, where ozone rich gas is introduced at the bottom with a plate diffuser, followed by contact chambers for reaction.

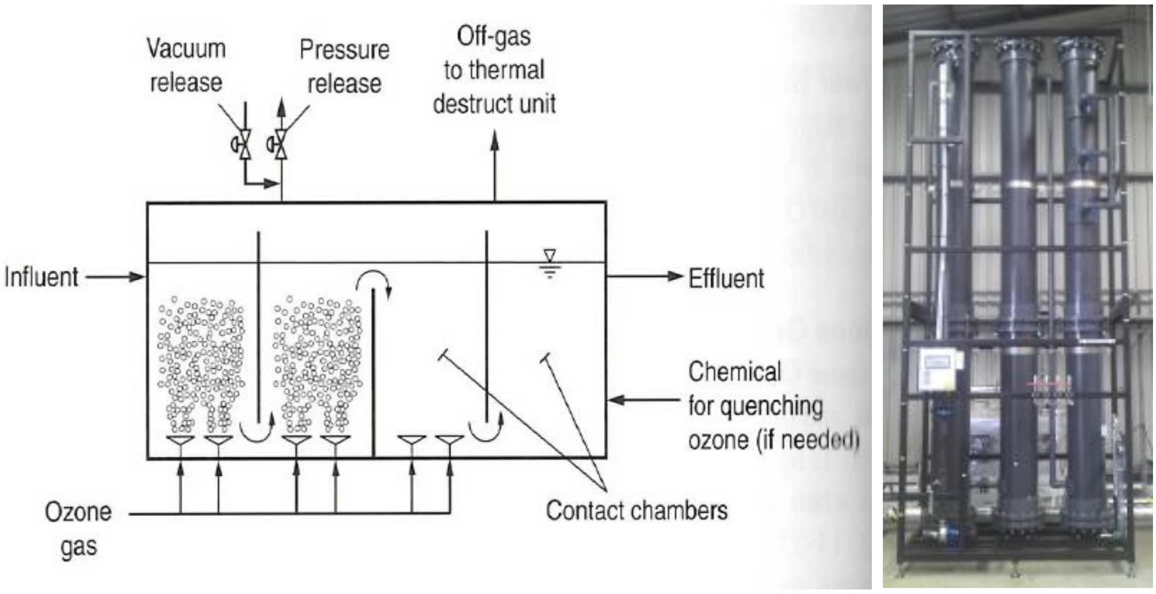

Figure 36 Left: Scheme of a four compartment ozone contactor (adapted from Asano et al. (2007)); right: Ozone contactor designed for up to 10 m^3/h (Stüber & Godehardt 2013)

Figure 37 shows the process flow sheet for the ozone contactor displayed in Figure 36. The shown measurement devices indicate the high automation and control possibilities.

7.3.2 Control strategy

As discussed before, dissolved parameters, e.g. DOC, NOM or nitrite, play an important role for the ozone depletion and online monitoring tools for these parameters are recommended to be used for the control scheme.

To evaluate the transferred ozone online measurements of the product gas concentration as well as the off-gas concentration are necessary. This way, malfunctions in the mass transport (e.g. blockage of the diffuser and too larges bubbles) are instantly recognized and maintenance can be planned.

Measuring the influent DOC helps to maintain a DOC specific dose in order to operate the ozonation in a cost efficient way. Since nitrite (NO_2^-) leads to an increased demand of ozone and peaks of NO_2^- may appear at WWTPs effluents, it is recommended to install a nitrite (NO_2^-) probe in the feed of the ozonation unit.

A control scheme using the difference of inlet and outlet UV absorption at 254 nm is currently developed for trace organic removal (Gerrity et al. 2012; Stapf & Miehe 2015). The difference in UV absorption between the inlet and outlet of the ozone contactor directly shows the effectiveness of the treatment. The impact of water constituents which increase the ozone demand, such as NO_2^-, is directly acounted for by this control scheme. Figure 37 shows a flow diagram of an ozone contactor and the recommended online measurement techniques. The need of a sophisticated control concept also shows a cost driver for ozonation plants, because online measurements devices are high in investment costs as well require trained personnel for regular maintenance.

