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D2.1 – Technology configuration and basic design for each CS

WP2 - Industrial Water Saving, Recovery, Treatment and Re-use Technologies & Practices

31st May 2021

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ABSTRACT	This Deliverable is focussing on the definition of the different technologies to be investigated within the AquaSPICE project in all the Case Studies (CS). The report is first presenting the current situation at each study site, before identifying the drivers for improvement for one or several streams within the factory or across the wider study site. Common to the water visions of all case studies is a reduced water intake achieved by a higher water efficiency and/or an (improved) treatment and reuse of various water streams.

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MOST USED ABBREVIATIONS/ACRONYMS

ACF	Activated Carbon Filters
AOP	Advanced Oxidation Process
BFW	Boiler Feed Water
CoC	Cycles of Concentration
CS	Case Study
CT	Cooling Tower
CTBD	Cooling Tower Blowdown
DAF	Dissolved Air Flotation
DSPW	Dilution Steam Process Water
EDBM	Electrodialysis with bipolar membranes
EDR	Electrodialysis Reversal
GAC	Granular Activated Carbon
GHF	Granular Ferric Hydroxide
HX	Heat Exchanger
IEX	Ion Exchange
KPI	Key Performance Indicator
MBR	Membrane Bioreactor
MF	Microfiltration
NF	Nanofiltration
UF	Ultrafiltration
UV	Ultraviolet
RO	Reverse Osmosis
WAPEREUSE	Peroxide wastewater reuse
WaterCPS	Water-specific Cyber-Physical-System
WP	Work Package
WRP	Water Reclamation Plant
WWTP	Wastewater Treatment Plant

1 Executive summary

Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations (AquaSPICE) aims at materializing circular water use in the European Process Industries, fostering awareness in resource-efficiency and delivering compact solutions for industrial applications.

This deliverable D2.1 *Technology configuration and basic design for each CS* is based on a project-wide questionnaire, which gathered information on industry sector specifications, stakeholders, current raw water and product water qualities but also on targets for future developments related to water issues. The questionnaire, which was answered individually by each case study team, is a key starting point for the activities in Work Package (WP) 2 *Industrial Water Saving, Recovery, Treatment and Re-use Technologies & Practices* but also for many other WP in AquaSPICE.

The present deliverable is a summary of central aspects of the questionnaire, focussing first on the current situation at each study site, before identifying the drivers for improvement for one or several streams within the factory or across the wider study site. Common to the water visions of all case studies is a reduced water intake achieved by a higher water efficiency and/or an (improved) treatment and reuse of various water streams.

This report highlights the different technologies to be tested within AquaSPICE at each case study site, illustrating a wide variety of processes, including:

- Physico-chemical processes (e.g., CS#1A, CS#1B, CS#2, CS#3B, CS#5)
- Membrane-based processes (e.g., CS#1A, CS#1B, CS#2, CS#3B, CS#5, CS#6)
- Biological processes (e.g., CS#2, CS#5, CS#6)

Pilot installations of different treatment capacity will be deployed at each site, supported by a strong monitoring programme. As presented in this deliverable, modelling activities of the water treatment technologies are forming an integrative part of the case study investigations, e.g., in CS#1A, CS#1B, CS#3B for cooling systems or CS#2 for the WAPEREUSE pilot plant. Furthermore, modelling activities are planned for a region or an area to support operational decisions, e.g., CS#3A for the water intake.

The information compiled in this report is valuable for and beyond WP2.This Work Package prepares the ground for the deployment of the pilot installations, which will allow for a demonstration and evaluation of the AquaSPICE solutions at the individual sites, an involvement of local and/or regional stakeholders and finally a transferable evidence on the applicability of the AquaSPICE solutions.

Due to the non-availability of the SynDi plant in CS#4, this CS is considered as void case and no work related to this CS is reported in this deliverable.

2 Introduction

Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations (AquaSPICE) aims at materializing circular water use in the European Process Industries, fostering awareness in resource-efficiency and delivering compact solutions for industrial applications.

AquaSPICE follows a systemic approach in water management where optimal efficiency can be achieved through an adaptation of appropriate technologies and practices at different levels, from a single industrial process (unit operation), to an entire factory, to other collaborating industries (industrial symbiosis) or other sectors (e.g., domestic and/or agriculture).

That challenging aim necessitates:

- multiple state-of-the-art water treatment and re-use technologies
- diverse closer-loop practices regarding water, energy, and substances
- a cyber-physical-system controller in the form of a system for real-time monitoring, assessment, and optimization of water (re-)use at different interconnected levels
- an effective methodological, regulatory, and business framework.

Work package 2 (WP) aims to define and configure the best and most feasible practices and treatment technologies for each particular CS in order to foster circular water reuse. On the basis of pilot plant installations, the optimal design and operational procedures will be determined, as well as procedures, protocols, requirements and constraints for technology application. Furthermore, an Evidence Database with real practices on industrial water recycling and reuse will be developed.

This deliverable D2.1 *Technology configuration and basic design for each CS* is based on a project-wide questionnaire, which gathered information on industry sector specifications, stakeholders, current raw water, and product water qualities but also on targets for future developments related to water issues. The questionnaire, which was answered individually by each case study team, is a key starting point for the activities in WP2 *Industrial Water Saving, Recovery, Treatment and Re-use Technologies & Practices* but also for many other WP in AquaSPICE.

Deliverable 2.1 presents a global overview of the case studies mostly in technical terms. For each case study, an initial approach in the framework of AquaSPICE project is given, presenting the main objectives and KPIs to measure them. Furthermore, for each case study, the current situation of the industrial partner is explained in terms of current water streams characteristics and treatments applied, as well as control and monitoring systems implemented. Furthermore, the basic design of the treatment technology pilots for each case study is presented with determination of the sequence of treatment units, treatment capacity and basic operational regime to be investigated.

3 Technology configuration and basic design for each Case Study

AquaSPICE aims at materializing circular water use in European Process Industries, fostering awareness in resource-efficiency and delivering compact solutions for industrial applications.

In this chapter, the case studies of AquaSPICE, which are part of the chemical, food as well as oil and refinery sectors, are described. As shown in Figure 1, the case studies are located in different European countries and Turkey.

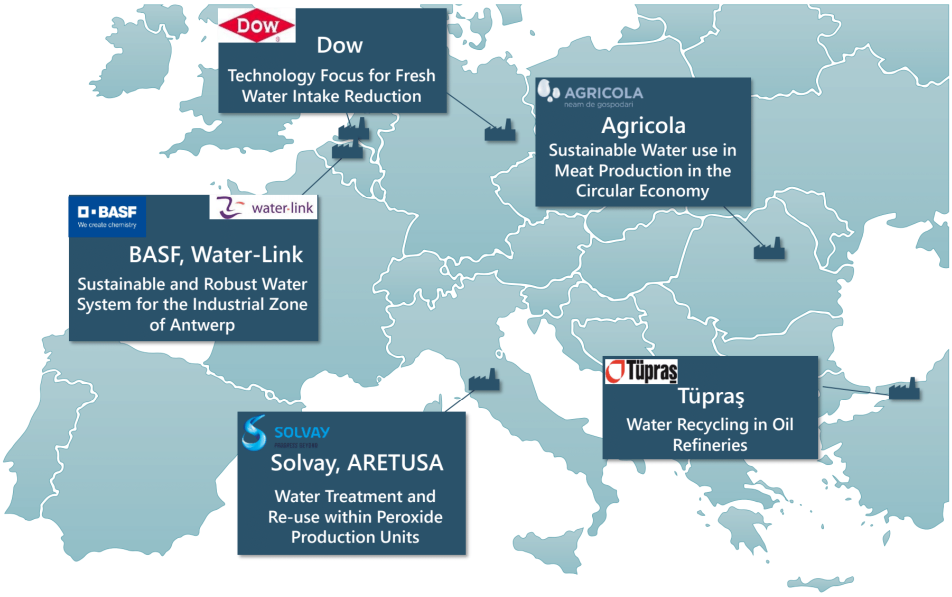


Figure 1 – AquaSPICE Case Studies locations

First of all, a brief introduction and a global overview are presented for each CS, describing the main objectives to be achieved in AquaSPICE. The current situation is then explained and finally, the proposed technologies to be investigated in the framework of the project are exposed.

In the following table, a summary of the different AquaSPICE case studies information is compiled, presenting the CS leader, CS owner, industrial sector and location.

The following chapters provide a detailed description of the case studies and their baseline conditions before AquaSPICE started. Furthermore, the technological objectives are described and the specific Key Performance Indicators (KPI) for the innovative technologies are presented.

Case study	CS Leader	CS owner	Industrial sector	Location
1A	Dow Benelux BV (DBBV)	Dow Benelux BV (DBBV)	Chemical	Netherlands
1B	Dow Olefinverbund GmbH (DOW)	Dow Olefinverbund GmbH (DOW)	Chemical	Germany

Case study	CS Leader	CS owner	Industrial sector	Location
2	Universita Politecnica Delle Marche (UNIVPM)	Solvay Chimica Italia SPA (SOLVAY)	Chemical	Italy
3A	Vlaamse instelling voor technologisch onderzoek N.V. (VITO)	Water-link OV (WL)	Chemical	Belgium
3B	Vlaamse instelling voor technologisch onderzoek N.V. (VITO)	BASF Antwerpen N.V. (BASF)	Chemical	Belgium
4	Not reported			
5	Business Development Group SRL (BDG)	Agricola International SA (AGRICOLA)	Food	Romania
6	Fundacio Eurecat (EUT)	Turkiye Petrol Rafinerileri Anonim Sirketi (TÜPRAS)	Oil and refinery	Turkey

Table 1 – Summary of the AquaSPICE case studies

3.1 Case Study #1A: I-PARC DOW TERNEUZEN (Netherlands)

3.1.1 Case study owner

Dow's businesses include specialty chemicals, advanced materials, and plastics. They offer technology-based products and services to clients in about 160 countries and in high growth sectors like food and specialty packaging, industrial and consumer packaging, health and hygiene, electronics, energy, architectural and industrial coatings, home care and personal care, as well as infrastructure. The Dow Terneuzen site is an I-Parc with 23 production units (17 of them owned and operated by Dow Benelux BV) and over 3,000 employees. At the Terneuzen site hydrocarbon-based feedstocks are processed to produce monomers for plastics and derivatives (polyethylene, polystyrene, polyurethanes, latex, and others).

3.1.2 Global overview

I-Parc Dow Terneuzen is under severe water stress as it is located in a coastal area with very limited availability of fresh water. For this reason, it strives to reduce its freshwater intake intensity by:

- enhancing the internal recycle of various process water streams – these comprise (but are not limited to) cooling tower blowdown and dilution steam blowdown streams
- creating a next level of site water management by using smart monitoring, algorithms and control on raw water, discharge and recycle streams.

The I-Parc Dow Terneuzen has a long history in water reuse and recycling. In the next step the fresh water use per unit of product can only be decreased by further closing the internal water loop, decreasing discharges and reclaiming non-polluted rainwater.

3.1.3 Objectives

In this case study, the following objectives have been established:

- Reuse of Cooling Tower Blowdown (CTBD). The Terneuzen I-Park has 16 evaporative towers with varying size and operation mode (make-up quality, treatment program, blowdown discharge). Four of these comprise 90% of the total cooling capacity and are addressed in this project (total blowdown rate of 1.5 million m³/y). Approximately 50% of the blowdown is currently directly discharged to the river, the rest is sent to Dow's Wastewater Treatment Plant (WWTP). The first objective for this CS is to treat CTBD for direct reuse as cooling tower make-up.
- Reuse of dilution steam process water (DSPW). Within the naphtha cracker area, a purge stream is generated from the dilution steam/process water stripper system (DSPW) and currently discharged to the WWTP (total of 1.5 million m³/y). The DSPW condensate is currently sent to the wastewater plant where the enthalpy of the stream is lost. Ideally this stream can be treated closer to its source, its heat can be recovered, and the stream can be reused as boiler feed water or returned into the return condensate pool (returned condensates are further polished to reach high quality boiler feed water (BFW), called polished water).
- Create a WaterCPS of the Dow Terneuzen case. Currently the flows of return steam condensates, demineralized water, cooling tower make up and blowdown are directed based on operator decisions using measurements of temperature, conductivity and TOC. A sensor network of these and likely additional parameters is to be created in real time

and a model constructed to facilitate decisions-making in the most economical and ecological way.

3.1.4 As-Is Situation

Two different water streams are involved:

Stream 1: Cooling tower blowdown (CTBD).

Stream 1 is generated during the operation of the cooling tower (CT). Non-volatile constituents in the cooling water loop are concentrated while water is being evaporated. Stream 1 is slightly higher in volume during summer when more cooling capacity is being used. The volume may raise by 10-15% maximum.

Four different cooling tower systems are within the scope of AquaSPICE. The trials will be conducted at one of these towers, LHC-3, which is the largest one (~280 MWth) and receives make-up water supplied from two distinct sources, whose ratio varies depending on the availability and quality of the WWTP effluent recycle:

- recycled treated wastewater from Dow's WWTP (effluent recycle)
- fresh water from storage basins owned by Evides

Looking at all site CTs, approximately 50% of the blowdown is directly discharged to the river Scheldt without further treatment if the quality is within permitted limits. The rest is sent to Dow's WWTP, and treated in a saline (comprising 30% of the CTBD) and a freshwater train (with 70% of the CTBD), the latter being partly recycled as make-up for the LHC-3 CT. Effluent of the saline WWTP train is discharged to the river Scheldt.

Stream 2: Dilution steam process water (DSPW).

Dow Terneuzen has three so-called naphtha crackers. In its furnaces' section dilution steam comes into direct contact with the hydrocarbon product mix. In a series of unit operations hydrocarbons are separated from the water phase and returned into the process, leaving a blow down of water containing certain amounts of hydrocarbons, called DSPW. Streams from all three crackers are collected and stored in a tank. Collected streams currently run off to Dow's WWTP (discharge to the freshwater train, total 1.5 million m^3/y).

Stream 2 is not impacted by seasons, but its composition is dependent on the raw material feedstock used in the cracking process.

Figure 2 shows a scheme of the current water system. Stream 2, which is to be investigated in AquaSPICE, is highlighted in green.

Control system

Dow deploys its own process control system, which is centralized at the Power and Utilities department (P&U). Relevant parameters are collected (hard wired) and are visualized in the central control room. Parameters are monitored with temperature probes, flow rate measurements, conductivity probes and TOC analyzers at various locations in the network. Operators take day-to-day decisions to direct streams to the appropriate locations (direct customer, storage tank, further treatment) – most condensate dump systems (in case quality is not met) have automatic actions.

For cooling towers each facility has its own process control system, but water treatment control is done in close collaboration with the site's water treatment provider.

