EXPERTISES

DKarbonation

Jan. 2024

A quality model for the circular economy of industrial water

ZIBAC Call for Projects – DKarbonation project – Building a territory that leads industrial decarbonization

1. Introduction

Since 1973, the industrial water service has supported the industrial development of the Dunkirk region by ensuring the water supply for major companies in the port area. This network, fed by raw water drawn from the Bourbourg Canal, makes it possible to replace drinking water in industrial processes, thereby helping preserve this vital resource. Managed by the Dunkirk Water Syndicate (SED), it now supplies 16 industrial companies in the Dunkirk industrial and port zone, with a production volume reaching 22.6 million m³ in 2024.

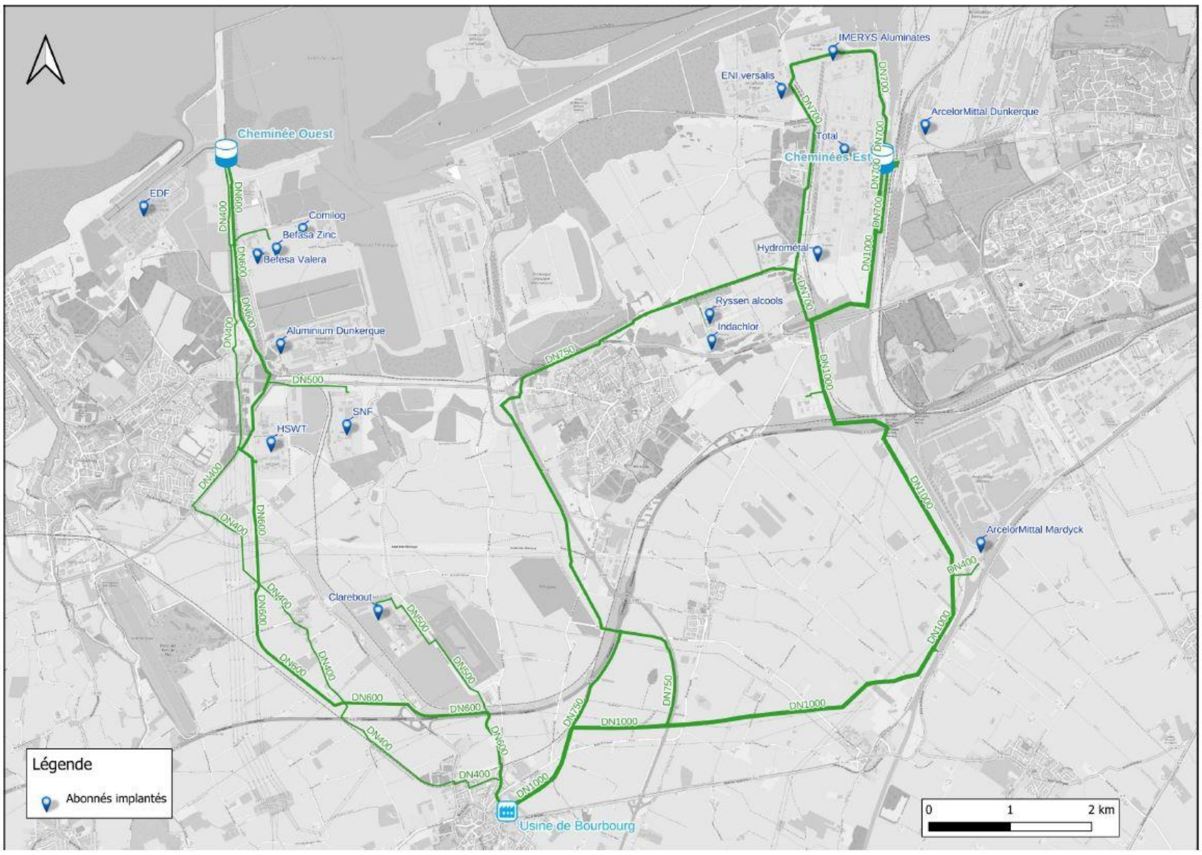

Figure 1 Industrial Water Network with the East Branch and the West Branch

The Dunkirk territory is actively committed to promoting industrial ecology and implementing circular-economy principles applied to water management. Studies conducted so far have highlighted innovative solutions, such as the reuse of wastewater generated by industrial activities. This reuse can occur either directly between different industrial sites or through the reinjection of these waters into the existing Industrial Water network. Such an approach helps significantly reduce pressure on surface water resources.