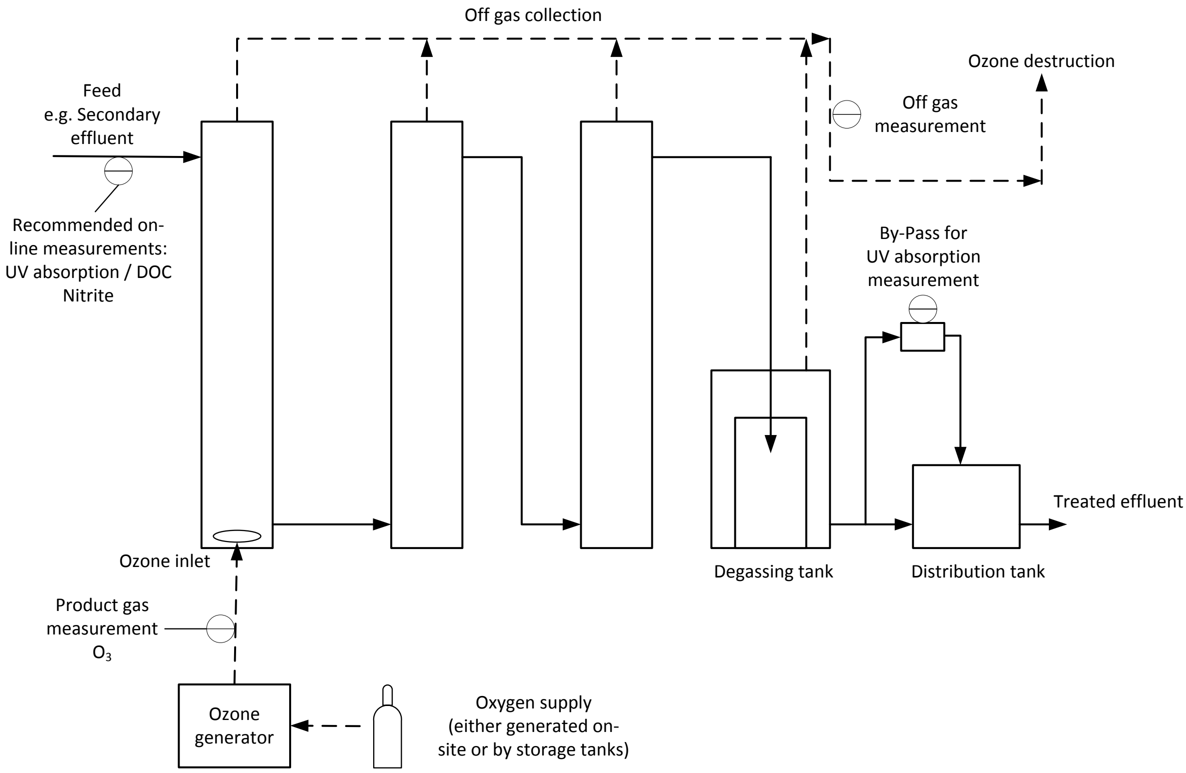

Figure 37 **Scheme of ozonation contactor**

7.4 UV Disinfection

According to Whitby & Scheible (2004) UV installations gained more attention lately due to safety consideration and by-products formation connected with chlorination.

The two key water quality issues that can impact UV disinfection performance and efficiency are the presence of particle-associated microorganisms and the UV transmittance (UVT) of the wastewater (Mosher & Vartanian 2012). Thus, TSS/turbidity online detection as described for chlorination and PFA dosing should be installed at the inlet. Scaling propensities have a severe effect on the UV disinfection plant and the cleaning interval needs to be planned accordingly. As shown in the pilot testing, mechanical wiping helps to achieve the desired UV doses after a sludge run-off incident as quickly as the PFA installation, yet the long term effect should be monitored closely.

7.4.1 Reactor design

As mentioned above, the contact time (seconds) for UV disinfection plants is short compared to chemical disinfection technologies (10 – 30 minutes) therefore the hydraulic design is crucial. For large WWTPs, open channel systems are common and the contact basins should be designed with weirs for level control. This level control assures the maximum depth the UV light has to penetrate. In Figure 38 examples for open channel UV reactors are given (adapted from (Asano et al. 2007)). Access to the lamps for maintenance and replacement should be assured by design of crane lifters or similar tools.

Open channel reactors are often designed with 2 or 3 banks in serial. In order to assure an optimal hydraulic distribution and due to the required redundancy, the design flow rate is divided equally among a number of parallel channels (Asano et al. 2007).

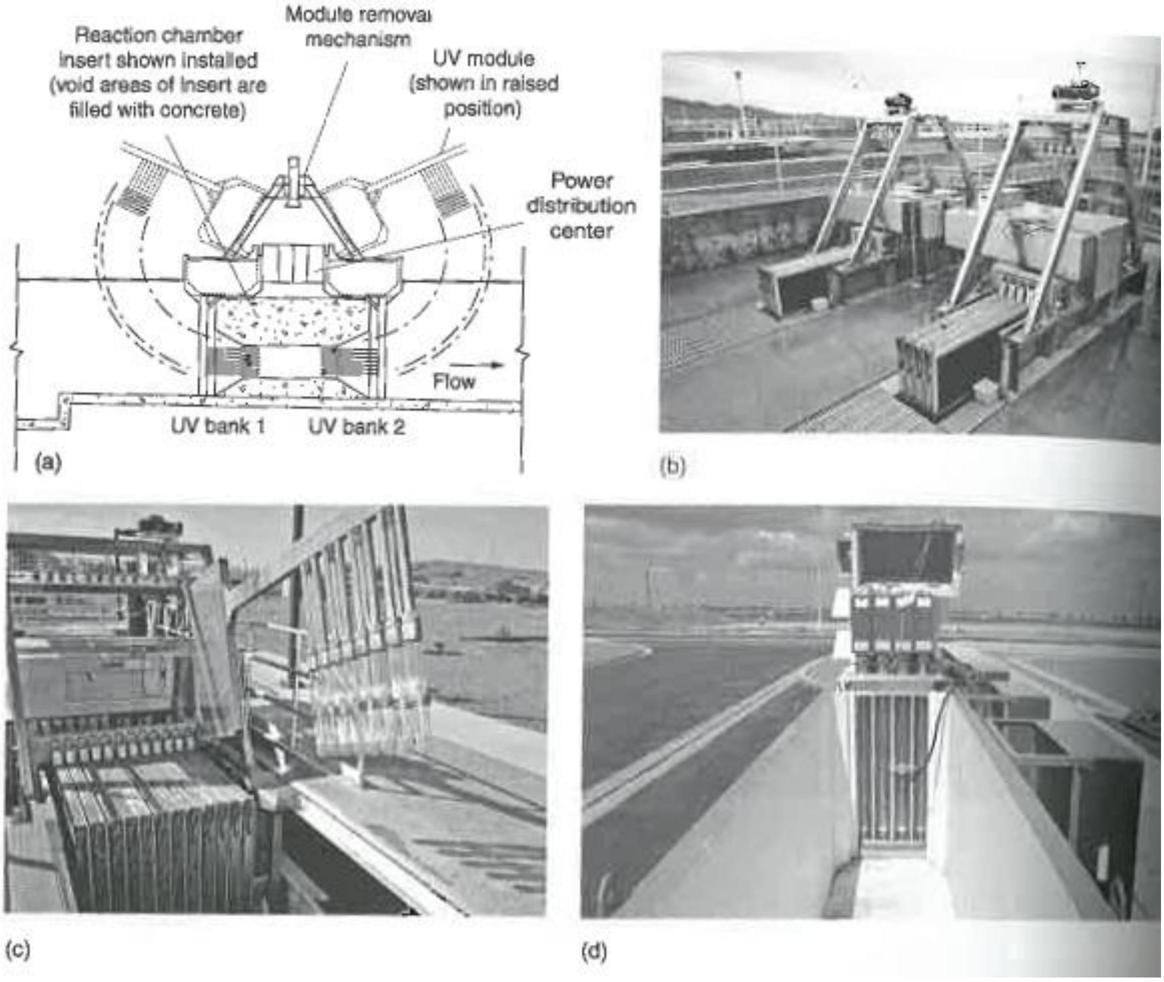

Figure 38 **Examples for open channel reactors adapted from Asano et al. (2007)**

Closed in-line reactors provide the advantage to be hydraulically designed by the manufacturer and the required flow regime in the reactor has been demonstrated during the development process. The UV installations presented in chapter 6 both are closed in-line reactors and short circuiting is not likely to happen when the flow constraints defined by the manufacturer are respected. With attention to the required flow, parallel installations treating a share of the design flow are often applied. The same constraints for a redundant set-up apply for closed-reactors as for open channels installations.