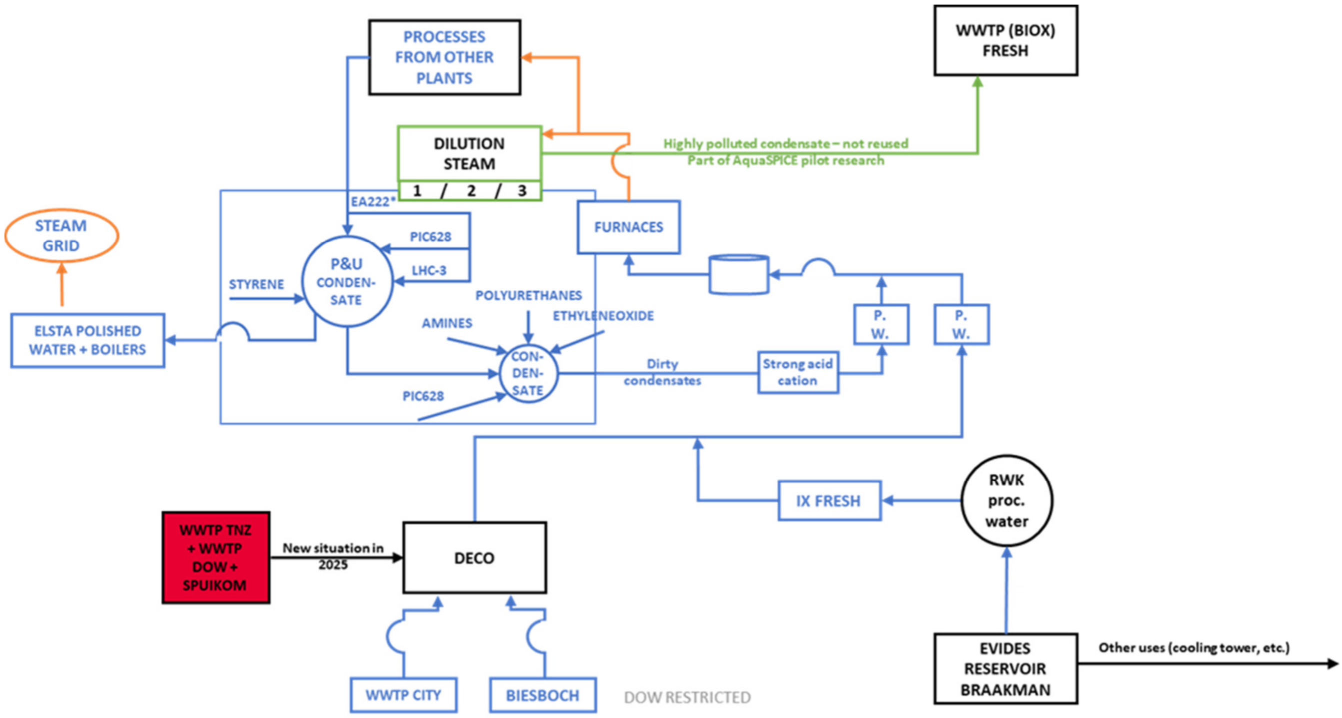


Figure 2 – CS#1A Current water system

3.1.5 Investigations within AquaSPICE

Water treatment trials on both Stream 1 (CTBD) and Stream 2 (DSPW) will be done with the IMPROVED containerized piloting infrastructure. The containers comprise several water treatment technologies, most of which are equipped with online sensors. The data can be accessed online as well as downloaded at a later stage. These trials will be complemented with lab-tests and modelling as well as with pilot trials using the Merades pilot, which allows to simulate and find the optimal performance of a cooling tower.

Stream 1: cooling tower blowdown (CTBD).

In order to achieve higher water efficiency, the Cycles of Concentration (CoC) of cooling towers can be increased. The challenge for Dow is to increase CoC with the future make-up water quality for LHC-3 CT (as of 2024), while meeting the performance targets set internally, and match the treated CTBD with this desired make-up quality.

The quality of the make-up water depends on the original make-up water combined with the treated cooling tower blow down. Variables here are conditioning chemicals dosed for legionella growth suppression, corrosion protection and minimization of scaling, pH and CoC of the cooling tower. The higher the CoC, the higher the water efficiency, but also the risk of scaling and corrosion. This also must be linked to dynamic OpEx analysis of the operation of the cooling tower. Dow's specific interest is to mimic the make-up water quality, which will be delivered to LHC-3 as of 2024.

Both pre-treatment and desalination steps will be tested according to the scheme below.

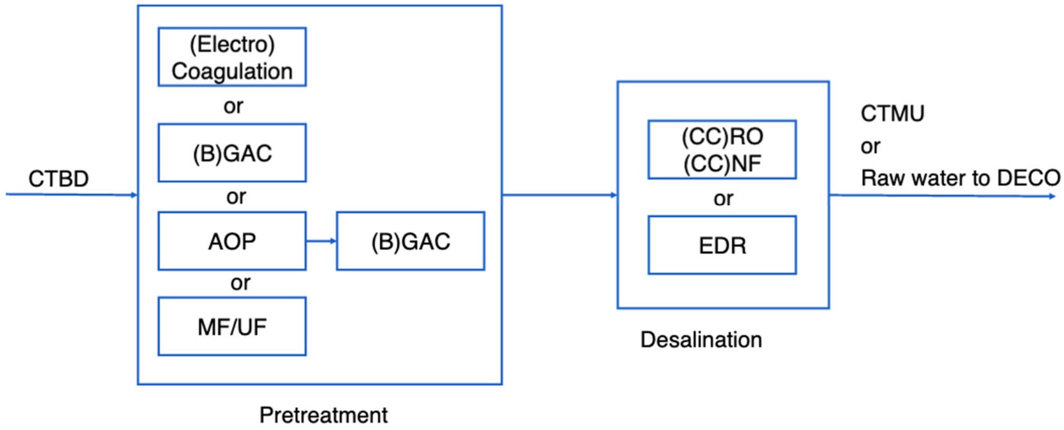


Figure 3 – CS#1A stream 1 (CTBD) proposed treatments

Abbreviations used in Figure 3 comprise:

(B)GAC: (Biological) Granular Activated Carbon
AOP: Advanced Oxidation Processes
MF/UF: Microfiltration/Ultrafiltration
RO: Reverse Osmosis
NF: Nanofiltration
EDR: Electrodialysis Reversal
CTMU: Cooling Tower Make-Up
DECO: Evides' Demiwater & Cooling Water production facility

The optimization of the cooling tower performance will be done based on the experimental results of the Merades cooling tower pilot and combined with modelling. The Merades pilot itself is equipped with online sensors for internal use. These comprise sensors for corrosion, hardness, several specific ions, pH, temperature etc. and can simulate the performance of two cooling loops simultaneously. As feed to the Merades pilot the water produced during the trials with the IMPROVED containers (or equivalent) will be used serving as a base line (matching the current make-up water quality) – specific trials will be conducted to mimic the future make-up water quality and its impact on cooling tower performance. The Merades pilot tests will be executed at the Linkebeek site of Laborelec.

The data obtained by the Merades cooling tower pilot will also be used in the development of a model, which will focus on the performance of the cooling tower and the associated water treatment technologies, specifically targeting scaling, corrosion and biofouling.

Stream 2: Dilution steam water process (DSPW).

Two lines will be tested in parallel in the IMPROVED container for DSPW (see Figure 4). In Line A, the following techniques are planned:

- Oxidative treatment using O_3/UV/H_2O_2/electrochemical reactions to oxidize the portion of the organic load (approx. 15%), which is not biologically degradable
- (Biological) activated carbon to adsorb the breakdown products
- UF using solvent-/oil-resistant Polycera membranes
- Single-pass RO
- Mixed-bed IEX (Ion Exchange resin)

Energy recovery is performed here using a cross-heat exchanger (HX) connected to a cooling unit.

In Line B, the tests inside the IMPROVED containers will be performed with cooled streams due to practical limitations. Following treatment steps will be investigated:

- Coagulation followed by high-temperature ceramic NF (or a combination of solvent-resistant UF and ceramic NF) to concentrate the organics, followed by discharge of the concentrate to the WWTP
- Mixed-bed IEX at high temperatures

Energy recovery is not foreseen here, vessels are insulated as much as possible. The high temperature treated water will be fed again to BFW. The pilot-scale trial will be performed with cooling for safety reasons and because of practical limitations due to plastic piping and vessels.

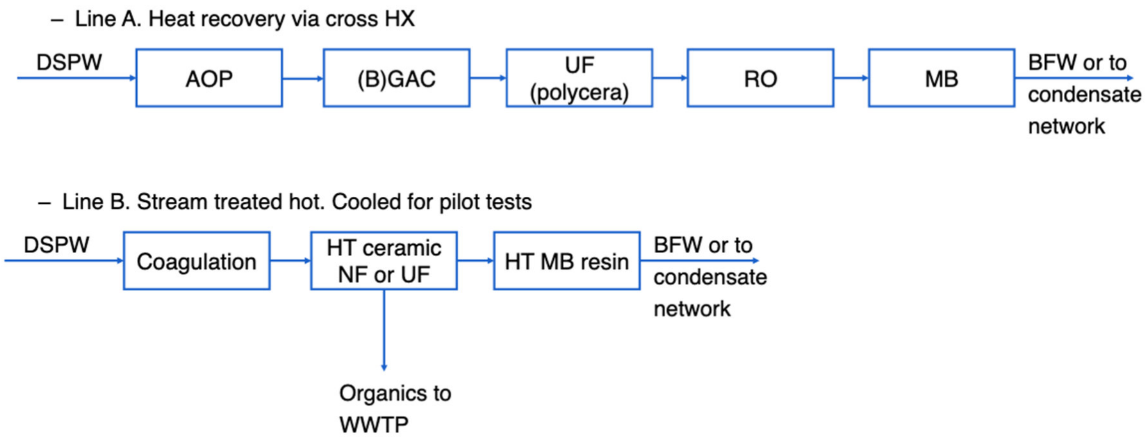


Figure 4 – CS#1A stream 2 (DSPW) proposed treatments

3.1.6 Case study KPI

The CS specific key performance indicators (KPIs) are shown in Table 2. They will allow to evaluate the improvement of the technological solutions to be developed and implemented in AquaSPICE.

KPI	Impact within the AquaSPICE project	Relative priority
Decrease fresh water intake demand by 15% (approx. 1.5 Mio m³/a).	Trials will be executed with CT (cooling tower) blowdown and DSPW (dilution steam blowdown).	High
Reuse of blowdown of four Cooling Towers (representing 90%).	Technology assessment for reuse: 1.Direct as make-up cf. current quality or, 2.Reuse as raw water feed for demiwater production.	Moderate
Reuse of Dilution Steam Blowdown, including potential of 12 MW energy recovery.	Order of reuse: 1.Return as direct BFW make-up. 2.Return in condensate return grid. 3.Reuse as raw water feed for demiwater production.	Moderate
Reduce water losses by 5% by improving condensate return management.	Digitilization by means of optimizing data visualization and decision making (temperature, routing, dumping criteria, etc.).	High

Table 2 – CS#1A KPI

3.2 Case Study #1B: DOW BOEHLEN (Germany)

3.2.1 Case study owner

Dow's businesses include specialty chemicals, advanced materials, and plastics. They offer technology-based products and services to clients in about 160 countries and in high growth sectors like food and specialty packaging, industrial and consumer packaging, health and hygiene, electronics, energy, architectural and industrial coatings, home care and personal care, as well as infrastructure.

Dow´s commitment in Germany began in 1960 with the establishment of its first sales office in Frankfurt am Main. Today, Dow Germany has 3600 employees at 13 sites. The five locations Schkopau, Leuna, Teuschenthal, Bitterfeld and Boehlen, with a total of 1600 employees, belong to Dow Olefinverbund GmbH.

3.2.2 Global Overview

Due to the tight water balance in the region south of Leipzig, Germany, the Boehlen location of Dow is classified as water scarce. The site Boehlen strives to reduce their freshwater intake intensity by:

- Enhancing the internal recycle of various process water streams. These comprise (but are not limited to) cooling tower blowdown and dilution steam blowdown streams
- Creating a next level of site water management by using smart monitoring, algorithms and control on raw water, discharge and recycle streams.

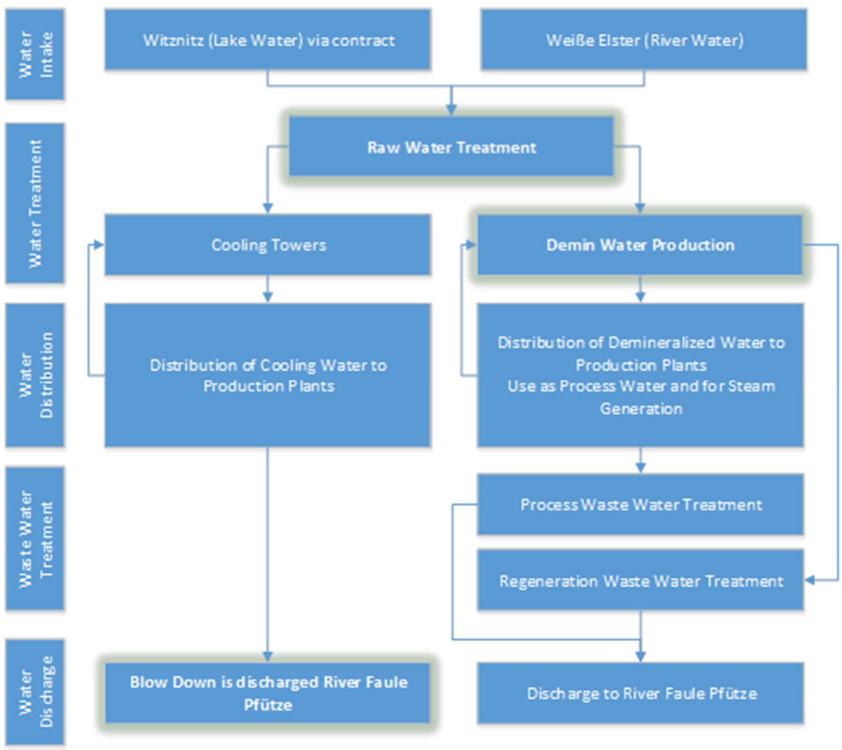


Figure 5 – Global overview of CS#1B water treatment scheme

The entire water treatment is owned and operated by Dow. The Witznitz (Lake Water) intake is owned by the power station (LEAG). Furthermore, the interests of the authorities with respect to the water intake from the river Weiße Elster (in the upcoming chapters only called “Elster”) must be considered.

3.2.3 Objectives

For the Dow location Boehlen, top priorities within AquaSPICE comprise:

- an optimized sourcing (by smart monitoring and control) of fresh raw water streams to produce customized water qualities for different downstream applications
- the treatment and direct reuse of cooling tower blowdown water and slightly polluted process water streams

3.2.4 As-is situation

Figure 6 describes the value chain of the water treatment steps at the Dow site Boehlen. The highlighted steps are part of the AquaSPICE project.

