IN THE MED

Innovative and Sustainable Groundwater Management in the Mediterranean

D5.3a Report on the Appropriate Innovative Remediation Process Developed

VERSION 1.0

PRIMA
PARTNERSHIP FOR RESEARCH AND INNOVATION IN THE MEDITERRANEAN AREA

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Glossary

CERTE	Centre de Recherches et des Technologies des Eaux
COD	Chemical Oxygen Demand
D	Deliverable
DSS	Decision Support Systems
GMB	Group Model Building
M	Milestone
MED	Mediterranean
NGO	Non-Governmental Organizations
SD	System Dynamics
WP	Work Package

Executive Summary

The overall objective of the InTheMED project is to implement innovative and sustainable management tools and remediation strategies for MED aquifers (inland and coastal) in order to mitigate anthropogenic and climate-change threats by creating new long-lasting spaces of social learning among different interdependent stakeholders, NGOs, and scientific researchers in five field case studies. These are located at the two shores of the MED basin, namely in Spain, Greece, Portugal, Tunisia, and Turkey.

InTheMED will develop an inclusive process that will establish an ensemble of innovative assessment and management tools and methodologies including a high-resolution monitoring approach, smart modelling, a socio-economic assessment, web-based decision support systems (DSS) and new configurations for governance to validate efficient and sustainable integrated groundwater management in the MED considering both the quantitative and qualitative aspects.

This document collects the work done in the first part of Task 5.3 " Development and Upscaling of Remediation Technologies" and represents both D5.3a Report on the Appropriate Innovative Remediation Process Developed and M5.3a First Draft of the Innovative Remediation Strategies Performed. The aim of this document is to define specific water remediation strategies for the different cases studies of the project. This subtask is based on the results of the training session on sustainable integrated water management and the living lab, which involved stakeholders in a social learning process for the design of new water management in accordance with the 4Rs principle (Reduce, Recycle, Reuse, and Recover). Alternative technologies, specifically for the treatment of industrial wastewater, have been evaluated to establish the most eco-efficient practice.

1. Overview

The present deliverable is a component of Task 5.3, "Development and Upscaling of Remediation Technologies," and it seeks to investigate water remediation technologies in order to address the issues in each case study: i) In Grombalia, the textile industrial activities and overexploitation of groundwater resources, ii) in Konya, soil salinization resulting from excessive use of brackish groundwater for irrigation, iii) in Requena-Utiel, the sustained decline of water levels due to excess pumping for irrigation activities, and iv) in Tympaki, salt water intrusion and overexploitation, and v) in Castro Verde, contaminants originating from mining activities.

2. Development of water remediation technologies and strategies

2.1. Grombalia case study, Tunisia

2.1.1. Capacity building on innovative remediation technologies: Industrial activity

2.1.1.1. Planning and designing of training session

In Grombalia, the Tunisian demonstration site, the focus was put on industrial activity which is one of the most developed sectors in this area represented by almost 56 industries, directly affecting the local aquifer by increasing pressure on water resources and harming their quality., due to its untreated or partially treated effluents [1]. The sustainable developed model for textile sector is applicable to other type of industrial activities.

The selected industry is one of the most important companies of textile and clothing industry implemented in Grombalia case study. The commitment of this company is underlined by its support to a cleaner industry and its attempts to respect the environment. The selected industry is equipped a wastewater treatment plant to treat its highly contaminated effluents, generated from the garments washing process before discharge.

The first step after having had the agreement of the industry and ensuring their commitment was to make a field visit to the industry (Figure 1) to:

- present the InTheMED project and its purposes,
- share & present the CERTE expertise in industrial wastewater treatment,
- listen to the feedback and perception of the industry,
- present the road map to achieve the common goals.
- understand the in-situ treatment process.

Figure 1. Meeting with textile industry representatives

Therefore, several sampling campaigns were carried out after the visit to analyse the industrial water in the different stages of the process. As results, several electrochemical treatment alternatives were tested to allow us to develop a comparative study highlighting the high performance and advantages of electrochemical treatment technology over different industrial scale treatment steps.

Once the qualitative analyses were assessed and the electrochemical industrial-water treatment technology was developed and approved at laboratory scale, the textile industry representatives were invited to a training session on innovative remediation technologies.

The training session was designed to be in two parts:

1. Development of a sustainable industrial water treatment technology: Electrochemistry, advanced oxidation processes and electrochemical treatment of industrial effluents,
2. Reuse of treated wastewater: Institutional and regulatory context and benefits.

2.1.1.2. Training session conduction

The training session was organised on January 26th, 2023 at the Water Research and Technologies Centre CERTE. It was conducted in the local language (Arabic and French) by the InTheMED project team for the benefit of textile industry representatives (https://youtu.be/3bRK_MtAUH0).

- FIRST SESSION

The first session of the training focused on the concepts of electrochemistry, the basis of the developed water remediation technology (Figure 2).