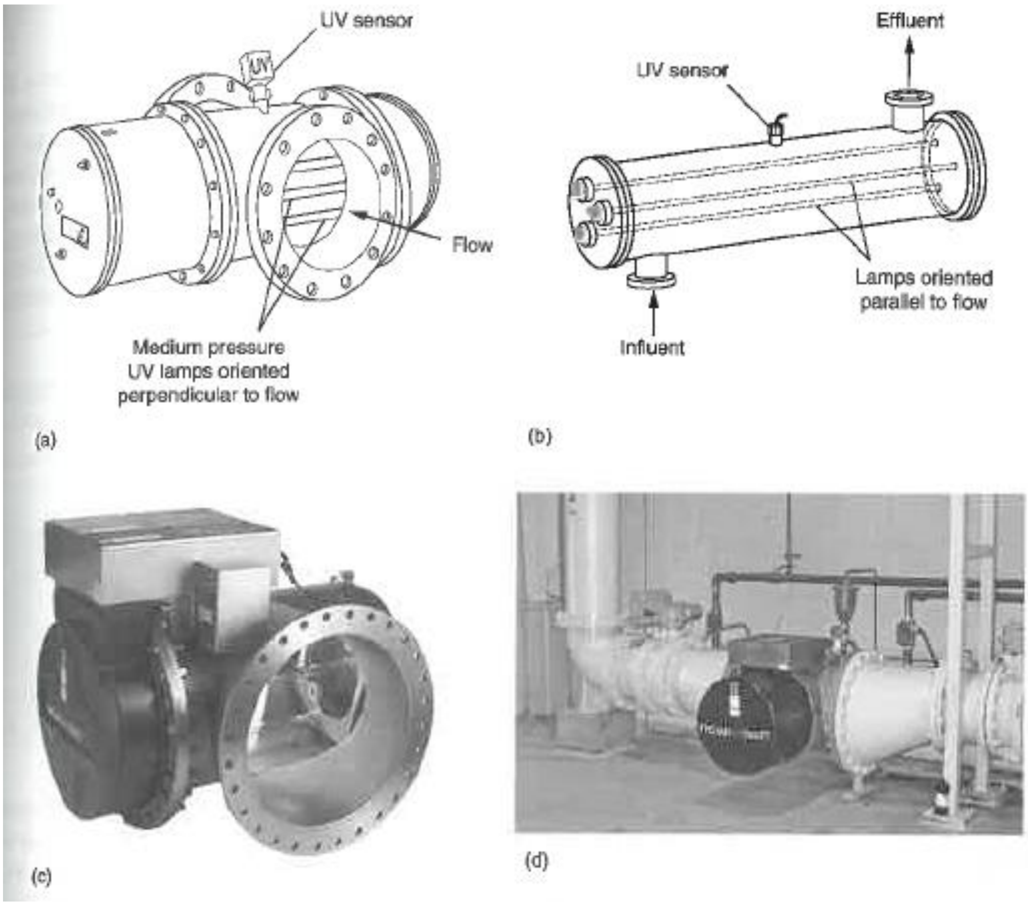

Figure 39 **Examples for closed in-line UV reactors adapted from Asano et al. (2007)**
a) schematic of close reactor with flow perpendicular to UV lamps b) schematic of close reactor with flow parallel to UV lamps
c) view through in-line UV reactor (Trojan Technologies) d) view of installed UV system

7.4.2 Control strategy

Closed UV reactors usually have a UV probe installed at the wall of the reactor and this value is used to maintain a minimum UV dose. This measurement serves as an alarm mechanism in order to detect lamp ageing or deposition on the glass sleeves. The effectiveness of the UV system can be significantly diminished by increased values of TSS and/or NTU, see section 6.1.4. Therefore TSS/NTU measurements are recommended in the inlet of the UV reactor. Measuring UV absorption at 254 nm at the inlet is another possibility to increase the reliability, when the flow can be adapted accordingly. Increasing absorption should be used to decrease the flow, which leads to a longer retention time inside the reactor. This should lead to a stable disinfection performance.

When treating wastewater with a high scaling propensity special care is required and the cleaning interval needs to be adapted. When regular chemical cleanings are required, an automated chemical cleaning system in addition to the wiping system reduces the personnel efforts. The used chemicals need to be handled according to their safety regulation.

7.5 Outlook control strategies

The development of on-line measurements detecting microbiological organisms (e.g. E. coli) or correspondent enzymatic activity showed major progress recently and cost efficient solutions are thought to be introduced in the coming years (Appels 2015; Ryzinska-Paier et al. 2014; Storey et al. 2011). When the robustness of these systems is proven and the costs can be reduced to an acceptable amount, these systems can help to gain higher reliability levels by minimizing the risk of using water exceeding the concentration limits. Maintenance intervals and precision of on-line analyses have to be tested on the specific site in order to estimate these expenditures precisely.

The implementation of these tools can be done for all disinfection technologies and a direct measurement of the indicator organisms on-line would significantly help to make the processes more reliable and reduce the costs.

8 Cost estimation

8.1 WWTP Brunswick

Within Demoware pilot scale investigations comparing one chemical and one physical disinfection technology were carried out for WWTP Brunswick. An economic evaluation with regards to the disinfection level and necessary reduction of indicator organisms is presented in the coming sections.

The net present value helps to compare different options considering investment, re-investment and operational costs over the expected lifetime and cost evolution. Since ClO_2 does not react with Ammonia this disinfection agent was chosen for this economic evaluation.

It has to be noted that chlorination is not discussed for wastewater disinfection in Germany due to the risk of AOX formation, so chlorination was not tested during the pilot scale trials.