Four different water streams are considered within AquaSPICE:

Stream 1: Cooling Tower Make-Up Water (treated water from lake Witznitz and river Elster).

Stream 2: Pre-decarbonized water made up in raw water treatment plant.

It is relevant to mention that for both streams,1 and 2, the two water sources, Witznitz and Elster Water, are used in varying fractions to produce cooling tower make-up (Stream 1) and supply for the demineralized (demin) water production (Stream 2). The fractions are adjusted within the treatment process to meet the required specifications for either Stream 1 or 2. The pre-treatment for both streams is done separately in the current scheme.

Stream 3: Cooling Tower Blow Down (from cooling cycles with high conductivity).

This stream is currently discharged directly into the river. The AquaSPICE goal for this stream is to reach near zero liquid discharge to diminish the water footprint. This goal shall be achieved by an increased make-up water quality and by returning it as make-up water to the nearest cooling tower system.

Stream 4: Condensate discharge from one production plant (steam condensate, slightly polluted water).

The off-spec condensate from the production plant is currently treated in the Dow wastewater treatment plant.

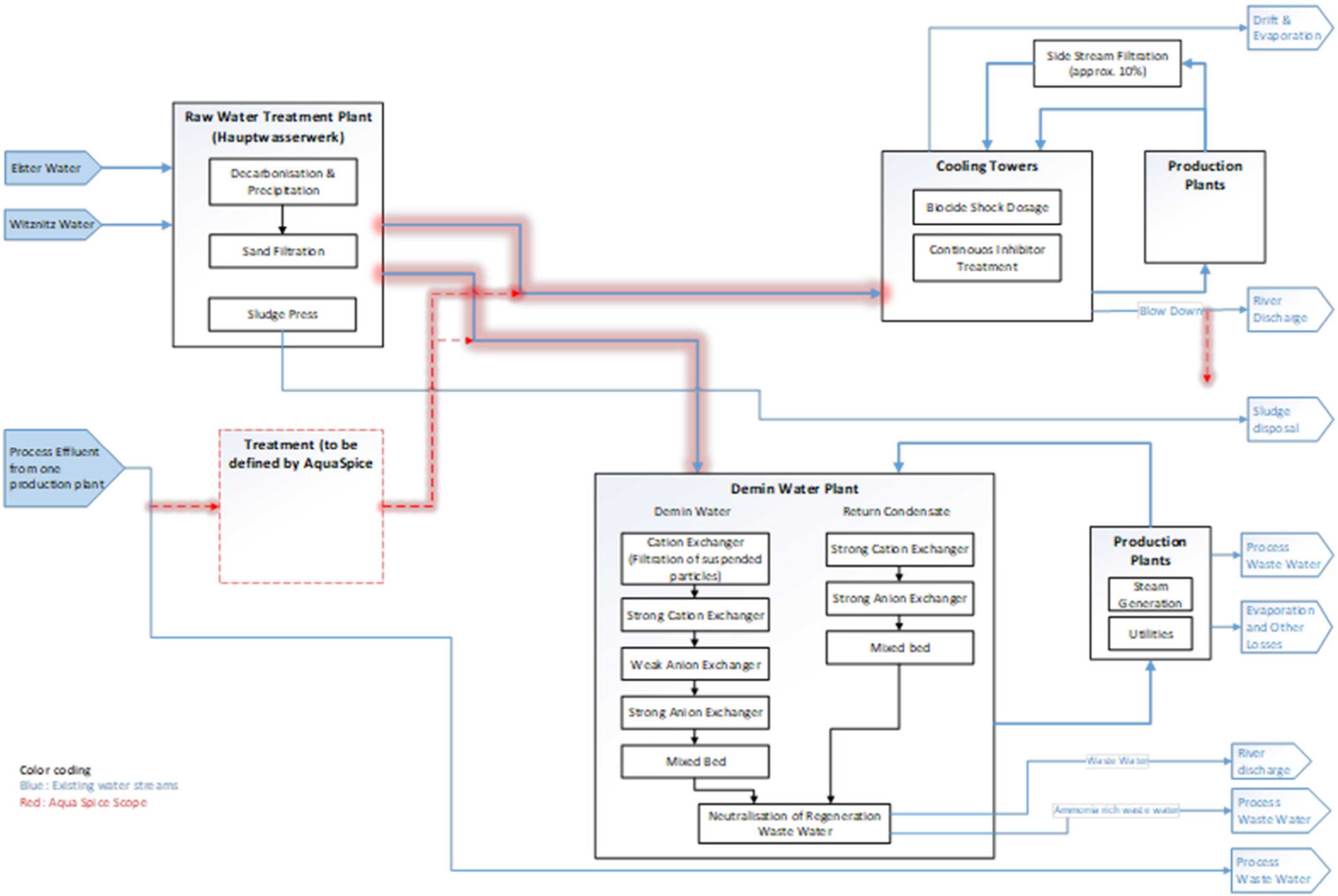


Figure 6 – Process flow diagram of current system CS#1B

3.2.5 Investigations within AquaSPICE

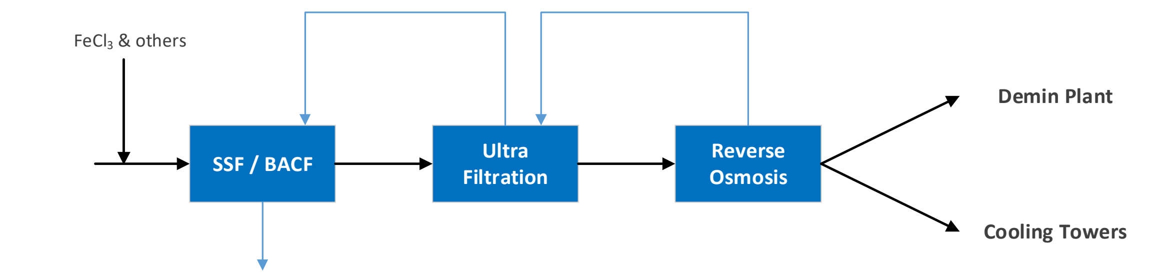
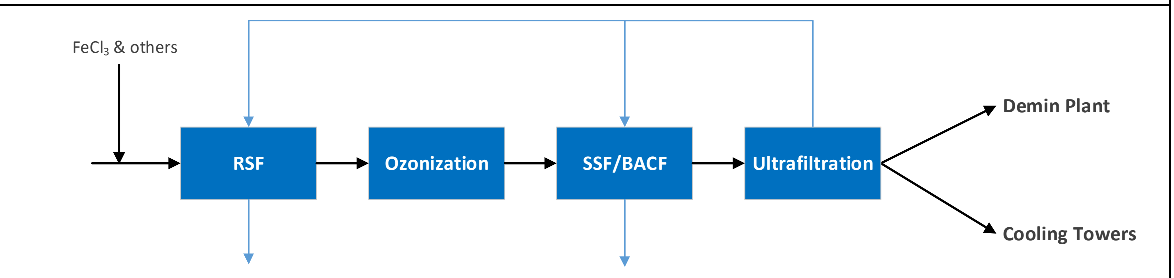
In this chapter, the technologies to be tested for each water stream are presented:

Stream 1: To achieve water intake savings in the cooling system it is required to achieve higher cycles of concentration (CoC) within the cooling cycle. Therefore, the make-up water quality must be improved by lowering the salt content and other permit related process / stream limits. The electrical conductivity (indicator for salt content in water) is one of the major criteria for blow down water from the cooling tower system. High salt contents lead to scaling and damage in the customer plants. AquaSPICE quality improvements for the make-up water shall be evaluated against their water saving potential. Since stream 1 offers the biggest potential for water savings, improvements for this stream have the highest priority in AquaSPICE and will be focused on.

Stream 2: In the demin plant pre-treated water is used to produce demin water by ion exchanger technology (cation IEX, anion IEX and mixed beds). The current demin water treatment can often not meet the quality specifications regarding Total Organic Carbon (TOC). However, a good quality is required for downstream customer (mainly steam generation). In AquaSPICE the degradation of TOC in the pre-treatment and IEX technology is to be analysed and evaluated in order to find solutions for lowering the TOC.

Stream 3: Cooling Tower Blow Down Water has not been considered as a water source so far. In order to save water, the reuse of this blow down water is to be evaluated. This evaluation has to consider the changed cooling tower water composition based on the improved raw water treatment and adjustments in the cooling tower water conditioning (s. stream 1).

Stream 4: The condensate from one production plant is treated in the Dow wastewater treatment plant. As condensate does not offer many nutrients for the activated sludge process, it shall be considered as water source for other purposes. Moreover, condensate offers a high water quality as it is a relatively clean water source. In AquaSPICE, a solution shall be developed to reuse this water source to generate water savings.

Stream 1 and 2: Raw Water Treatment	
Option 1	
Option 2	

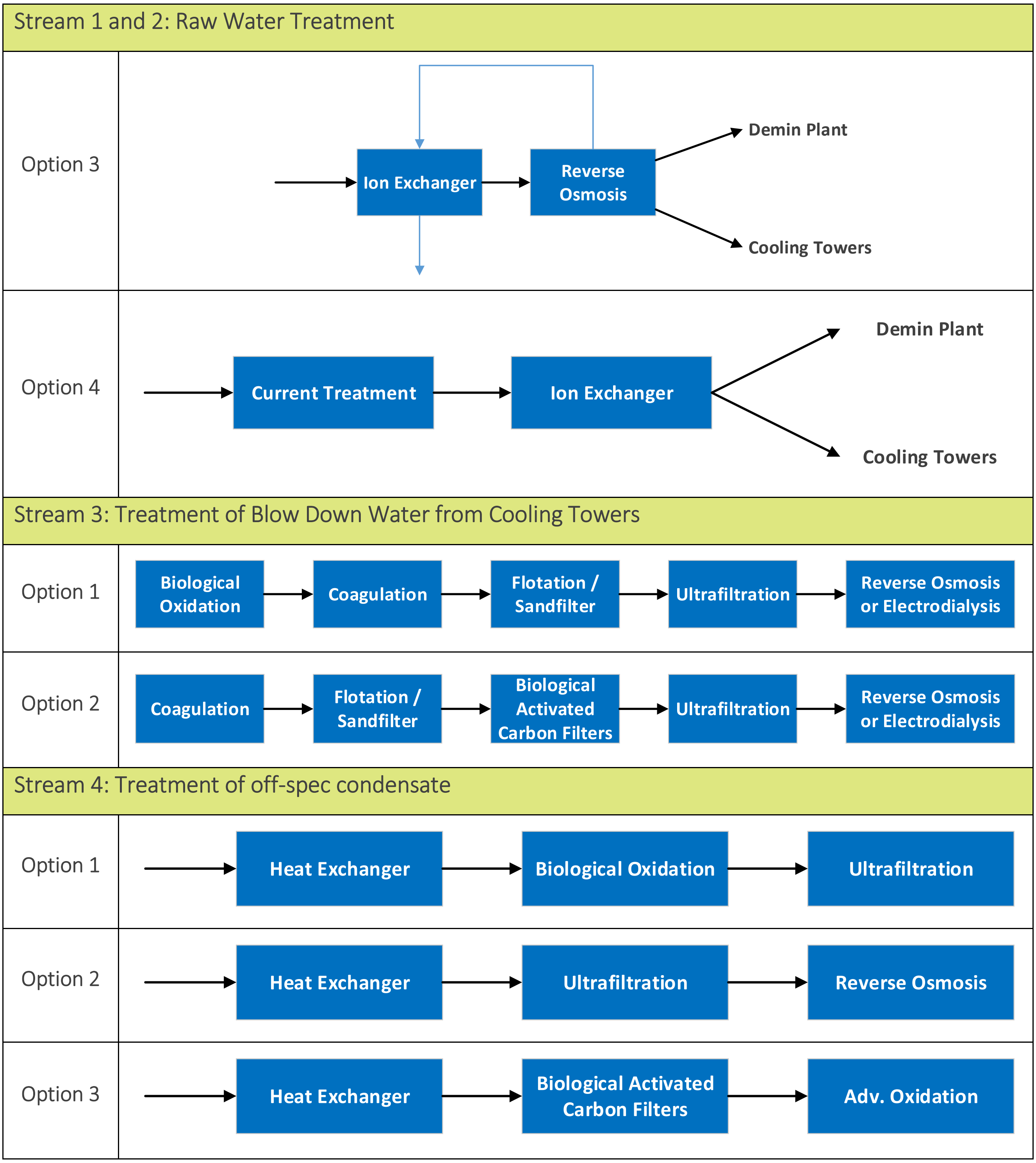


Figure 7 – Different proposed configurations to treat streams in CS#1B

During the AquaSPICE project, water treatment trials will be conducted with the IMPROVED pilot containers, which comprise several water treatment technologies, most of which are equipped with online sensors (cf. description of CS#1A). The data can be accessed online as well as downloaded at a later stage.

Additionally, the cooling tower performance will be optimised based on experimental trials within the Merades cooling tower pilot, similarly to the activities to be conducted in CS#1A. The pilot itself is equipped with online sensors for corrosion, hardness, several specific ions, pH, temperature etc. and can simulate the performance of two cooling loops simultaneously. This will be the background for the feasibility study of using improved make up water quality in the cooling system.

3.2.6 Case study KPI

The case study specific key performance indicators (KPIs) are shown in Table 3. They will allow to evaluate the improvement of the technological solutions to be developed and implemented in AquaSPICE.

Block	KPI (AquaSPICE)	Boundaries
Stream 1: Cooling Tower Make-Up Water.	Decrease freshwater intake demand by approx. 1.1 Mio m³/a. Reach near zero liquid discharge in relation to cooling tower blow down.	The decreased amount is based on the water savings in the cooling tower make-up water. - No Legionella. - Keep the general technology and construction. - Design Data Boehlen must be considered.
Stream 3: River Discharge of Blow Down.	Near zero liquid discharge.	- Meet permanent permit requirements. - Permit outlook: decrease zinc and phosphates.
Stream 2: Demin Plant.	Guarantee TOC < 0.2 mg/L in the boiler feed water. Guarantee conductivity. < 0.1 µS/cm	- Keep silica concentration < 0.02 mg/L. - Keep the general technology and construction. - Design Data Boehlen must be considered.
Stream 1: Cooling Water Cycle (Production Plants).	Realize 8 years without Turnaround (high reliability).	- Low corrosion rates (CS and copper). - No visual pitting. - Low scaling. - No heat transfer losses. - Low bio-fouling. - Keep the general Construction.