2. Objectives of the study

A potential reinjection capacity of nearly 3 million m³ of water into the industrial water network has been identified to date. Reusing this volume would have a positive impact on water resources and could support the development of decarbonization solutions based on the use of industrial water within the ZIBaC.

To continue exploring and developing these synergies, it has become essential to integrate a quality module into the hydraulic modelling of the industrial water network. The purpose of this module is to precisely assess the impact of reinjection on the quality of the water distributed throughout the network.

The quality module must make it possible to measure the network’s ability to integrate and accept water resources of different types. It must also validate certain assumptions related to direct reinjection, support the evolution of existing scenarios, and enable the design of new ones based on the territory’s needs and objectives.

Water-quality modelling, conceived as an evolving digital tool, will be a key component in supporting decision-making in the field of industrial ecology applied to water management. It fully aligns with the dynamics of the circular water economy, serving as a major lever for supporting and transforming the industrial landscape of the Dunkirk territory.

In this context, the Dunkirk Water Syndicate (SED) has launched a project management assistance contract, entrusted to SUEZ Consulting, for the development of this tool. The SED has expressed the need for the model to assess the impact of reinjection on the quality of industrial water flows, taking into account several specific parameters.

The specific parameters are as follows :

pH	DCO
Température	Arsenic
Turbidité	Cadmium
Conductivité	Chrome
Nitrate	Cuivre
Nitrite	Nickel
Ammonium	Plomb
Chlorure	Zinc
Sulfate	Manganèse
Dureté	Fer
TAC	Mercure
Matières en suspension	Indice hydrocarbure
Calcium	Lithium
Magnésium	Orthophosphates
Sodium	Fluorure
Potassium	Bromure

In addition, the service provider was asked to put the developed quality module to the test by examining seven distinct scenarios. This approach aims to ensure the model’s ability to reliably assess the impact of different reinjection assumptions on industrial water quality.

Furthermore, training sessions for SED staff were planned to enable them to independently operate the model. This step ensures that SED teams acquire the necessary skills to continue studies and analyses autonomously, thereby guaranteeing the long-term continuity of the actions undertaken and strengthening the territory’s ability to adapt to future challenges in industrial water management.

3. Methodology

The study was carried out in five main stages:

1. **Data collection and analysis:** Updating the hydraulic model of the network using the latest data and measurements.
2. **Development of the quality module:** Integration of 32 physico-chemical parameters to simulate industrial water quality under different scenarios (summer period, winter period, rainy period).
3. **Definition of reinjection scenarios:** Construction of 7 scenarios with different injection points and volumes, incorporating available data on the quality of effluents from selected industrial sites.
4. **Simulation and impact analysis:** Assessment of variations in water quality for each scenario.
5. **Training and support:** Training SED staff in the use of the model to ensure autonomy and long-term continuity of analyses

4. Data collection, data analysis et development of the quality module

4.1 Description of the quality module of he PICCOLO software

The first step consisted in gathering and analyzing all the data required for the modelling process. SUEZ CONSULTING updated the hydraulic model of the industrial water network developed using the PICCOLO software. This update incorporated the latest available information on existing and planned structures, as well as the most recent hydraulic measurements. The structure of the network is illustrated in the following figure, showing the distribution of pipe diameters.

The model reflects the hydraulic conditions of 24/07/2024 (model calibration) and integrates the consumption profiles of the various industrial users based on the collected measurements.