Six set-ups are compared with changing assumptions for water flow, energy costs and chemical doses:

1.	Ultraviolet radiation as a single line	UV
2.	Ultraviolet radiation in a redundant set-up	UV (n+1)
3.	Performic acid as a single line	PFA
4.	Performic acid in a redundant set-up	PFA (n+1)
5.	Ultraviolet radiation and performic acid as a back-up	UV + PFA
6.	Disinfection with ClO_2 in a redundant set-up	ClO_2 (n+1)

The redundant set-up increases the safety and availability of the disinfection treatment, because all critical parts are installed twice. This means for the UV disinfection plant a second UV reactor is installed and ready to use. A second reactor for PFA production and a second reactor for ClO_2 production, respectively, are installed and integrated in the control system for the latter set-ups. This increases the investment costs to a great extent, but the operational cost only in minor parts, as only maintenance is affected by the second installation. Depending on the reuse application and the local regulations, a redundant set-up might be required to increase reliability requirements.

In order to reduce the increased investment costs for a UV system in a redundant set-up, a hybrid system with one UV reactor and one PFA reactor (UV + PFA) was included in the cost estimation. The major part (95 %) of the annual water treatment is done by the UV disinfection and only in cases of maintenance and uncontrolled stops of the UV system, the PFA system is activated (5 %). This way, a redundant disinfection treatment scheme can be installed with comparably low investment costs. Considering the operational constraints of such a system, e.g. training of personnel for both systems, the decision for such a hybrid system needs to be done carefully.

The following assumptions were chosen to start with the cost estimation and kept constant, whereas other factors are varied in order to show the sensibility of the disinfection step:

- Rate of interest (i): 3 %
- Planning costs 18 %
- Life time of construction: 30 years
- Lifetime of machinery: 12years
- Lifetime of electric equipment: 10 years
- Lifetime of UV lamps: 3 years
- Peak flow: 0.65 m^3/s
- Evaluation over 30 years (n)

Costs for UV radiation can be assumed to be strongly dependent on investment costs, whereas PFA and ClO_2 are affected by operational costs. These different dependencies can be best compared by calculating the net present value (NPV). The NPV gives the costs for an installation/process over the planned lifetime in relation to the year when the investment is done. It is a financial tool to compare different investment options. The NPV is calculated according to LAWA (2005) as follows:

The annual costs are the sum of operational costs and capital costs:

$$Annual\ costs\ (AC) = operational\ costs\ \left[\frac{Euro}{a}\right] + capital\ costs\ [\frac{Euro}{a}]$$

The operational costs are the yearly costs for energy, chemicals, labour, maintenance and spare parts, e.g. UV lamps. The capital costs are calculated using the depreciation factor (DEF) based on the interest rate and the economic lifetime:

$$Capital\ costs = \sum_i investment\ costs\ [Euro] * DEF_i[\frac{1}{a}]$$

$$DEF(i,n) = \frac{(1+i)^n - 1}{i * (1+i)^n}$$

The NPV is now identified by the sum of the investment costs and the annual costs multiplied with the discount factor (DF).

$$NPV = Investment\ costs + annual\ costs * DF(i,n)$$

Figure 40 shows the results for a total of 11 mio m^3 of water being disinfected per year. The recommended doses of 2 g/m^3 PFA, 35 Wh/m^3 UV and 2.0 g/m^3 ClO_2 were used for design and operational cost constraints. An energy price of 0.12 €/kWh has been given by WWTP Brunswick as the current energy price. WWTP Brunswick has a high production of biogas due to the co-fermentation of energy plants. Efficient heat-and-power stations help to reduce the energy costs.

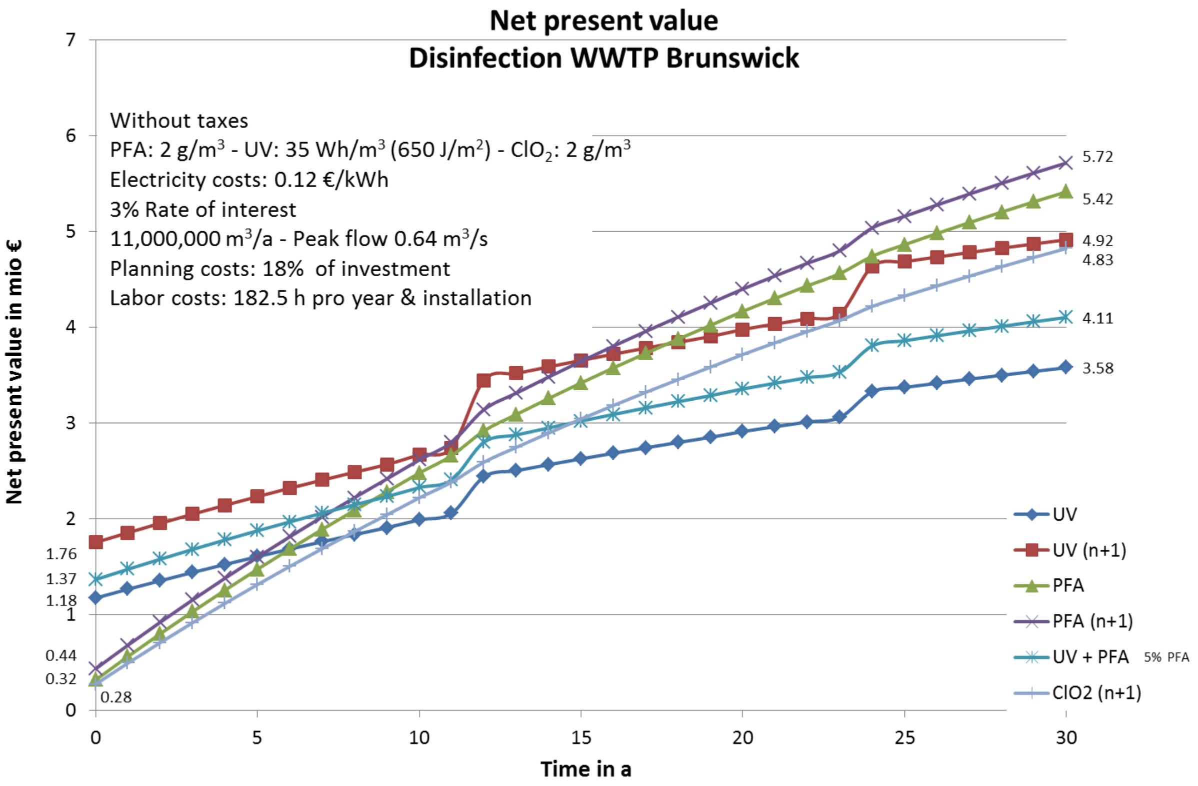

Figure 40 Net present value for different disinfection technologies at WWTP Steinhof – 11 mio. m³/a