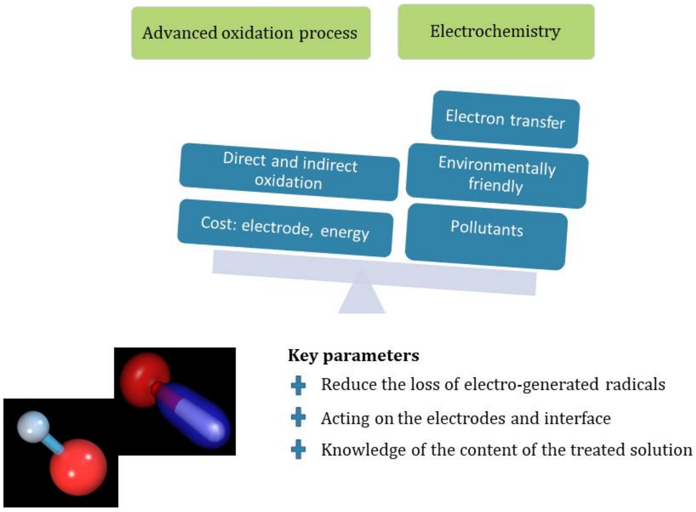


Figure 2. Electrochemistry (advanced oxidation processes)

In addition, a demonstration video of real laboratory-scale electrochemical treatment was presented which shows closely the effectiveness of the technology in treating such industrial effluent (https://youtu.be/aOSRLdnOzUw).

Then the project team presented and explained the results of the research done on the raw effluent from the industry (Figure 3).

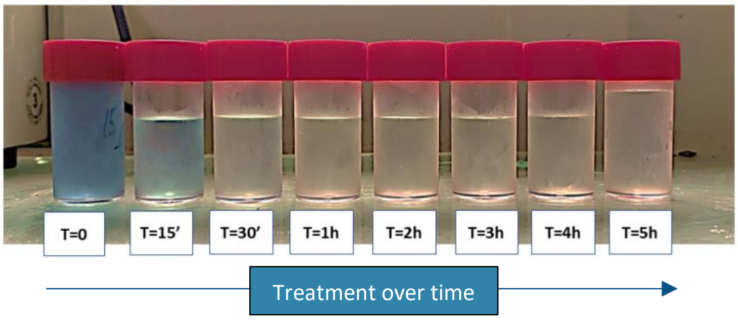
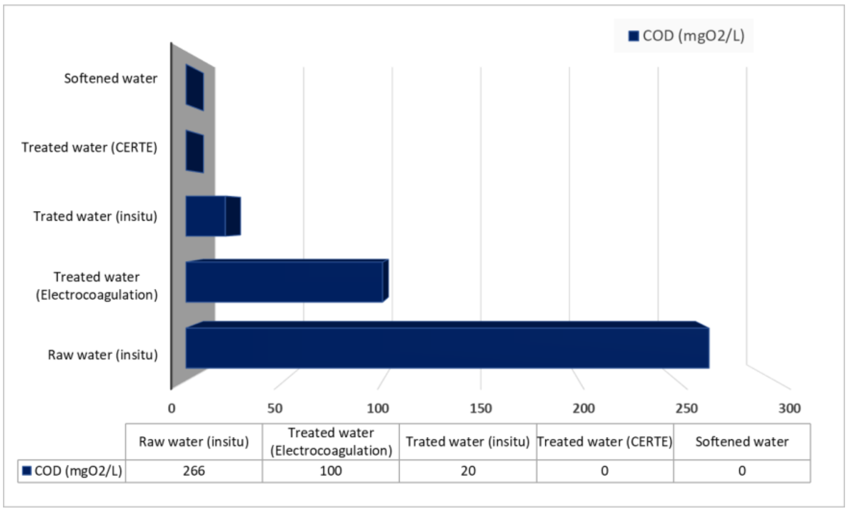


Figure 3. Samples from electrochemical treatment

The trainers from the InTheMED team emphasised the performance of the developed technology to treat industrial wastewater in a reduced time producing a better quality than the treated water released by the industry and even better than the softened water introduced at the start of the treatment.

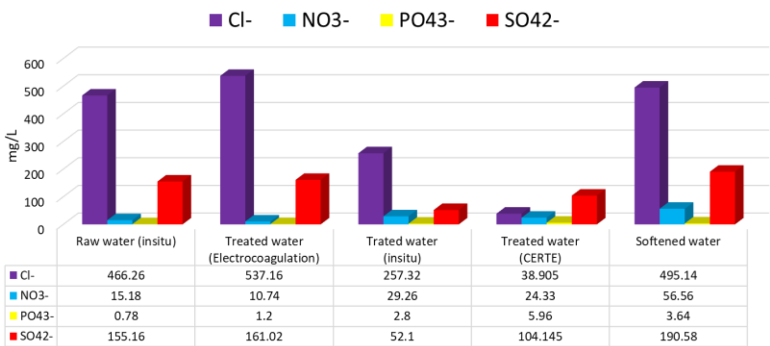
Electrochemical treatment efficiency

The electrochemical treatment technology developed at laboratory-scale has shown high efficiency in treating textile effluents and removing a large percentage of the organic matter or even completely (Figure 4) and reducing the concentrations of mineral elements (Figures 5 & 6) to comply with discharge standards and for reuse options with a simple design and reduced cost.