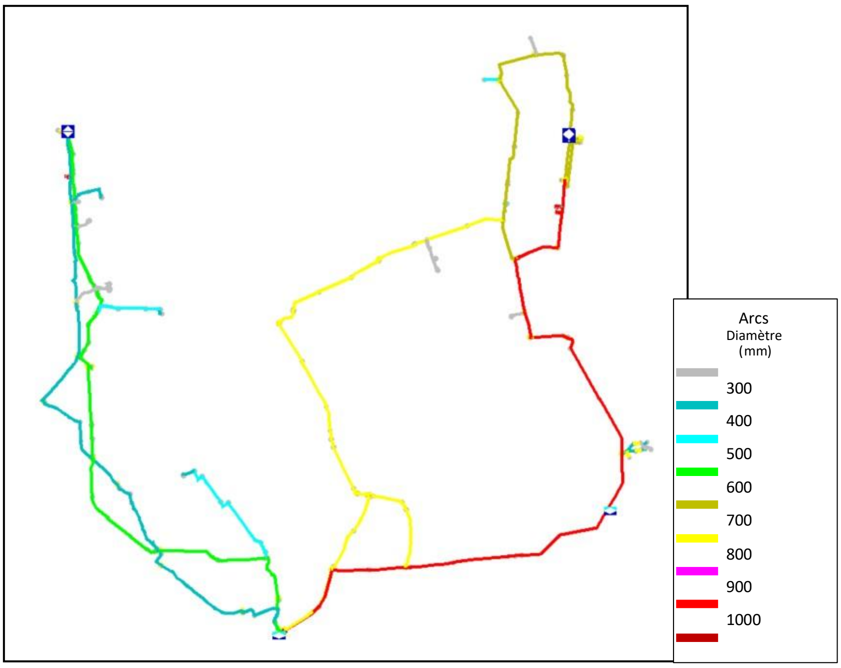

Figure 2 Diagram of the Industrial Water Network in the PICCOLO modelling software

The PICCOLO quality module incorporates advanced features for modelling water quality within distribution networks, including :

The calculation of residence times in pipes and reservoirs

The determination of water origin, the influence zones of resources and reservoirs, and the assessment of water renewal within storage facilities

The modelling of up to 36 conservative and stable compounds, taking into account dilution effects resulting from the mixing of waters of different origins

The modelling of one non-conservative compound, with a degradation kinetics comparable to that of chlorine

This module makes it possible to simulate, under steady-state conditions, the propagation of compounds within the network, whether they are conservative (non-reactive) or non-conservative (subject to decay over time or chemical reactivity).

For the purposes of this study, the 32 analysed parameters are considered conservative. This means they undergo no chemical transformation, no adsorption onto pipe walls, and no degradation during their transit through the network. Their spatial and temporal evolution is governed solely by transport mechanisms (advection, dispersion) and dilution between different water sources.

4.2 Adjustments and parameter settings

The following adjustments were applied to the models:

- Integration of raw-water quality parameters at the Bourbourg plant. This configuration was carried out for three distinct periods: summer period, winter period, and rainy period.
- Integration of flow rates and associated quality parameters related to the reinjection projects involving industrial process water.

4.3 Study of raw-water quality at the Bourbourg Canal intake

The water quality at the intake point was assessed using monthly self-monitoring measurements collected between 2018 and 2023, as well as CARSO laboratory analyses from 2020. A statistical comparison was carried out on both datasets. The values were found to be very similar, with a relative difference of less than 10% in 66% of cases. To best represent the observed concentrations, the average of the two measurement series was selected as the input dataset for the model.

The summer period is defined as a six-month interval from May to October inclusive, while the winter period covers November to April.

Rainy periods were identified using Météo France data from weather station n°59183001 [Dunkerque Sémaphore]. A day is classified as rainy when the daily precipitation total (RR) exceeds the 90th percentile (k > 0.9), corresponding to a threshold of 6.4 mm. On 9 March 2020, a total of 10.7 mm was recorded, corresponding to the 93rd percentile, confirming the rainy nature of that day. CARSO conducted sampling and analyses on 10 March 2020. It is therefore proposed to consider the concentrations measured by CARSO on 10 March 2020 for the 32 studied parameters as representative of a rainy-weather episode.

5. Reinjection scenarios studied

Once the models were built, several reinjection scenarios were defined. This step aims to explore different hypotheses for the reuse of industrial waters, based on identified needs and territorial objectives, in order to assess the potential impacts on the quality of the water distributed.

The study examined a range of possible synergies and selected 9 industrial sites as candidates for reinjection, based on quantitative and qualitative criteria.
Accordingly, 7 reinjection scenarios were developed and are presented in the table below :

Scenario No.	Title
1	Reinjection of REUT effluent from the Gravelines WWTP to supply the future EPR units
2	Reinjection from Versalis
3	Reinjection from Hyet Sweet
4	Combined reinjection from Hyet Sweet & REUT effluent from the Gravelines WWTP
5	Reinjection from Air Liquide
6	Reinjection from Versalis (alternative injection point)
7	Reinjection of “REUT effluent from the Gravelines WWTP” with the installation of a new balancing chimney

In the Piccolo model, the theoretical reinjection points must meet specific criteria:

- They must be located on the main (structuring) network ;
- They must be positioned in accordance with the direction of flow within the structuring network, in order to maximise mixing between reinjected effluents and to avoid any return of these effluents into the industrial user’s own connection.