The different nature of the disinfection technologies is shown by the intersection of the graphs. Even though 4 times higher investment costs are required for the UV (n+1) set up compared to PFA (n+1), after 16 years the lower operational costs pay off and the UV disinfection is favourable.

Dividing the specific costs into capital and operational costs, as shown in Figure 41, the costs driver behind each technology is further emphasized.

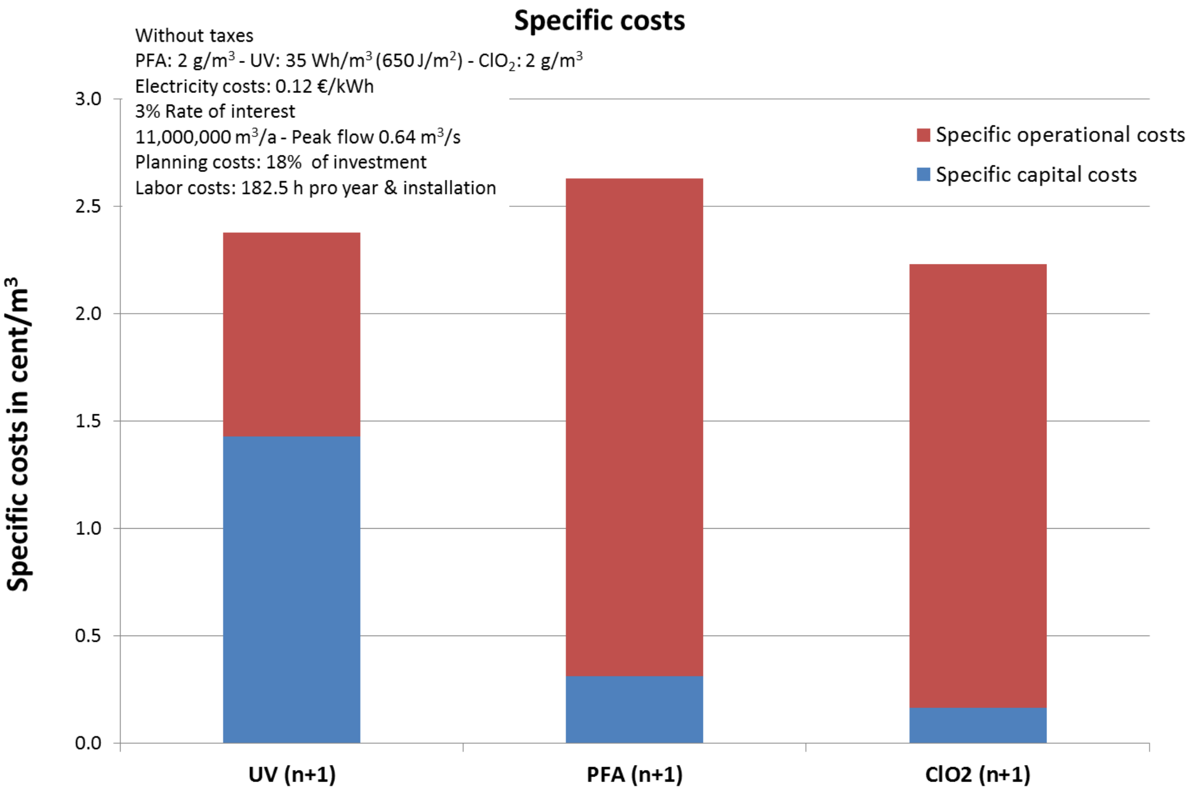

Figure 41 Specific capital and operational costs – Over 30 years treating 11 mio. m^3 per year

As shown before, UV disinfection requires high investment costs compared to the set-up of PFA and ClO_2 units. The electrical equipment differs significantly between UV installations and PFA/ClO_2, which is an explanation for the difference. Figure 41 emphasizes the dependency of the chemical disinfection technologies on the operational costs, which are mostly the chemical costs.

Table 19 Net present values over 30 years - sensitivity to dosage and energy costs

Conditions	UV (n+1)	PFA (n+1)	ClO_2 (n+1)
2 g/m^3 PFA, 35 Wh/m^3, 2 g/m^3 ClO_2 0.12 €/kWh	4.92 mio €	5.72 mio €	4.83 mio €
2 g/m^3 PFA, 35 Wh/m^3, 2 g/m^3 ClO_2 0.2 €/kWh	5.8 mio €	5.72[9] mio €	4.83 mio €
2.7 g/m^3, 47 Wh/m^3, 2.7 g/m^3 ClO_2 0.12 €/kWh	5.66 mio €	7.39 mio €	6.34 mio €

Over 30 years, a benefit of 1.6 mio € is accumulated comparing the redundant set ups, see Table 19. ClO_2 it is the most economical alternative with a net present value of 4.83 mio €, comparing the redundant set-ups only.

8.1.1 Disinfection based on crop demand

The previous calculation was based on the fact that all treated water has to be disinfected, which accumulates to 11 mio m^3 per year. Considering the crop demand of the irrigated fields with a yearly need of 120 mm/ha the total volume which needs to be disinfected declines to 3.6 mio m^3 per year. Calculating the net present value with these preconditions changes the evaluation.