Table 3 – CS#1B KPI

3.3 Case Study #2: ROSIGNANO SOLVAY ITALIA (Italy)

3.3.1 Case study Owner

The Rosignano Solvay industrial site is one of the oldest and largest in Italy. It produces sodium carbonate, sodium bicarbonate (also for pharmaceutical use), calcium chloride, chlorine, hydrochloric acid, chloromethane, polyethylene, hydrogen peroxide and peracetic acid. To deliver more sustainable water management, Consorzio ARETUSA was established in 2001 as a public-private partnership among water utility (ASA Livorno), industry (Solvay Chimica Italia) and technology provider (Termomeccanica). Thanks to ARETUSA, the Solvay chemical plant is implementing a utility-industry (public-private) symbiosis system to optimize the regional water cycle by reusing about 3 million cubic meters per year of urban wastewater treated in the ARETUSA reclamation plant.

3.3.2 Global Overview

Nowadays, to reduce the intake of freshwater from local aquifers, the secondary wastewater effluents produced in the municipalities of Cecina and Rosignano Marittimo are further treated at the Water Reclamation Plant (WRP) of ARETUSA, so they can be reused in the cooling towers of the Solvay plant. However, industrial wastewater resulting from the peroxide and peracetic acid production at the Solvay plant are currently discharged to the sea.

To reduce the amount of fresh water used by Solvay, the wastewater generated during peroxide and peracetic acid production is to be reused. The WAPEREUSE (Peroxide Wastewater Reuse) system aims to treat the industrial wastewater coming from the Solvay plant. According to the obtained water quality and impacts in the following water and sludge value chains, three possible water reuse scenarios will be evaluated: the water might be reused directly in the cooling towers of Solvay (option 3 - intra-factory reuse), sent to ARETUSA WRP (option 2) before being reused in cooling tower, or discharged to the sewer system, treated in the municipal wastewater treatment plant of Rosignano Marittimo and subsequently by Aretusa WRP for final industrial reuse (option 1). All these scenarios result in an industrial wastewater reuse, and thus in closed loop systems.

3.3.3 Objectives

Current treatments of the industrial wastewater resulting from peroxide production at the Solvay plant can produce a wastewater stream in compliance with the national environmental permit that allows its discharge to the sea.

The proposed WAPEREUSE system will further treat the industrial wastewater, so it can be reused in the Solvay production plant for cooling purposes. Summarizing, the implementation of WAPEREUSE in the Solvay plant has the following objectives:

- Reduce the amount of industrial wastewater discharged to the sea
- Reduce the intake of freshwater from the local aquifer
- Increase the water value and the environmental sustainability

3.3.4 As-is situation

CS#2 focuses on implementing a water reuse technology for the wastewater of peroxide and peracetic acid production from the Solvay plant.

Currently, 5 wastewater streams are collected at the Solvay plant within the production process and sent to the so called “Skimmer” tank:

a. Aqueous phase coming from the distillation column top condensate; a decantation step is used to remove organics
b. Alkaline aqueous phase pre-treated by an acidification step with sulphuric acid to separate a significant part of the organic content of this sub-stream; its effluent is maintained at a controlled pH < 2
c. Acid aqueous phase from acid washing
d. Rainwater and water used as protection spray for equipment, collected from the bunds and pumped to the Skimmer. Intermediate separators are used to remove any trace of organic phase that is then weekly recovered and stored before disposal
e. Water accumulated inside the emergency pits

The wastewater collected in the Skimmer goes into a lamella settler and finally into a granular activated carbon filter (GAC) as shown in Figure 8. The stream leaving the GAC is the so-called Stream 1, which is the stream to be treated and reused in CS#2. Stream 1 is continuously monitored by online measurements of pH, temperature, and flowrate. Sensor probes for these 3 parameters are installed after GAC filter.

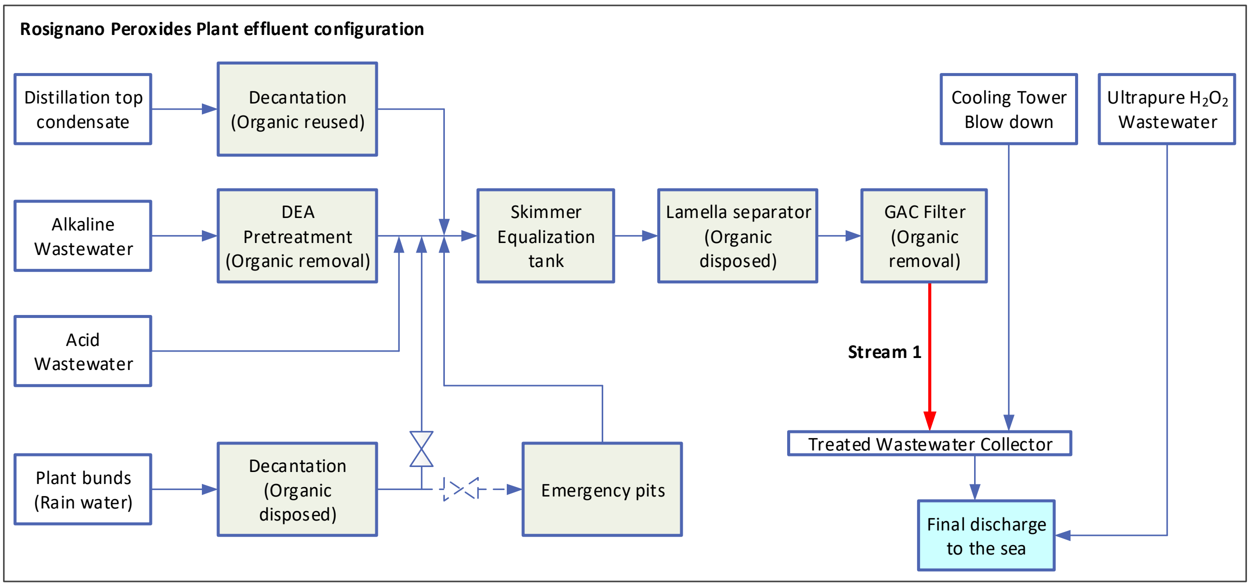


Figure 8 – As-is situation of wastewater streams in Rosignano Peroxides plant: Current pre-treatment before disposal to the sea and identification of Stream 1 to be treated in CS#2

After this pre-treatment, Stream 1 is discharged, together with other industrial wastewater effluents of the Solvay industrial plant in Rosignano Marittimo, to the sea according to the Environmental Permit released by the National Authority (Ministry of Environment). Consequently, to date, there are not closed loops (intra-factory or across the value chain) within the treatment line of the industrial wastewater resulting from the peroxide production at the Solvay plant in Rosignano Marittimo.

Stream 1 is characterized by high concentrations of TOC (350 mg/L), COD (1000 mg O_2/L), nitrates (200 mg N-NO_3/L), sulphates (1000 mg SO_4/L), hydrogen peroxide (0.3 g H_2O_2/L) and, to a lesser extent, phosphates. The organic fraction consists mainly of acids, alcohols, and aromatic compounds. The metals are essentially those coming from stainless steel and carbon steel since the plant is mostly built with these materials. Nitrates and sulphates derive from acidification processes using nitric acid and sulphuric acid, whereas mineral alkalinity is given by sodium hydroxide.

3.3.5 Investigations within AquaSPICE

To reuse water in the Solvay cooling towers, Stream 1 needs to be treated to reach a certain water quality. To do so, the WAPEREUSE pilot plant will test different processes to remove the target compounds. The pilot plant consists of the following treatment units (cf. Figure 9):

1. Equalization and chemical pre-treatment for pH control
   Stream 1 is an acidic flow, pH adjustment is therefore required for the effectiveness of the next steps, especially for the biological process.
2. Adsorption and/or AOP to remove H_2O_2 and metals in Fixed Bed Column. The reactor can be filled with different alternative materials:
   i. Granular Ferric Hydroxide (GFH) – commercial or in-house
   ii. Iron Oxide-Coated Gravel/Sand
   iii. Iron Oxide-Coated GAC
   iv. Iron oxide (geothide)
3. High-load biological denitrification to remove nitrate and COD
   The effectiveness and feasibility of the biological process are critically influenced by the biodegradability of the organic content of the influent (i.e., presence of biodegradable COD). Powdered activated carbon (PAC) may be added into the biological reactor to further remove metals or recalcitrant organics.
4. Enhanced filtration and/or adsorption on granular activated carbon as final polishing
5. Chemical disinfection, preferably using industrial by-products

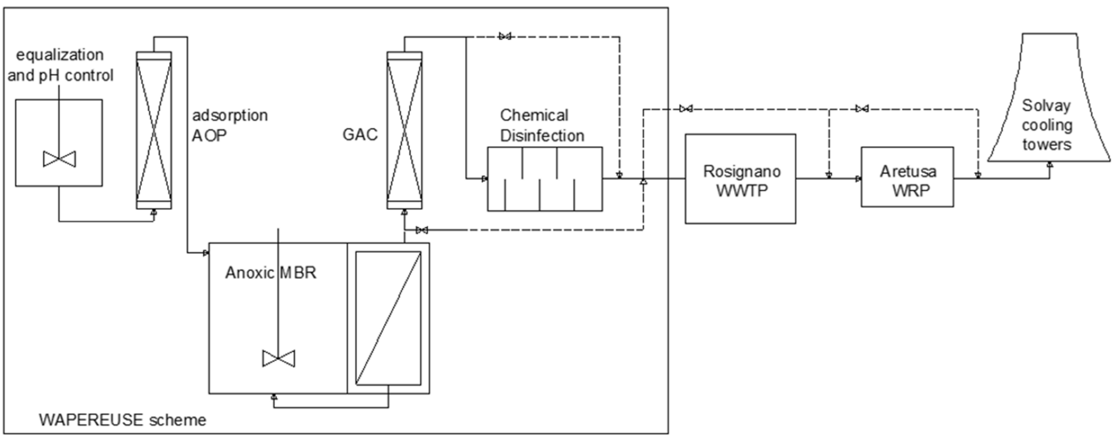


Figure 9 – WAPEREUSE simplified treatment scheme

As an alternative, "conventional" chemical-physical technologies can be considered to overcome the drawbacks of instability and complexity of the biological process (in spite of its cost and environmental efficiency) and treat industrial wastewater. Conventional technologies can be considered as a technological benchmark. The treatments train may include:

- Homogeneous Fenton process to remove COD and H_2O_2
- pH adjustment to remove metal by precipitation (iron)
- Refinement through filtration or activated carbon
- Reverse osmosis (RO) or selective ion exchange for nitrates and sulphates removal

The main drawbacks when dealing with these latter solutions are the environmental and economic impacts. The first 2 steps (Fenton and metals precipitation) produce a high amount of chemical sludge to be disposed of. At the same time, 20 – 50% of water filtered through RO will be rejected, producing a brine, which needs to be further treated and/or disposed of.

In CS#2 the WAPEREUSE pilot-scale technology will be validated for the treatment of industrial wastewater. The treated wastewater will be reused in the industrial site (cooling towers) following different pathways depending on the obtained water quality:

Option 1. Discharged in municipal sewers to be further treated in the municipal wastewater treatment plant and the ARETUSA reclamation plant, before being finally re-used for cooling processes back in the Solvay chemical plant.

Option 2. Discharged in the headworks of the ARETUSA water reclamation plant where tertiary treatments are carried out to provide suitable reclaimed water for the Solvay cooling towers.

Option 3. Reused internally for cooling processes - internal (in-factory) closed loop.

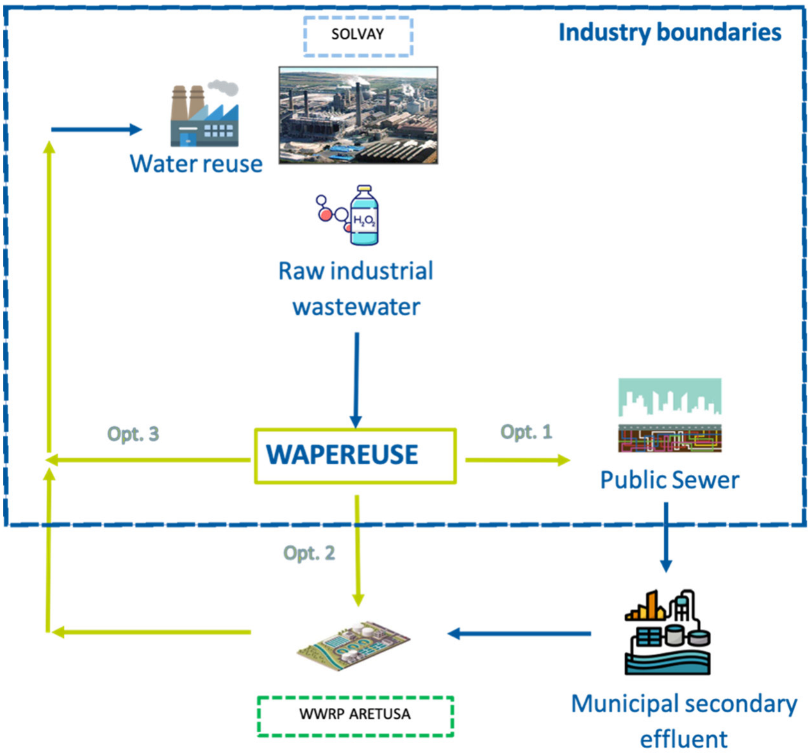


Figure 10 – Water reuse options and scenarios that will be evaluated depending on the WAPEREUSE water quality obtained

3.3.6 Case study KPI

The case study specific key performance indicators (KPIs) are shown in Table 4. They will allow evaluating the improvement of the technological solutions to be developed and implemented in AquaSPICE.

KPI	Impact within the AquaSPICE project	Relative priority
Amount of reclaimed and reused water (m^3/year).	AquaSPICE solution will increase the reuse of reclaimed water at Solvay plant.	High
Energy footprint in wastewater treatment. (kWh/m^3 or kWh/$COD_{removed}$ or kWh/$H_2O_{2removed}$ or kWh/pollution load removed).	Energy for water reclamation will be compared with the energy required for freshwater intake from the local aquifer. Calculation will be accomplished for the three reuse options.	High
Carbon footprint of wastewater treatment (kg CO_2 eq/m^3).	Carbon footprint for water reclamation will be compared with the carbon footprint related to freshwater intake from local aquifer. Calculation will be accomplished for the three reuse options.	Medium
Amount of produced waste /m^3.	The amount of produced waste and its specific disposal will affect the environmental impact of the solution.	High
Cost of treated wastewater (€/m^3).	AquaSPICE solution will optimize the cost of wastewater treatment.	High

Table 4 – CS#2 KPI

3.4 Case Study #3A: WATER-LINK (Belgium)

3.4.1 Case study owner

The Port of Antwerp is the leading European petrochemical and chemical cluster in Europe and home to key industrial players in chemicals production. Several of these chemical companies are large water users that require water for processing products, for cooling and for steam production. The freshwater source that connects to the Antwerp harbour is the Albert Canal. The Albert Canal on its turn takes its water from the river Meuse. Drinking water company Water-link abstracts water from the Albert Canal for drinking water production.