Each predefined scenario was then examined in detail. This analysis makes it possible to assess the effects of each reinjection configuration on the network, to confirm or invalidate certain assumptions, and to identify the best practices to adopt in order to preserve the water resource.

The water-quality modelling of the Dunkirk industrial water network evaluated seven reinjection scenarios across 32 physico-chemical parameters. Each impact is quantified using a relative deviation index (ranging from 0 to 6) comparing simulated concentrations with the reference concentration (criterion 0 = <10% deviation; criterion 6 = >200% deviation). The simulations show that certain critical parameters exhibit very pronounced deviations depending on the scenario and the location of the industrial sites.

- Calculation of the relative deviation (σ) for each parameter compared with the industrial water quality, across different periods of the year, highlighting the impact of reinjection on each industrial site and for each parameter.

$$\sigma = \left| \frac{Modelled\ concentration - Reference\ concentration}{Reference\ concentration} \right|$$

Critères	Ecart relatif à la valeur considérée dans l’eau brute (σ)
Critère 0	σ < 10%
Critère 1	10 % < σ < 30%
Critère 2	30 % < σ < 50%
Critère 3	50 % < σ < 100%
Critère 4	100 % < σ < 150%
Critère 5	150 % < σ < 200%
Critère 6	σ > 200%

6. Main results

Scénario 1 – Scenario 1 – Reinjection of effluents from the Gravelines WWTP

The daily reinjection (1,300–3,000 m³/d) affects Befesa Zinc and EDF. For EDF, chloride, sodium and potassium reach criteria 4–5 (deviations >100%). Befesa Zinc, located immediately downstream of the injection point, shows the same three parameters at criteria 4–6, with zinc also exceeding thresholds. During rainy periods, these deviations intensify (reaching criterion 6) and extend to parameters that were previously less affected (conductivity, sulfates, bromides). Other industrial users (Clarebout, SNF, upstream Hyet Sweet, etc.) are not impacted and maintain a quality equivalent to that of the raw water.

Scenario 2 – Reinjection of effluents from Versalis

The discharge of 1,000,000 m³/year has a strong impact on Kerneos, which is located very close to the injection point. Eleven of the 32 simulated parameters reach criterion 6 (relative deviations multiplied by 6 to 20). Four additional parameters reach criteria 4–5. These exceedances are explained by the high organic and mineral load of the Versalis effluent — very high COD and hydrocarbons, dissolved metals, and ions (chlorides, sulfates, sodium). Further downstream, Total benefits from significant dilution (most deviations fall to criteria 0–2), whereas Air Liquide, despite partial dilution, still shows 16 parameters at criteria 4 or higher due to its very high withdrawal flow rate.

Scenario 3 – Reinjection of effluents from Hyet Sweet

The Hyet Sweet effluent (~490,000 m³/year) injected into the western branch affects all four downstream clients in a similar way (EDF, SNF, Befesa Zinc, Aluminium Dunkerque). Several key parameters consistently reach criterion 6 (>200% deviation): COD, nitrites, chlorides, sulfates, hydrocarbon index and sodium. These deviations are consistent with the chemical composition of the effluent (chlorides, sulfates and sodium in the thousands of mg/L, i.e. roughly 100 times higher than raw water; COD, nitrites and hydrocarbons multiplied by a factor of 10 to 30 compared with the reference). Conversely, parameters such as temperature, nitrates, suspended solids or pH remain only slightly affected (limited deviations, criteria 0–2).

Scenario 4 – Combined reinjection of effluents from Hyet Sweet and the Gravelines WWTP

The dual reinjection combines the previous effects on the western branch (total injection volume ≈964,000 m³/year in dry weather and 1,584,000 m³/year in rainy conditions).

Only Clarebout and Hyet Sweet remain unaffected. For all other users, the impact is multifaceted: dominant parameters (COD, nitrites, chlorides, sulfates, hydrocarbons, sodium from Hyet Sweet) remain at criteria 4–6, while the WWTP also contributes significantly to conductivity, zinc and potassium (criteria 3–4).

Other parameters (nitrates, bromides, magnesium, TAC) show only moderate deviations (criteria 1–2), and temperature, suspended solids and pH remain stable (deviations occasionally <10%). During rainy periods, the increased WWTP flow further amplifies contrasts and pushes several parameters toward criterion 6.