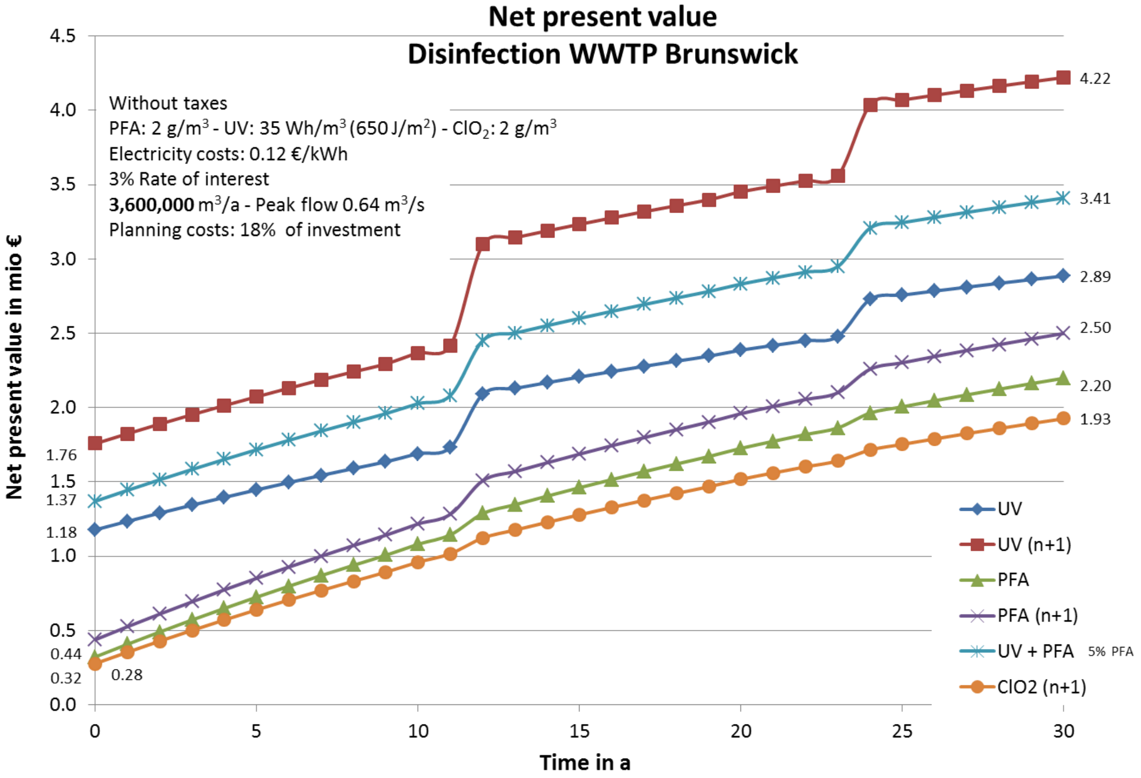

Figure 42 Net present value of different disinfection technologies at WWTP Steinhof - 3.6 mio. m³/a

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[9] Energy costs are assumed to be neglectable for PFA and ClO_2, because only little energy is required for the dosing pumps

Due to less water and therefore less chemicals required, the opex driven technologies are more favorable and lowest net present value is calculated for the chlorination step with 1.93 mio €, followed by PFA in the redundant setup, 2.5 mio €, and the highest net present value is given for the UV in a redundant design with 4.22 mio €. No trade-off can be defined as the curves do not intersect for these preconditions.

Considering the utilization of the installed capacity, the specific costs can be evaluated as shown in Figure 43. The assumptions for energy and chemical costs were taken as the first case: 2 g/m^3 PFA, 35 Wh/m^3 and 2.0 g/m^3 ClO_2. A utilization of 1.0 represents the maximum flow of 0.64 m^3/s throughout the year, coming to 20.1 mio m^3.

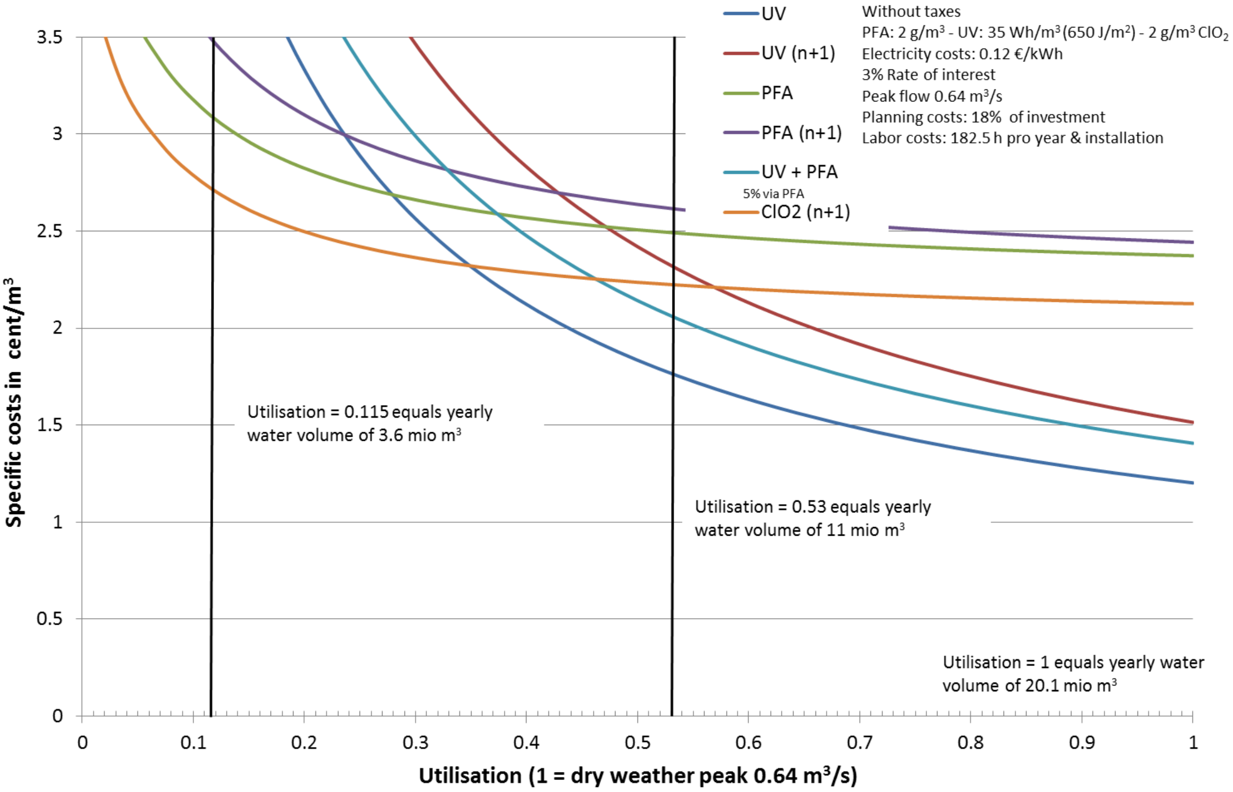

Figure 43 Specific costs according to utilisation of disinfection step

8.2 Ozonation

During the research project ASKURIS (Askuris 2015), (Jekel et al. 2015a)) the costs for an ozonation step at a WWTP treating 132,000 m^3/d were evaluated using the NPV as explained above. Following assumptions were used:

- Rate of interest (i): 3 %
- Life time of construction: 30 years
- Lifetime of machinery: 15years
- Lifetime of electric equipment: 10 years
- Peak flow: 2.3 m^3/s (= dry weather peak)
- Energy costs: 0.15 €/kWh (different energy price given by operator)
- Costs for liquid oxygen: 110 €/t
- Personnel costs: 47.40 €/h

- Maintenance construction: 0.5 % of capital costs
- Maintenance machinery: 2.5 % of capital costs
- Maintenance electric equipment: 1 % of capital costs
- Mean DOC concentration: 12 mg/L

The specific costs for three specific doses were calculated in order to show the sensibility to this crucial parameter. Doses of 0.4, 0.7 and 1.0 mgO_3/mgDOC were evaluated. As described in section 6.3.2, a dose of 0.6 mgO_3/mgDOC showed a reduction of approximately 2 LUR for E. coli and can therefore serve as a target dose for partial disinfection. Considering the daily throughput of 132.000 m^3 (1.53 m^3/s) the mean utilisation of the ozonation unit is approximately 0.66. Table 20 gives the specific costs for these circumstances.

Table 20 Specific costs for ozonation according to the used dose

Dose in mgO_3/mgDOC	Specific costs in cent/m^3
0.4	3.8
0.7	5.4
1.0	7.2

Due to the high capital and operational costs, the specific yearly costs at a utilisation of 0.66 for a dosage of 0.7 mgO_3/mgDOC are 5.4 cent/m^3 and clearly lie above the presented costs for UV (n+1) = 2.0 cent/m^3, PFA (n+1) = 2.5 cent/m^3, and ClO_2 (n+1) = 2.2 cent/m^3. It has to be kept in mind that a comparable high DOC concentration of 12 mg/L requires a high ozone dosage and consequently leads to high specific costs.

Besides disinfection, ozonation also reduces the amount of trace organic compounds present in the water for reuse, which could be an important advantage over other disinfection technologies.

9 Conclusion

Partial disinfection is an appropriate way to balance costs and benefits, because high disinfections levels come with the costs of high energy and chemical dosages, respectively. Wherever a reuse application is considered in order to act against water scarcity, the level of disinfection should be defined according to the requirements. Partial disinfection can be achieved with all chemical disinfection technologies as well as UV radiation.

Table 21 summarizes the dosages defined for 2 LUR of E. coli and the corresponding specific costs calculated for some of the previous presented case studies. The local constraints of the case studies have to be kept in mind, e.g. water quality or available space for treatment train and the given values shall serve as a rough estimation. Other aspects like formation of DBPs or the need to reduce trace organics play furthermore an important role. Regulations on water reuse are discussed continually and future requirements should be considered designing a disinfection treatment train.

Table 21: Dosages and specific costs of case studies – 2 LUR for E. coli

	PFA[10]	UV[10]	Ozone[11]	ClO_2[12]
Dosages for 2 LUR for E.coli	2 g/m^3	35 Wh/m^3 – 650 J/m^2	0.7 mgO_3/mgDOC	2 g/m^3
Specific costs cent/m^3	2.6	2.4	5.4	2.2

The ongoing development of online analysis, e.g. microbiological analysis, increases the precision and availability and reduces the maintenance effort at the same time. The implementation of these analytical tools helps to obtain the goal of partial disinfection and will increase the robustness of the system. Control schemes using these online tools apply only the necessary dosage for a given application and operation is more economic and sustainable through savings of energy and chemicals, respectively.

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[10] Results of pilot trials at WWTP Brunswick, with a utilization of 0.53

[11] Results of R&D project Askuris, Jekel et al., M. (2015a) ASKURIS - Anthropogene Spurenstoffe und Krankheitserreger im urbanen Wasserkreislauf: Bewertung, Barrieren und Risikokommunikation (Abschlussbericht) - (available online 03/2016 - http://www.askuris.tu-berlin.de/).

[12] Theoretical evaluation based on experience – precise figures require pilot scale testing

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11 Appendix

Table 22 Microorganisms present in treated wastewaters and diseases caused (adapted from Alcade-Sanz & Gawlik (2014), Adams et al. (1999), (Hochstrat & Wintgens 2015) and Tchobanoglous et al. (2014))

Organism	Disease caused
Escheria coli	Gastroenteritis
Leptospira (spp.)	Leptospirosis
Salmonella typhi	Typhoid fever
Salmonella (=2100 serotypes)	Salmonellosis
Shigella (4 spp.)	Shigellosis (bacillary dysentery)
Vibrio cholerae	Cholera
Campilobacter jejuni	Gastroenteritis
EHEC	Hemolytic urmic syndrom (HUS)
Leptospira spp.	Leptospirose
Shigella	Shigellose (dysentery)
Vibrio cholera	Cholera
Yersinia enterocolitica	Yersinose, Gastroenteritis
Legionella	Pneumonia
Balantidium coli	Balantidiasis
Cryptosporidium parvum	Cryptosporidiosis, diarrhea, Fever
Entamoeba histolytica	Amebiasis (amoebic dysentery)
Giardia lamblia	Gardia
Helminths	
Ascaris lumbricoides	Ascariasis
T. Solium	Taeniasis
Trichuris trichiura	Trichuriasis
Enteroviruses (72 types, e.g. polio echo, and coxsackie viruses)	Gastroenteritis, heart anomalies, meningitis
Hepatitis A virus	Hepatitis
Norwalk agent	Gastroenteritis
Rotavirus	Gastroenteritis
Norovirus	Gastroenteritis
Adenovirus	Conjunctivitis Gastroenteritis