The Port of Antwerp and De Vlaamse Waterweg are local authorities involved in different parts of the study area. Port of Antwerp manages most of the Antwerp harbour territory. Other authorities involved in the Antwerp harbour area are the city of Antwerp (stadshavendienst) (some docks) and MOW Maritieme Toegang (water manager of most waterways in the harbour). De Vlaamse Waterweg manages the water of the Albert canal and the connected canals in the upstream area.

3.4.2 Global Overview

Freshwater of the river Meuse transported through the Albert Canal plays a key role in the Flanders' navigation transport and water use for economic activities. Water is transported from the river Meuse towards the Antwerp harbour through the shipping transport and the sluice activities.

On a yearly basis, 150 Mio m^3 of drinking water is produced using fresh water transported from the River Meuse through the Albert Canal. Drinking water is provided to the residential area of Antwerp (30 Mio m^3), the harbour industry (60 Mio m^3) and other drinking water companies (60 Mio m^3) in Flanders. Water-link thus supplies a major amount of drinking water in Flanders.

For normal activities, a minimal depth of water is required in the Antwerp harbour. This is governed by the supply of the Albert Canal, tidal effects of the river Scheldt and sluice activities. Fresh water can be provided through the Scheldt-Rhine Canal in agreement with the Dutch authorities. In drought periods a lower water depth in the harbour can become an issue which impacts pumping activities of De Vlaamse Waterweg.

Due to climate change, there is increasing salinization of the dock waters in the port of Antwerp, as well as of the River Scheldt and the Albert Canal. The available amount of freshwater is declining; thus, authorities and water suppliers are facing increased problems of managing freshwater resources – for drinking water, industry and transport (inland shipping) – in terms of both water quantity and water quality. The stakeholders in the area need to develop strategies that ensure that water quality and scarcity are factored into decisions that protect current operations and support business growth.

Salinization is a key environmental issue, and its levels vary in time and space; with the highest levels occurring in summer-autumn. During drought periods Water-link is vulnerable for rapid deterioration of the raw water quality caused by an increase in conductivity and possible presence of micropollutants (WWTP Deurne). The saline water becomes potentially untreatable by the conventional treatment schemes of Water-link.

3.4.3 Objectives

CS#3A aims to develop real time smart monitoring and management information system for monitoring water quantity and quality to:

- Manage water allocation decisions (right quality for right use)
- Switch from current water supplies to alternative water supplies for industrial use (cooling and process water) during drought periods
- Assess scenarios for long-term water and salt balances to develop climate adaptation strategies

To achieve these goals, conductivity, temperature, and depth (CTD) sensors will be installed in the harbour docks and in the Albert Canal. Connection to existing sensors and monitoring activities will increase data coverage, taking into consideration meteorological and tidal conditions, sluice operations (both ship locking and pumping activities to maintain the required water levels for shipping), water uptake by industry or water companies, and wastewater discharges. The sensor monitoring data will be taken up in a modelling approach for the area, focused on the (operational) requirements of the stakeholders.

The following objectives have been established:

- Deployment of a monitoring network with CTD sensors measuring water temperature, water depth, and electrical conductivity (proxy for salinity) at about 45 locations in the case study area (Antwerp harbour + Albert Canal + upstream area).
- Visualisation and analysis of the data from the installed sensor network to provide insights on the water system and the main drivers for salinization in view of potential climate adaptation strategies (salinity levels, water scarcity, drought periods).
- Set-up of an early warning system and an operational model to support operational decisions on water intake by Water-link from the Albert Canal and on pumping activities by De Vlaamse Waterweg.

3.4.4 As-is situation

CS#3A include 3 different zones (with associated streams) as shown on Figure 11:

- The river Meuse and the connected canals in the upstream area
- The Albert Canal
- The Antwerp harbour docks at the right bank of the river Scheldt

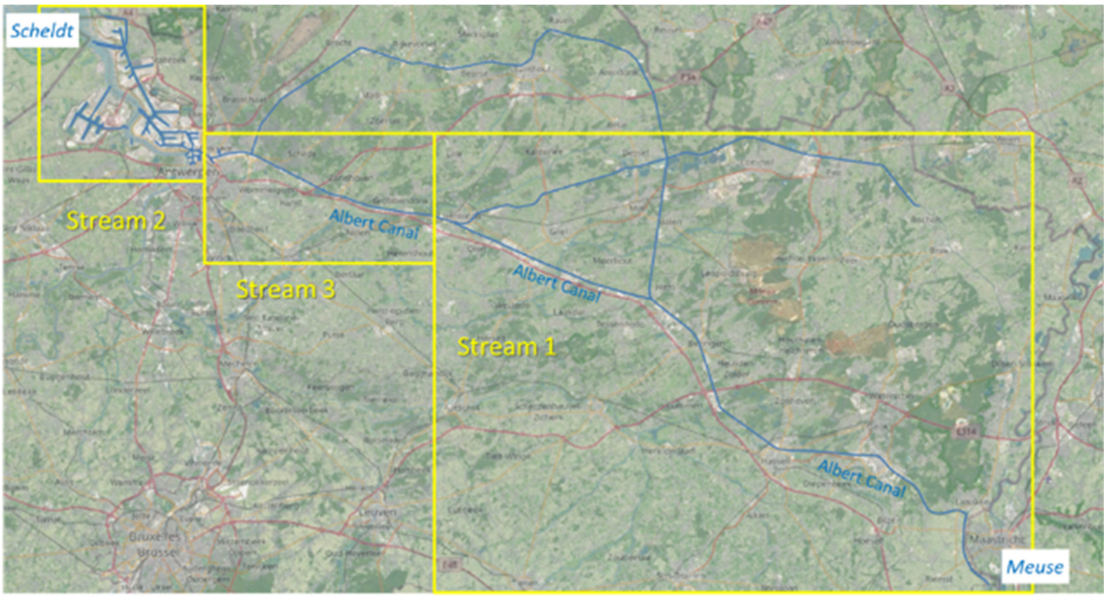


Figure 11 –Streams (zones) in the study area

The Water-link intake points for drinking water production are located along the Albert Canal. One raw intake location is at Oelegem and the other at Broechem. At both locations, Water-link abstracts water from the Albert Canal for drinking water production at the production site in Oelegem.

The BASF site, which is in the north of Antwerp harbour, near the Dutch border, abstracts water from the docks for cooling purposes. BASF is also discharging into the surface water at 2 locations: one discharge point is at the entrance of harbour dock and the second discharge point is on the Scheldt-Rhine canal, just downstream of the harbour area (see Figure 12).

Figure 12 –Intake and discharge points of BASF

The sluices in the study area and the pumping activities at sluices for controlling the water levels for shipping have a major role in the salinity balance and salinity variations in the study area. The sluice of main concern for pumping activities that affect salinity intrusion into the Albert Canal is Sluice Wijnegem, about 2.2 km downstream of the Water-link intake at Oelegem.

For CS#3A, different water streams are considered:

Stream 1: Fresh surface water supply by the river Meuse into the Albert Canal and the connected canals in the upstream area.

The water supply for the river Meuse is the main freshwater source for the drinking water production sites of Water-link on the Albert Canal.

Stream 2: Brackish water in the Antwerp harbour docks.

The water in the docks of the harbour is brackish (elevated salinity levels) due to connection with the tidal river Scheldt by means of several sluices. Water from the docks (specifically dock B3) is abstracted by BASF for cooling water. On the other hand, BASF also discharges into the harbour dock B3 and into the Scheldt-Rhine canal, downstream of the harbour area.

Stream 3: Mixed zone of fresh water and brackish water in the downstream part of the Albert Canal that connects to the harbour area.

The mixing zone starts approximately from the Viaduct Noorderlaan and reaches potentially up to the sluice at Herentals/Olen, depending on drought conditions and pumping activities of De Vlaamse Waterweg. During drought conditions (when there is a lack of fresh water supply from the river Meuse) back-pumping of water at the sluices is necessary to maintain the required water levels for shipping activities on the Albert Canal. The back-pumping activities cause intrusion of brackish water from the harbour area into the Albert Canal. In this way, a mixed zone is gradually migrating from the Antwerp harbour upstream into the Albert Canal towards the raw water intake of Water-link located in Oelegem and Broechem.

Stream 1, Stream 2 and Stream 3 are surface waters that are connected to each other. The water in the Antwerp harbour is a mixture of brackish to salt water from the Scheldt (entering via the sluices) and freshwater entering via the Albert Canal. The Albert Canal is fed by freshwater from the river Meuse and other connected canals in the upstream area.

The entire Albert Canal is allocated as surface water used for drinking water production. Specific environmental quality standards are defined for this type of surface water.

Control system

Current monitoring of the surface water streams is mainly based on monthly grab sampling at several locations in the study area. Additional monitoring through grab samples is performed by the port of Antwerp at a couple of locations in the harbour and by Water-link on the Albert Canal between the harbour and the sluice of Herentals. BASF and Water-link are monitoring their intake water at each abstraction point. BASF is also monitoring the discharged water. Some sensors are currently used by BASF and Water-link.

Based on the current monitoring and reporting, the dynamics of these waterbodies (streams 1, 2 and 3) are unknown or insufficiently known. There is a lack of real-time monitoring or/and modelling. Besides, operational information is mainly gathered through sampling on working days. Furthermore, the real-time monitoring devices are scarcely available and do not provide the required overall short-term overview. In this sense, an integrated monitoring system, based on real time data on conductivity, temperature and depth is to be implemented. Neither a predictive model nor a mid-term early warning system is currently available to support operational decisions on pumping activities by De Vlaamse Waterweg or raw water intake by Water-link.

3.4.5 Investigations within AquaSPICE

As previously stated, several needs are to be addressed in the scope of CS#3A:

- Install sufficient online monitoring devices to monitor required geographical area of streams 1, 2 and 3
- Assure data transmission and capture through development and installation of required IT-architecture
- Develop maintenance schemes on monitoring devices and evaluate devices and long-term availability
- Process data flow and assure visual representation of all the monitoring devices showing water body system dynamics
- Develop a predictive model to support operational decisions
- Develop a mid-term early warning system to support operational decisions to prevent salinization at raw water intake point of Water-link
- Provide monitoring data to the stakeholders (Havenbedrijf (PoA), De Vlaamse Waterweg, VMM, others…)

To improve water quality and quantities in the framework of CS#3A for the 3 considered streams, the following activities will be conducted within AquaSPICE:

- Deployment of a monitoring network with CTD sensors at about 45 locations that measure water temperature, water depth, and electrical conductivity of the water as a proxy for salinity and freshwater availability in the entire study area (Antwerp harbour + Albert Canal + upstream area)
- Operational water quality (salinity) modelling that facilitates decision taking and optimization for water intake by Water-link from the Albert Canal and pumping activities by De Vlaamse Waterweg
- Analysis of the water quality monitoring data in view of climate adaptation strategies (salinity levels, water scarcity, drought periods)

This case study does not include any treatment solution but focuses on real-time monitoring and operational modelling (see Figure 13).

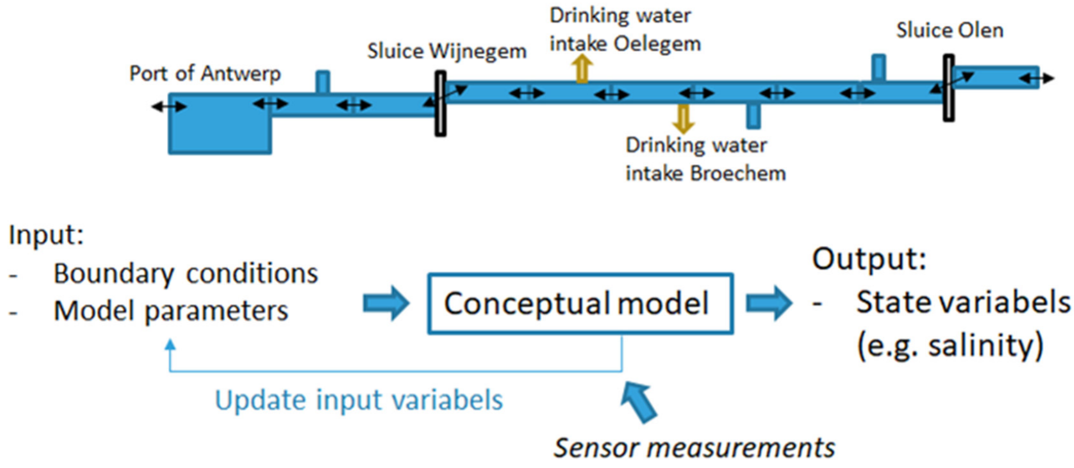


Figure 13 –Modelling in CS#3A

3.4.6 Case study KPI

The case study specific key performance indicators (KPIs) are shown in Table 5. They will support the evaluation of the improvement of the technological solutions to be developed and implemented in AquaSPICE.

KPI	Impact within the AquaSPICE project	Relative priority
Monitoring of salinity in harbour docks and Albert Canal: - Install online sensors at 45 locations. - Availability of online sensor data is > 80%. - Assure data capture of > 80% of the deployed online sensors.	Substantial improvement in monitoring and follow-up of salinization both in time and in space.	High
Operational management for drinking water based on water quality prediction in Albert Canal: - Availability of the online monitoring system > 80%. - Availability of modelling predictions > 80%.	Clear improvement in availability of data and derived information to support operational management and decision taking.	High
Analysis of the factors that affect salinity in harbour, especially dock B3 (BASF intake), e.g., climate change, sluice operations, etc.	Improved insight in the water system and the main drivers for salinization.	Moderate

Table 5 – CS#3A KPI

3.5 Case Study #3B: BASF ANTWERPEN NV (Belgium)

3.5.1 Case study owner

The Port of Antwerp is the leading European petrochemical cluster in Europe and home to key industrial players in chemicals production. The companies are large water users, with water required for processing products, for cooling, as well as for steam production. The largest water user in the port of Antwerp is the BASF site, which abstracts water from the docks for cooling purposes.

3.5.2 Global Overview

For operating a chemical site such as BASF Antwerpen, an integrated thermal management is of major importance to perform such energy intensive activities in a sustainable way. For this thermal transfer, water is mostly used as carrier. For heat transfer, demineralized water is used in the aggregation phases of steam and condensates, where cooling is mainly provided by the available water sources and ambient air. For its cooling water purposes, the BASF utilities plant operates internal grids where cooling water is exchanged between production plants and cooling towers. Due to the fact that the cooling water being used is derived from the brackish water harbour docks, this water contains a substantial concentration of salts, which can form unwanted deposits on heat exchangers. As make-up water, fresh brackish water is added to the system. In case of climate change for example, the water quality of the harbour dock will change, and this will undoubtedly affect the management of cooling water in the system.