Scenario 5 – Reinjection of effluents from Air Liquide

The Air Liquide reinjection affects the eastern branch. The Total site is the most impacted: 5 of the 9 parameters fall within criteria 5–6 (COD, chlorides, zinc, sulfates and hydrocarbons).

This reflects the high mineral content of the Air Liquide effluent (e.g. chlorides ~400 vs 46 mg/L in raw water; sulfates ~850 vs 38 mg/L; zinc 650 vs 12.7 µg/L; COD 60 vs 11 mg/L; hydrocarbons 5 vs <0.1 mg/L). Air Liquide itself retains 4 major parameters at criteria 4–6 (chlorides, zinc, sulfates, hydrocarbons), but the overall impact on its own supply is mitigated by its very high withdrawal volume (≈1.4 million m³/year, which dilutes the reinjected effluent).

Scenario 6 – Reinjection of effluents from Versalis (alternative point)

Scenario 6 mirrors the configuration of Scenario 2, but with the injection point shifted further downstream. The simulations confirm that this relocation spares the Kerneos site, which is now positioned upstream of the discharge. However, the impacts persist for Air Liquide and Total, both of which retain a significant number of parameters classified at criterion ≥4 (with COD, hydrocarbons and certain metals remaining strongly affected compared with the raw-water baseline).

Scenario 7 – Reinjection of effluents from the Gravelines WWTP with the installation of a new balancing chamber

Scenario 7 retains the injection point used in Scenario 1 but significantly modifies the reinjected volumes (≈650 m^3/d in dry weather and ≈2,350 m^3/d in rainy conditions) and incorporates the future 5,000 m^3 balancing chamber on the western branch. Overall, the combined effect of reduced volumes and the relocation of the balancing chamber decreases the impact observed in Scenario 1.

In addition, the redistribution of flows induced by the chamber alters the spatial pattern of impacts: Befesa Zinc, which was heavily affected in S1, is now spared, while SNF and Aluminium Dunkerque show occasional qualitative impacts during rainy periods.

7. Conclusion and outlook

The scenarios show that certain parameters (chlorides, sodium, potassium, COD, hydrocarbons, sulfates) are particularly sensitive to reinjection. Depending on the scenario and the location, significant increases in these parameters may be observed, sometimes multiplied by a factor of 10 to 20 compared with the reference. The effects vary according to the time of year (dry or rainy periods) and the configuration of the network.

The quality module developed is now fully operational and mastered by the SED teams. The simulations make it possible to optimise reinjection scenarios within the Industrial Water network. Work is ongoing to refine the scenarios and plan concrete actions with the industrial partners involved. Modelling remains an evolving tool, supporting water circularity and the decarbonisation of the Dunkirk territory.

The circular economy of industrial water represents a major opportunity for the Dunkirk area. Thanks to advanced modelling and the involvement of local stakeholders, it is possible to reconcile industrial development, resource preservation and ecological transition. The SED, in partnership with local actors and industries, continues its efforts to implement innovative and sustainable solutions for the benefit of the entire territory.

RÉSUMÉ

The Dunkirk Water Syndicate (SED) manages an Industrial Water network supplying 16 industrial users, helping preserve drinking-water resources through the use of raw water from the Bourbourg Canal. In line with an industrial ecology and circular-economy approach, the project aims to reuse industrial wastewater, thereby reducing pressure on the water resource. The study identifies a reinjection potential of nearly 3 million m³/year into the Industrial Water network, requiring the integration of a quality module into the network's hydraulic model.

This module, developed in PICCOLO by SUEZ Consulting, makes it possible to assess the impact of reinjection on the quality of the distributed water by simulating 32 physico-chemical parameters across different scenarios and periods (summer, winter, rainfall). Seven reinjection scenarios were analysed, involving various industrial sites and injection points. The simulations show that certain parameters (chlorides, sodium, potassium, COD, hydrocarbons, sulfates) are particularly sensitive to reinjection, with deviations that may be multiplied by a factor of 10 to 20 depending on the scenario and the location of the injection points.

The results highlight the importance of both the positioning of injection points and the reinjected volume in limiting negative impacts on water quality. Adjustments such as relocating injection points or modifying reinjection volumes help mitigate some undesirable effects. The quality-modelling tool is now fully mastered and enables the identification of viable reinjection solutions for industrial-process water, contributing to the decarbonisation of the Dunkirk territory.

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