Table 23 Standards on water reuse – Europe and Worldwide; adopted from Alcade-Sanz & Gawlik (2014) and own review

Country	Standard / Guideline	Issuing organization
Cyprus	Law 106 (I) 2002 Water and Soil pollution control and associated regulations KDP 772/2003, KDP	Ministry of Agriculture, Natural resources and Environment Water development Department

	269/2005	(Wastewater and reuse Division)
France	JORF num.0153, 4 July 2014 Order of 2014, related to the use of water from treated urban wastewater for irrigation of crops and green areas	Ministry of Public Health Ministry of Agriculture, Food and Fisheries Ministry of Ecology, Energy and Sustainability
Greece	CMD No 145116 Measures, limits and procedures for reuse of treated wastewater	Ministry of Environment Energy and Climate Change
Italy	DM 185/2003 Technical measures for reuse of wastewater	Ministry of Environment Ministry of Agriculture, Ministry of Public Health
Portugal	NP 4434 2005 Reuse of reclaimed urban water for irrigation	Portuguese Institute for Quality
Spain	RD 1620/2007 The legal framework for the reuse of treated wastewater	Ministry of Environment Ministry of Agriculture, Food and Fisheries, Ministry of Health
Australia – Victoria	Guidelines for Environmental Management (GEM): Use of Reclaimed Water (EPA publication 464.2) GEM: Dual Pipe Water Recycling Schemes - Health and Environmental Risk Management (EPA publication 1015). Guide for the completion of a Recycled Water Quality Management Plan - For Class A water recycling schemes Guidelines for validating treatment processes for pathogen reduction: Supporting Class A recycled water schemes in Victoria	EPA Victoria
USA – California	Groundwater Replenishment with Recycled Water - June 26, 2013 draft regulations Title 17 of the California Code of Regulations – for cross connections Title 22 – Water Recycling Criteria	EPA California
China	China National Reclaimed Water Quality Standard; China National Standard GB/T 18920-2002, GB/T 19923-2005, GB/T 18921-2002, GB 20922-2007 and GB/T 19772-2005.	
Israel	Ministry of Health regulation (2005)	Unrestricted agricultural irrigation use. Based on the California Title 22 standards, very restrictive. Methods of treatment and setback distances are included
South Africa	Policies: The latest revision of the Water Services Act of 1997 relating to greywater and treated effluent (DWAF, 2001) The latest revision of the National Water Act of 1998, 37(1)	Regulation: Government Gazette No. 9225, Regulation 991: Requirements for the purification of wastewater or effluent (EAF, 1984) Guidelines: The South African Guide for the

	(DWAF, 2004a) relating to irrigation of any land with waste or water containing waste generated through any industrial activity or by a water works	Permissible Utilization and Disposal of Treated Effluent (DNHPD, 1978) The South African Water Quality Guidelines (DWAF, 1996)

Table 24 Water for irrigation purposes - DIN 19650

Quality category	Use	Faecal-streptococci colony count per 100 ml	E. Coli Colony count per 100 ml	Salmonellae per 1,000 ml	Potenially infectious stages of human and domestic animal parasites Per 1,000 ml
1 (drinking water)	No restriction	Non-detectable	Non-detectable	Non-detectable	Non-detectable
2	a) Outdoor and greenhouse crops intended for raw consumption b) School sports grounds, public parks	≤ 100	≤ 200	Non-detectable	Non-detectable
3	a) Greenhouse crops not intended for consumption b) Outdoor crops for raw consumption before fruit development or vegetables up to two weeks before harvesting c) Fruit and vegetables for preserving d) Pasture or herbage up to two weeks before mowing or grazing e) All other outdoor crops f) Other sports grounds	≤ 400	≤ 2,000	Non-detectable	Non-detectable
4	a) For protecting wine and fruit crops from frost b) Cultivated forests, logging sites and wet habitats c) Sugar beet, starch potatoes, oil- seed fruits, nonfood plants for industrial processing and seed stock up to two weeks before harvesting (not for raw consumption) d) Cereals up to green ripeness e) Fodder for silage up to two weeks before harvesting	Wastewater which has passed through at least one biological purification stage			a) No standard recommendation possible for intestinal nematodes b) Taenia stages not detectable

Table 25 **Classes of reclaimed water and corresponding standards for biological treatment and pathogen reduction - (EPA Victoria 2003)**

Class	Water quality objectives - medians unless specified	Treatment processes	Range of uses– uses include all lower class uses
A	Indicative objectives • < 10 E. coli org/100 mL • Turbidity < 2 NTU • < 10 / 5 mg/L BOD / SS • pH 6 – 9 • 1 mg/L Cl2 residual (or equivalent disinfection)	Tertiary and pathogen reduction with sufficient log reductions to achieve: <10 E. coli per 100 mL; <1 helminth per litre; < 1 protozoa per 50 litres; & < 1 virus per 50 litres.	Urban (non-potable): with uncontrolled public access Agricultural: e.g. human food crops consumed raw Industrial: open systems with worker exposure potential
B	• <100 E. coli org/100 mL • pH 6 – 9 • < 20 / 30 mg/L BOD / SS	Secondary and pathogen (including helminth reduction for cattle grazing) reduction	Agricultural: e.g. dairy cattle grazing Industrial: e.g. washdown water
C	• <1,000 E. coli org/100 mL • pH 6 – 9 • < 20 / 30 mg/L BOD / SS	Secondary and pathogen reduction (including helminth reduction for cattle grazing use schemes)	Urban (non-potable): with controlled public access Agricultural: e.g. human food crops cooked/processed, grazing/fodder for livestock Industrial: systems with no potential worker exposure
D	• <10,000 E. coli org/100 mL • pH 6 – 9 • < 20 / 30 mg/L BOD / SS	Secondary	Agricultural: non-food crops including instant turf, woodlots, flowers