BASF is shifting towards a new demineralized water treatment using fresh surface water from the Biesbosch area based upon reverse osmosis (RO) technology. The concentrate from the RO, which will be highly loaded in terms of NaCl, could be reused. Three different options will be evaluated for this high flow of RO concentrate.

3.5.3 Objectives

Due to climate change, there is increasing salinization of ground waters in the port, as well as of the River Scheldt and the Albert Canal. In addition, the amount and quality of fresh surface water are declining. Therefore, large water users in this region are obliged to investigate alternative water sources.

The area is facing increasing problems of managing freshwater resources – for drinking water, industry and transport (inland shipping) – in terms of both water quantity and water quality. The Port of Antwerp Authority and its industrial partners need to develop a climate adaptation strategy that ensures that water quality and scarcity are factored into decisions that protect current operations and support business growth. This requires the development of integrated water-smart strategies for industrial processes, demonstrating water recycling technologies as well as real-time smart monitoring and management systems.

CS#3B has three main objectives, one for cooling water, one for the reuse of RO concentrate and another one for water reuse:

- The first objective is to evaluate the effects of an enhanced recirculation of cooling water at the site and examine possible future process conditions (scaling, fouling, corrosion). Therefore, a pilot study with the Merades pilot plant will be performed. In addition, the Merades pilot will be modelled for a deeper understanding and prediction of the cooling process related to performance, corrosion, chemical dosing, etc.

- The second objective is **to use RO concentrate, which is to be produced within the new demineralized water production plant, either as feed water for softener regeneration or for the production of acid and base**. Thus, produced acid and base could be used internally for the regeneration of the mixed beds in the demineralization plant.
- BASF has a number of organically and salt loaded wastewaters, which are currently not reused. **Process condensate streams will be evaluated for direct reuse as spraying water on air-cooled chillers and for reuse after treatment**. Several process streams from the steam cracker plant (wastewater, boiler blowdown, hydrocarbon- and phosphate-loaded process condensate) will be investigated for reuse options. The selection of treatment trains will be done after preliminary lab trials.

For CS#3B, key areas to be focused on are:

- Determination of fouling and scaling effects on heat exchangers (HX), depending on water temperature, HX surface temperature, salt concentration, pH, etc.
- Modelling of the cooling system
- Determination and increased knowledge of which treatments are cost-effective for water reuse

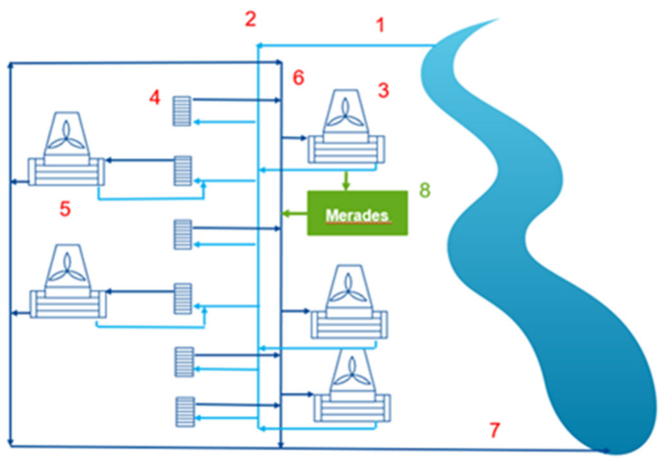
3.5.4 As-is situation

The current situation of the water streams that have been identified for investigation in AquaSPICE is as follows:

Stream 1a: Make-up water for cooling towers.

For this stream, surface water is pumped up out of the Antwerp harbour docks, sieved by means of grid and periodically shock treated with biocide (sodium hypochlorite) to prevent biofouling of the system. The water is then added to the cold-water cooling circuit.

Warm cooling water is discharged in the warm water grid by the production plants, transferred to the decentralized cooling towers on site and cooled down by air. Cooled water is pumped into the cold-water grid and recirculated over again. Warm water, which has not been pumped up by a cooling tower, is discharged in the harbour dock B3 or the Scheldt-Rhine canal.



1. Cold water pumped up out of the harbour dock B3, 2. Cold water directed to the cold-water main header, 3. Centralized cooling towers, cooling down warm water from the warm main header (6), 4. Heat Exchangers at production plants, 5. Cooling towers dedicated to specific production plants, 6. Warm water main header, 7. Discharge of warm water to the harbour dock B3 and Scheldt-Rhine canal, 8. Merades pilot plant, connected to a centralized cooling tower within AquaSPICE investigations

Figure 14 – Schematic simplified representation of the cooling system at BASF

Seasons affect mainly the salt concentration in the dock and BASF's cooling water system, with a lower salt concentration in winter/spring and a higher salinity in summer/autumn

Stream 2: RO concentrate produced during demineralized water production from the new demineralization plant.

This RO concentrate, which will have a high flow with high salt content, is to be produced from the fresh surface water of Biesbosch area as raw water source. The Biesbosch fresh water is impacted by seasonal effects, with a higher conductivity and organic load during warm periods. The sand-filtrated surface water is demineralized after passing through a softener, a double pass RO and a mixed bed.

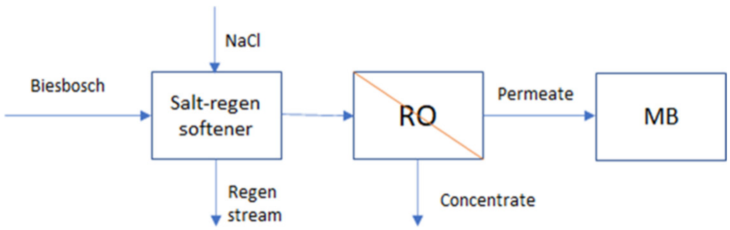


Figure 15 – RO concentrate demineralized water production (regen = regeneration; MB: Mixed bed ion exchanger)

Stream 3: consists of a mix of various streams:

- Steam cracker process streams from blowdown steam boilers: pure water with minor salt contamination
- Steam condensates (pure water containing Fe and NH_3): stream undergoes only a particle filtration and is partly recycled as boiler feed water
- Process condensates (water containing organics (aromatics) and phosphate): collected in the TBA tank and discharged to the centralized WWTP
- Collected spray water from the air condensers
- Rainwater

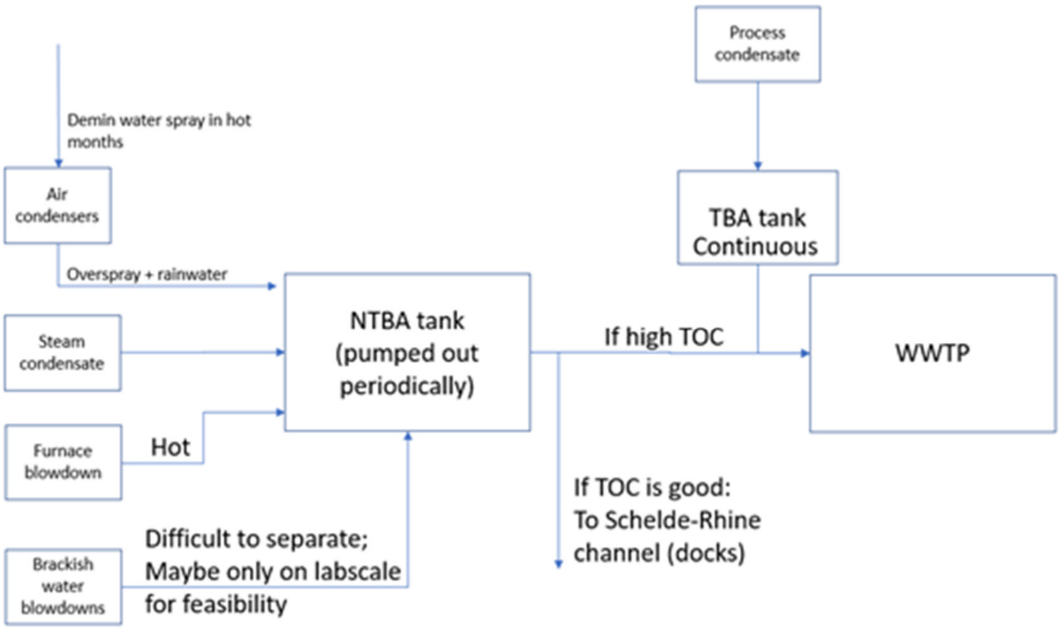


Figure 16 – Simplified schematic of the steam cracker process streams

Most of the streams of Stream 3 are collected in the NTBA tank. This is the largest stream on the cracker site and therefore of the highest interest for AquaSPICE. Because stream 3 includes the collected spray water from the air condensers as well as rainwater, its composition can have large seasonal effects. The treatment of the organically polluted process condensate, collected in the TBA tank is also considered, but with lower priority due to the challenging separation of these organics.

Currently, different water streams are reused, and heat is partially recuperated. For example, the return steam condensates of various plants are collected, polished, and reused as boiler feed water for steam generation. The condensate heat is recovered in the production of the boiler feed water.

3.5.5 Investigations within AquaSPICE

The following investigations will be carried out within the scope of CS#3B.

Stream 1a will be fed into the Merades pilot plant to investigate the cooling tower performance. The blow down water of the pilot (recirculation loop) is stream 1b, whose quality will depend on the operation of the pilot (cycles of concentration and chemical dosing). The quality is expected to vary from the current cooling water blowdown as the overall concentration factor in the cooling circuit is limited. For streams 1a and 1b, the investigations include:

- Modelling of the closed cooling water loop with water from the cooling system
- Estimation of the achievable Cycles of Concentration (CoC) without and with acid dosing
- Estimation of effect of higher salt content on used materials
- Estimation of long-term effect on water quality in harbour dock B3 (e.g., by climate change, sluice operation change, etc.)

The main aim for stream 2, RO concentrate, is to assess the feasibility of possible treatments to limit direct discharge of this stream. To valorise stream 2, several trials will be carried out:

- Investigate the reuse of the RO concentrate as a regenerant for the ion exchange softener.
- Utilize electrodialysis with bipolar membranes (EDBM) where acid and base are produced in parallel with the desalination process. The acid and base can be utilized for regeneration of mixed bed resins and cleaning-in-place processes.
- Investigate novel RO concept (Pulse Flow RO (PFRO)) where the RO is operated dynamically for e.g. 20 seconds in dead-end mode, followed by 2 second flush mode. This configuration is extremely innovative and has the advantage of increased recovery, lower fouling, eliminated or reduced biological fouling due to continuously varied salinity, and reduced scaling while maintaining higher flux. Additionally, the process can be performed in a single RO stage, which simplifies the technological configuration.

In Figure 17 to Figure 19, the different technologies to be studied for stream 2 can be seen.

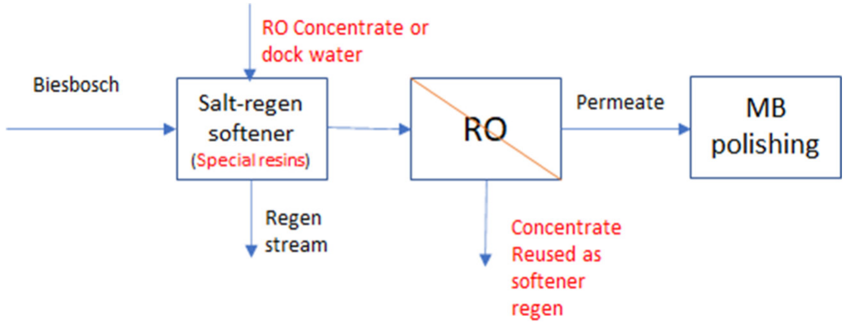


Figure 17 - Test for RO concentrate re-use

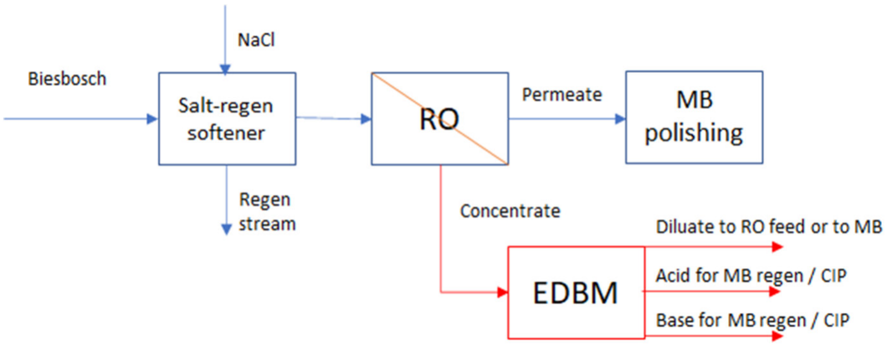


Figure 18 - Test for electrodialysis with bipolar membranes (EDBM) treatment

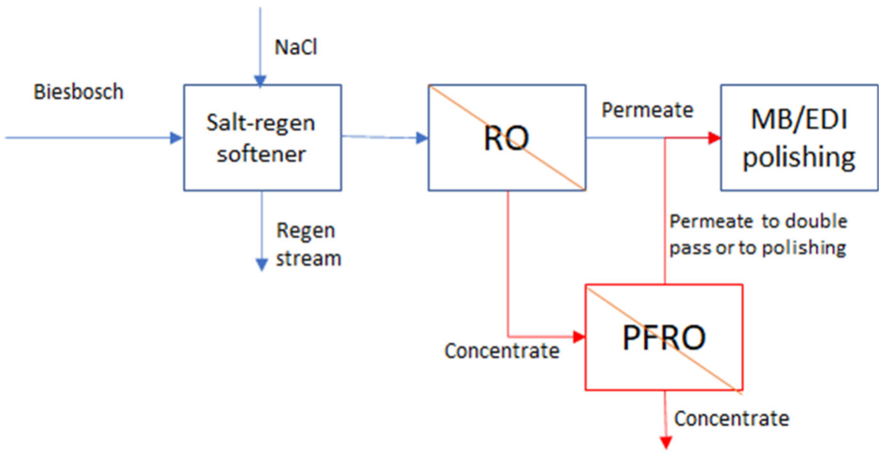


Figure 19 - Test with novel pulsed flow RO (PFRO) configuration

The objective for stream 3 (cracker process streams) is the overall reduction of demineralized water use (and raw water intake), i.e., to be assessed for the following streams:

- For NTBA: reduce discharge and reuse as water for air coolers
- For blowdown steam boilers: reduce discharge by minimized treatment and reuse as boiler feed water
- For steam condensates: maximize reuse as boiler feed water
- For process condensates: reduce discharge and maximize reuse

In Figure 20 tests carried out at the cracker site are shown.

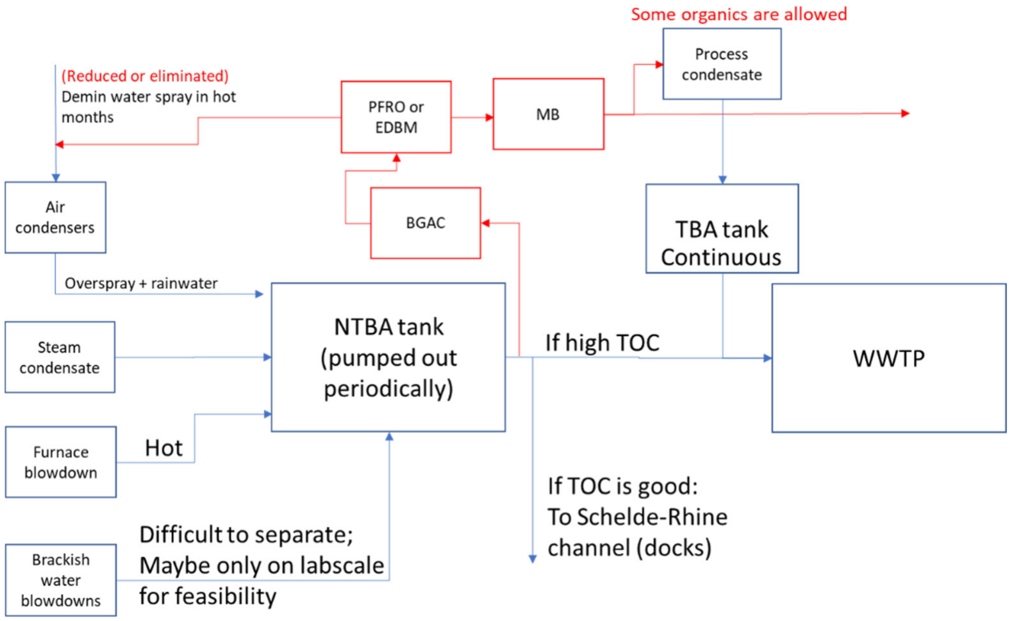


Figure 20 - Tests to be carried out (in red) at the cracker site

For stream 3 laboratory trials will help assessing the feasibility of possible treatments:

- Electrodialysis or RO desalination, with or without mixed bed resins polishing will be tested for boiler feed water production, process water production or reuse as spray water for the air coolers
- Depending on the composition of the steam condensates and blowdown steam boilers, a combination of resin treatment, reverse osmosis and biologically activated carbon treatment will be tested for boiler feed water production
- Advanced oxidation processes, biological activated carbon filtration, RO and mixed bed resins will be considered to treat the process condensate stream

3.5.6 Case study KPI

The case study specific key performance indicators (KPIs) are shown in Table 6. They will support the evaluation of the improvement of the technological solutions to be developed and implemented in AquaSPICE.

KPI	Impact within the AquaSPICE project	Relative priority
COOLING WATER: Determination of optimal cooling water heat exchange conditions at high salt content by Merades piloting.	Fully	High
COOLING WATER: Estimation of the effect of higher cycles of concentrations on water chemical, physical and biological characteristics of the blow down water.	To be defined	To be defined
WATER REUSE: feasibility study for RO concentrate reuse with economical evaluation.	50%	High

KPI	Impact within the AquaSPICE project	Relative priority
WATER REUSE: feasibility study for (partial) reuse of steam cracker streams with economical evaluation.	100%	High
WATER REUSE: required water quality for air coolers to avoid scaling and corrosion.	100%	Low

Table 6 – CS#3B KPI

The BeCircle platform by Laborelec will be implemented in this subcase, in order to identify relevant resource loops and potential industrial symbiosis. The BeCircle web-based platform allows to model industrial ecosystems in terms of resource consumption, production and transportation, helping territories to apply circular economy models. After identifying the relevant resource flow inputs and defining the industrial area to be included - which can also be linked to case Study #3A - the BeCircle platform will be applied to reveal potential synergies between the involved players and future opportunities to close resource loops within the Antwerp industrial area.

3.6 Case Study #4: JEMS (Slovenia)

Due to the non-availability of the SynDi plant in CS#4, this CS is considered as void and no work related to this CS is reported in this deliverable.

3.7 Case Study #5: AGRICOLA INTERNATIONAL S.A. (Romania)

3.7.1 Case study owner

Agricola SA is a well-known top private meat group of companies located in Bacău County, Romania, which delivers, on a daily basis, approximate 100,000 chickens (more than 150 tonnes of meat). The Group Agricola SA consists of more companies: Agricola Internațional (Fodder production, 4 specialized farms in poultry breeding, 15 chicken farms and slaughterhouse); Salbac (Cured salamis and boiled/smoked meat products); Europrod (Ready-meals and ready-to-eat products); Avicola Lumina, Constanța county (18 modernized warehouses of laying hens); and Aicbac (cereal production for fodders, small dairy farm, and dairy processing unit). Within the group, there is also a factory for egg powder production.

Besides the interaction within the Agricola Group companies, there are business relations with many suppliers, e.g., for materials for packaging and labelling, disinfection, chicken exchange.

3.7.2 Global Overview

AquaSPICE CS#5 is located at Agricola slaughterhouse in Bacău (Romania), where the key environmental issues as regard the water are:

- Water consumption (for a chicken slaughterhouse 6 L of water/1 kg meat)
- Generation of wastewater with high organic contents
- Energy consumption associated with refrigeration/freezing and heating of water.

The aim is to identify and to test a smart solution for sustainable water reuse, with the objective of improving water efficiency, monitoring and process optimisation. The poultry meat industry (throughout its entire life cycle - from farms and slaughterhouses to processing plants) needs to implement smarter solutions, reduce the environmental, water and carbon footprint and contribute to the circular economy.

3.7.3 Objectives

The aim of the CS#5 Agricola slaughterhouse is to implement a revolutionary wastewater treatment that will comply with the requirements for water reuse, both the Romanian requirements for water use in the meat industry and the Regulation 741/2020 issued by the European Commission last year with regard to the use of wastewater for irrigation.

Additionally, the following objectives have been established:

- Reducing freshwater (potable) consumption by a minimum of 70 m^3/day in the cooling area by recycling bacteriological-free treated effluent
- Reducing freshwater consumption by a minimum of 100 m^3/day in the hanging area and waste warehouse by recycling bacteriological-free treated effluent
- Exploring potential water reuse in the Agricola premises restrooms, depending on the extra investment needed

Regarding water reuse, it must be taken into account that being a food industry, the water used in all phases needs to be of potable quality. In the food industry, high attention is paid to the potentially harmful bacteria: *Escherichia coli* (*E. coli*), *Enterococci*, *Campylobacter*, *Salmonella* and *Pseudomonas aeruginosa*.

3.7.4 As-is situation

The fresh water used at CS#5 - Agricola slaughterhouse comes from two sources:

- Potable water from the Water Company CRAB SA Bacău, approx. 400 m^3/day
- Potable water from the two own wells (contract with Siret River Basin Administration), approx. 700 m^3/day

The water from both sources (CRAB SA and RBA Siret) is mixed in two reservoirs and is used for the cooling units (cooling and freezing the chicken meat), for the slaughterhouse and for the thermal plant. The wastewater generated by these 3 lines of activities is currently collected and sent to the WWTP of Agricola - approximate 900-1000 m^3/day (see Figure 21).

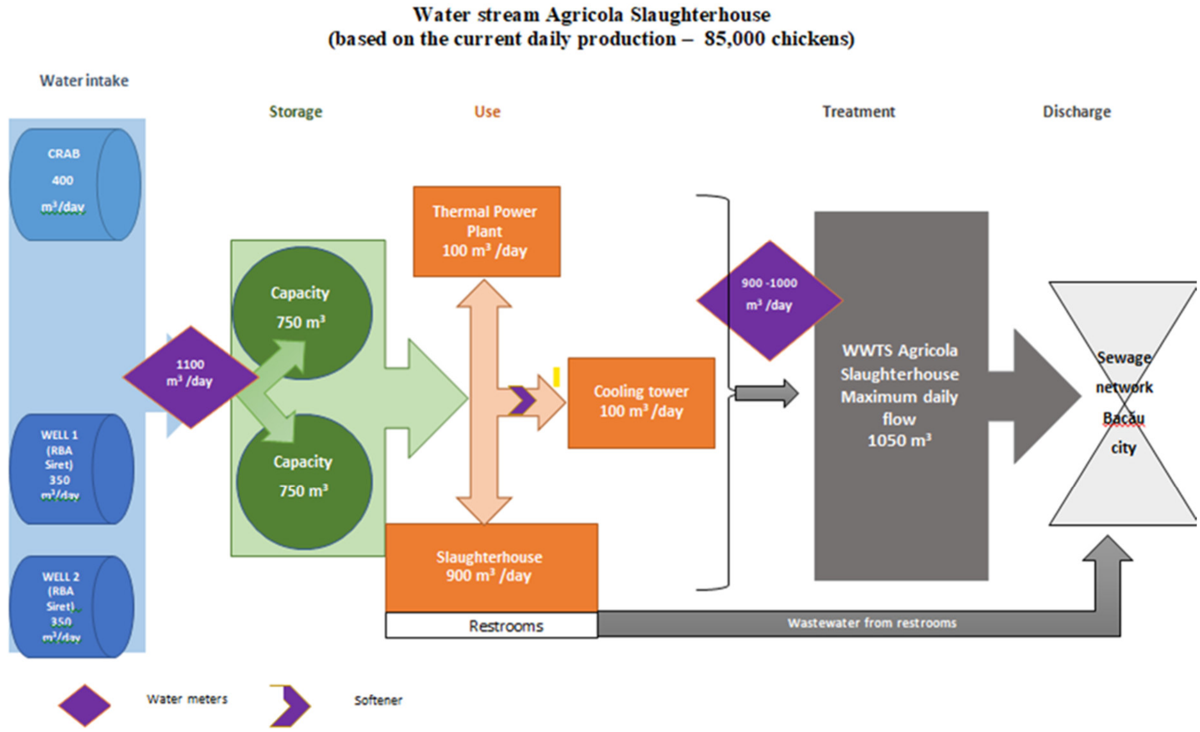


Figure 21 –Current water system scheme in CS#5

The wastewater treatment plant has the following stages:

- Mechanical stage: rotating filter
  A sieve with an admission compartment is placed so that the water passes 2 times before exiting the sieve. After first pass, solids in the suspension are accumulated on the cylinder exterior. Any solids that could block the sieve are cleaned with the second pass.
- Physical stage: flotation unit with dissolved air
  The flotation unit is supplied by gravity. The fats are separated from the water through flotation by introducing dissolved air. The fat-rich sludge formed at the surface is removed with a dedicated device.
- Biological stage: aeration basins

The wastewater flows first into the contact basin that limits the production of filamentous bacteria. From this basin the water is sent to an activated sludge basin, where oxygen is introduced through deep aeration. The system Aqua I.W.BIOART uses sedimentation to separate the activated sludge from the water. This process takes place in the aeration basin after aeration and mixing have stopped. Following the cleaned water evacuation, the system is ready to receive new wastewater for treatment.

After treatment, the wastewater is currently discharged in the public sewer network managed by the Water Company CRAB SA.

Within the investigations in AquaSPICE, 3 different water streams are currently evaluated, in order to establish the needed technology for the wastewater treatment that will secure the recycled water quality according with the legal parameters for reuse.

Stream 1: Raw wastewater at the inlet of the WWTP.

Stream 2: Degreased water after equalisation tank in the WWTP physical stage.

Stream 3: Partially treated water at the outlet of the aeration tank, before being discharge to the sewer network.

Control system

There are no sensors or control platform for the water monitoring in the current Agricola Slaughterhouse water operations. The only measurement is done through water meters that are not connected to any ICT network. Two water meters are for the intake water sources and one water meter is located before the WWTP to measure the volume of wastewater produced. The data from these water meters is collected manually.

The Agricola WWTP also has a level sensor in the biological treatment unit. This sensor activates the discharge of the water in the sewer network.

3.7.5 Investigations within AquaSPICE

The flowchart below shows the 3 potential streams of wastewater to be treated in the pilot plant. Only one stream will be selected for treatment in the pilot plant after the characterisation of the wastewater. A sampling programme is currently being developed for the characterisation of the 3 wastewater streams.

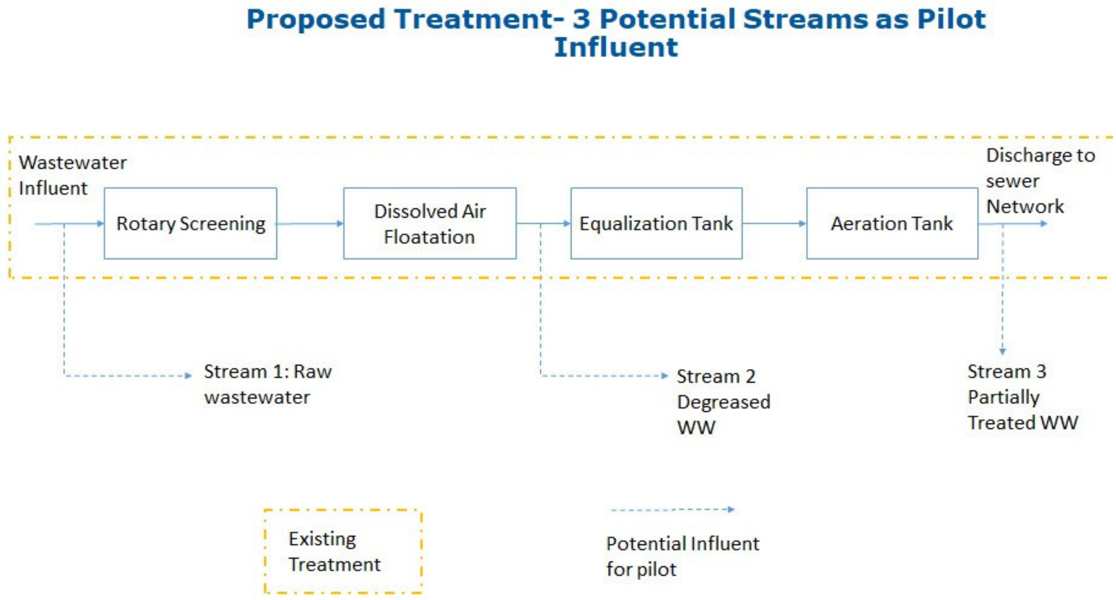


Figure 22 – Proposed wastewater streams to be treated in CS#5 pilot plant

The treatment plant configuration will depend on the selected wastewater stream quality to be treated. Based on the project partners expectations, it will consist of a membrane bioreactor (MBR) system integrating:

- Coarse screening to remove any debris and large solids
- Oil/grease removal by flotation process
- Fine screening to protect the MBR system
- Ultrafiltration membrane bioreactor for nutrient removal and clarification
- Tertiary treatment for disinfection and effluent polishing before re-use

Due to the very rigorous bacteriological parameters of water used in the food industry any technology used to treat the wastewater should take into account that results should be bacteriological-free water. AquaSPICE hopes to prove that technologies tested are suitable to achieve the goals for wastewater reuse for:

- Cooling towers – freezing meat and meat products (bacteriological free water)
- Slaughterhouse – wash the boxes, the trucks and the platforms for chicken transport and the waste warehouses (bacteriological free water)
- Restrooms – depends on the investment needed
- Irrigation of the green spaces and washing of the alleys around the slaughterhouse (EU Regulation 741/2020).

If desalination of the treated effluent is required for reuse in the cooling tower, a reverse osmosis system might be needed in addition to the existing softener system. In that case, a decision will be made whether the treated effluent reuse will be limited to operations where conductivity/salinity reduction is not required.

3.7.6 Case study KPI

The case study specific key performance indicators (KPIs) are shown in Table 7. They will support the evaluation of the improvement of the technological solutions to be developed and implemented in AquaSPICE.

KPI	Impact within the AquaSPICE project	Relative priority
Water consumption reduction.	Reduction by 30% of overall freshwater consumption.	High
Improve quality of the reclaimed water.	Meet the EU and National legislation requirements for water use in meat industry.	High
Contribute to improved knowledge as regards water reuse in the food industry.	CS#5 results to demonstrate sustainability for water use and reuse processes in the food industry.	Medium

Table 7 – CS#5 KPI

3.8 Case Study #6: TURKIYE PETROL RAFINERILERI ANONIM SIRKETI (Turkey)

3.8.1 Case study owner

Tüpraş (Turkiye Petrol Rafinerileri Anonim Sirketi) is one of the most important companies in Turkey. It is the first producer in Turkey's refining sector and largest industrial enterprise of the country, operating four oil refineries with a total annual processing capacity of 30 million tons crude oil.

3.8.2 Global Overview

Oil and gas refining industry is a water intensive consumer, requiring vast amounts of water used as cooling water, service water, firefighting water, demineralized water and for steam production. A refinery also has closed-loop water reuse opportunities embedded in the production line (e.g., drum wash water, stripped sour water, desalter, make/up water, coke-cutting water).

Tüpraş Izmit Refinery is consuming both fresh water from a nearby lake and treating the wastewater coming from refinery process units in its own wastewater recovery plants. During maintenance operations or in case of capacity problems, the refinery might need to rely heavily on the lake as water source. To increase the water reuse opportunities and decrease freshwater intake from the lake, any attempt approaching near zero liquid discharge goal is considered seriously.

Smart monitoring and advanced biological treatment, coupled with a separation process using regenerated membranes (end-of-life reverse osmosis (RO) membranes from desalination plants) will be tested to produce reclaimed water for industrial purposes.

3.8.3 Objectives

The wastewater treatment system that is studied in the scope of AquaSPICE is Ballast Water Treatment Plant. Although it is called ballast water, it is not solely composed of ballast water but also different wastewater streams from the refinery operations. Currently, the wastewater in this system can only be treated to meet the discharge limits to prevent any distortion of the ecological balance of the receiving water body with the available technology.

The main objectives of the ballast wastewater treatment system are:

- To minimize the damage to the environment (sea)
- To comply with discharge legal regulations
- To recover and reuse water in the refinery with advanced treatment technologies

With the ambition to take significant steps towards near-zero liquid discharge, investigations in AquaSPICE are focused on recycling and reusing the outlet stream of ballast water treatment system in the refinery, mainly as cooling water or firefighting water.

3.8.4 As-is situation

The contaminated water that is fed to the Ballast Water Treatment Plant comes from two different water tanks: TK-1 and TK-2.

Stream 1 from tank TK-1.

It is the storm drain and rainwater tank and receives backwash water of existing water reuse plants (MMF, ACF, UF, RO) as well. It is not highly contaminated with pollutants, but it can be highly conductive depending whether the water recovery system is active and backwash water from UF, RO etc. is present. This stream is mixed with Stream 2 before further processing.

Stream 2 from tank TK-2.

It consists of ballast water and hot wash water from the kerosene treatment unit. It is highly polluted with high levels of phenols, NH_4-N and S^{2-}. It has a high pH value and can have a high conductivity depending on the processed crude oils. Due to its contaminant levels, it needs to be mixed with other streams before biological processing.

Stream 1 and Stream 2 are currently mixed and primary treatment (physical and chemical) is applied at ballast water treatment plant, to separate suspended solids, oily contents, and sulphur. It also helps decreasing COD load, regulates pH, and increases alkalinity.

Ballast water treatment system consists of:

- A tilted plate separator, where physical treatment takes place; oil layer that is gathered on the surface is separated
- A coagulation step, where flocculation agent and Na_2CO_3 (pH regulator) are added to the wastewater
- A Dissolved Air Flotation (DAF) basin, where the flocs are brought to float by the help of air diffusers and are separated at the surface of the basin from the bulk wastewater.

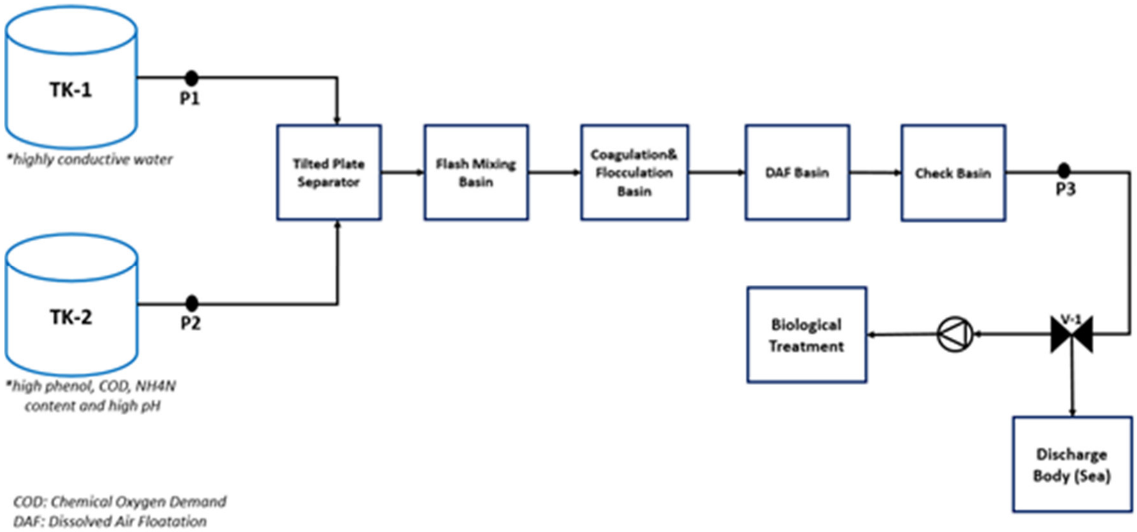


Figure 23 – Ballast water treatment plant scheme

After P3 point (see Figure 23), the effluent of the ballast water treatment system is connected to the biological treatment system, which consists of activated sludge basins. These are monitored by pH, temperature, and dissolved oxygen sensors.

Currently, the water quality at the ballast water treatment plant outlet is not suitable for biological treatment due to highly contaminated water (stream 2) and conductivity limitations (stream 1), which inhibit the microorganism activity. Therefore, it cannot be sent to the biological and tertiary treatment (membrane filtration system) and be reused in the refinery. Instead, it is discharged to the receiving body (sea). The discharge standards for wastewater are defined by the governmental authorities. There are analysers at the discharge points into the sea that are properties of the ministry and are not used to control the process. Offline laboratory measurements are carried out for the discharge stream (including COD, suspended solids, Cl^-, oil, sulphur, NH_4-N, phenol and iron).

Control system

This plant does not currently have any sensor to control the blending of streams 1 and 2 as well as to control the wastewater treatment process. The status of the equipment can be followed on a Distributed Control System (DCS) screen.

3.8.5 Investigations within AquaSPICE

The water to be treated will be a blend of the two wastewater streams (Tank-1 and Tank-2 streams). The blending process will be controlled by flow control valves connected to a monitoring system. There will be another automatic valve connected to the monitoring system after the current treatment train that will conduct the water, depending on its characteristics, to either:

a) AquaSPICE pilot plant

b) Existing biological treatment

c) Discharge body

AquaSPICE proposed treatment train, see Figure 24, starts with an aerobic granular bioreactor for removing the organic matter (principally toxic/recalcitrant organic matter) followed by a membrane separation step to remove the salts and produce high quality water that can be reused in the process as cooling water. For the membrane separation step, end-of-life regenerated RO membranes will be used. The regeneration of RO membranes consists in chemically modifying the active layer to give them new properties and uses. This allows to reuse these end-of-life membranes, which would otherwise end up in a landfill.

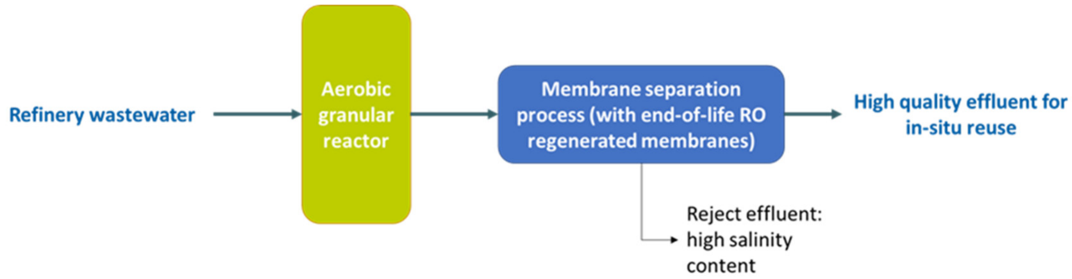


Figure 24 – Proposed treatment train scheme in CS#6

As it was previously mentioned, the mixture of stream 1 and 2 cannot always be fed to the current biological treatment because of some contaminants inhibiting the microorganisms responsible for biodegradation. Therefore, if the properties of the blended tanks meet the requirements of biological treatment, the P3 stream should be sent to the biological treatment. However, if the properties of the blended tanks do not meet the requirements of the large-scale biological treatment system, the blended stream will be sent to the proposed pilot plant, which will produce cooling water or firefighting water, depending on the water quality achieved. The input stream of pilot plant will be adjusted after the deployment of sensors and control valves in the future. Figure 25 shows where the pilot plant will be implemented.

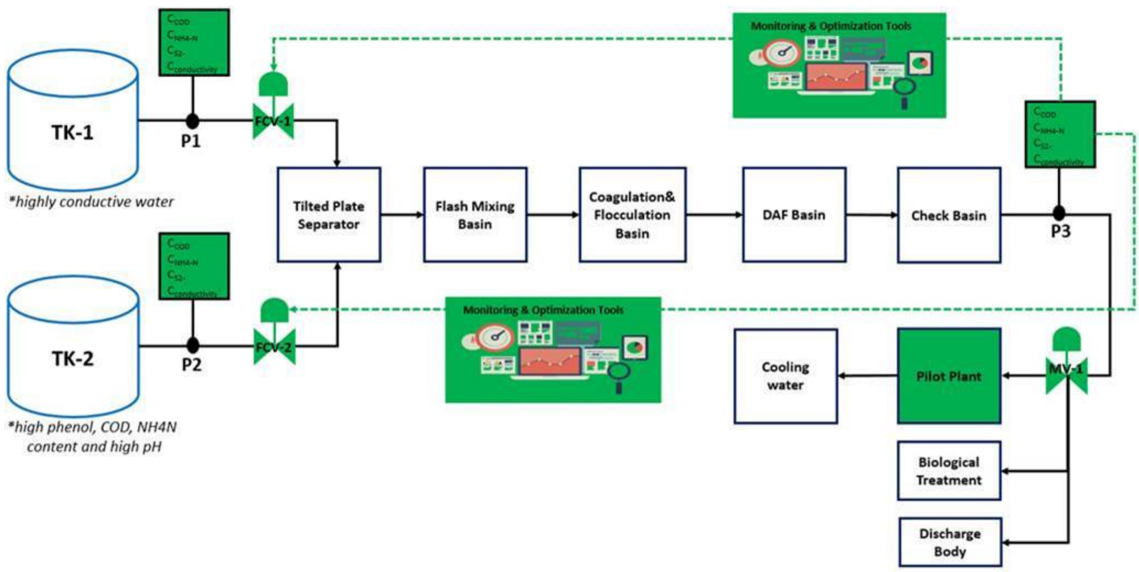


Figure 25 – AquaSPICE pilot plant implementation scheme in CS#6

3.8.6 Case study KPI

The case study specific key performance indicators (KPIs) are shown in Table 8. They will support the evaluation of the improvement of the technological solutions to be developed and implemented in AquaSPICE.

KPI	Impact within the AquaSPICE project	Relative priority
Water recycle ratio of the water treated in the pilot plant.	At least 50%	Medium
The number of days achieving concentration in discharge water below limits.	90 % of the year	High

Table 8 – CS#6 KPI

4 Conclusions

This deliverable D2.1 *Technology configuration and basic design for each CS* is based on a project-wide questionnaire, which gathered information on industry sector specifications, stakeholders, current raw water and product water qualities but also on targets for future developments related to water issues. The questionnaire, which was answered individually by each case study team, is a key starting point for the activities in WP2 *Industrial Water Saving, Recovery, Treatment and Re-use Technologies & Practices* but also for many other WP in AquaSPICE.

The present deliverable is a summary of central aspects of the questionnaire, focussing first on the current situation at each study site, before identifying the drivers for improvement for one or several streams within the factory or across the wider study site. Common to the water visions of all case studies is a reduced water intake achieved by a higher water efficiency and/or an (improved) treatment and reuse of various water streams.

This report highlights the different technologies to be tested within AquaSPICE at each case study site, illustrating a wide variety of processes, including:

- Physico-chemical processes (e.g., CS#1A, CS#1B, CS#2, CS#3B, , CS#5)
- Membrane-based processes (e.g., CS#1A, CS#1B, CS#2, CS#3B, CS#5, CS#6)
- Biological processes (e.g., CS#2, CS#5, CS#6)

Pilot installations of different treatment capacity will be deployed at each site, supported by a strong monitoring programme. As presented in this deliverable, modelling activities of the water treatment technologies are forming an integrative part of the case study investigations, e.g., in CS#1A, CS#1B, CS#3B for cooling systems or CS#2 for the WAPEREUSE pilot plant. Furthermore, modelling activities are planned for a region or an area to support operational decisions, e.g., CS#3A for the water intake.

The information compiled in this report is valuable for and beyond WP2, whose scope includes the configuration of the best and most feasible practices and treatment technologies for each particular CS. WP2 activities also comprise the definition of the operational procedures, protocols, requirements and constraints for technology application, before developing an evidence database with real practices on industrial water recycling and reuse.

WP2 prepares the ground for the deployment of the pilot installations, which will allow for a demonstration and evaluation of the AquaSPICE solutions at the individual sites, an involvement of local and/or regional stakeholders and finally a transferable evidence on the applicability of the AquaSPICE solutions.