	Raw water (insitu)	Treated water (Electrocoagulation)	Trated water (insitu)	Treated water (CERTE)	Softened water
COD (mgO2/L)	266	100	20	0	0

Figure 4. COD removal efficiency



	Raw water (insitu)	Treated water (Electrocoagulation)	Trated water (insitu)	Treated water (CERTE)	Softened water
Cl-	466.26	537.16	257.32	38.905	495.14
NO3-	15.18	10.74	29.26	24.33	56.56
PO43-	0.78	1.2	2.8	5.96	3.64
SO42-	155.16	161.02	52.1	104.145	190.58

Figure 5. Electrochemical treatment performance (anions)

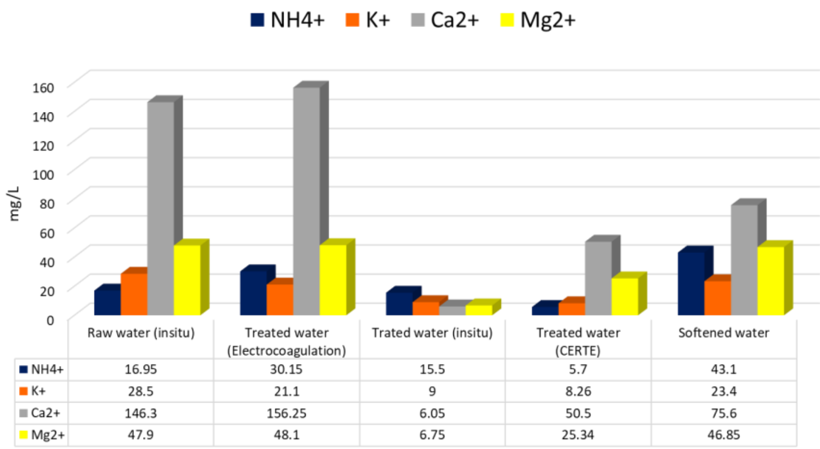


Figure 6. Electrochemical treatment performance (cations)

<u>Cost-benefit assessment</u>

The evaluation of the effectiveness of alternative treatment options in terms of economic and environmental aspects has been reviewed with industrial stakeholders during the training session. The project team has shared their experience conducting a cost-benefit analysis of wastewater alternative treatment for the textile sector. The various treatment options have been ranked according to their eco-efficiency and eco-inefficiency scores. The project team has demonstrated how an industrial manager should balance the advantages and disadvantages before establishing a certain treatment method. In fact, it appears that the most practical basis for guiding the decision-making process is the long-term costs and benefits that encompass both the economics and environmental components.

Case study: eco-efficiency of alternative treatment scenario of Textile wastewater

Textile wastewater pollution reduction is usually a highly costly process requiring high energy, operation, and maintenance costs [2]. The adoption of appropriate wastewater treatment options by a decentralized decision-maker at a local level is a measure of an effective remediation strategy. The cost-benefit assessment may guide decision-making, and to ensure stakeholder engagement in implementing the well-defined remediation strategy, it is necessary to argue the techno-economic feasibility and environmental advantage of wastewater treatment options. The relative performance of the wastewater treatment alternatives in term of the output-input ratio is investigated (Table 1). The outputs, which are the benefits of a treatment process, are divided into desirable and undesirable outputs. In two indicators could measure the environmental pressure: the salinity and eutrophication effect. The environmental benefit could be determined based on the reuse potential and COD removal enhancement indicators.

Table 1. Inputs/Outputs & Cost/Benefit indicators

Input/Output	Cost/Benefit	Indicators
Input	Economic Cost	Cost of m3 of treated wastewater (TND)
Undesirable Output	Environmental Pressure	Salinity (g/L)
		Eutrophication Effect (index)
Desirable Output	Environmental Benefit	Reuse Potential (categorical variable)
		COD Removal Enhancement (%)

- SECOND SESSION

The second session of the training focused on reviewing the institutional context and regulatory framework of the reuse of the treated wastewater in Tunisia. The current states of water resources and the prediction of their availability under the climate change effects have been presented. The session is designed to enhance awareness of the attendees about the role of the non-conventional water in increasing water availability and highlighted the reuse and the recycling of treated wastewater as a practice in line with the circular economy practices.

In addition, the industry representatives were exclusively informed about the revision of the National Water Act that will come into effect soon, and which will be the new regulatory framework in which the application of the 4Rs principle (Reduce, Recycle, Reuse, and Recover) will be required in Industry.

- Development of low-cost anodic oxidation treatment for bio-recalcitrant (antibiotic) vising the enhancement of the treated urban wastewater quality

Lab scale experiments were carried out to develop water remediations technologies to remove bio-recalcitrant compounds such as the antibiotic residue from wastewater, and to promote the safe reuse of treated wastewater. The first level of experiments was developed to remove pharmaceutical pollutant type from synthetic wastewater.

Indeed, research on the elaboration of highly modified stainless steel/lead dioxide anodes for enhanced electrochemical degradation of ampicillin in water had been conducted to improve the electrocatalytic activity and stability of the PbO_2 electrode by the introduction of a TiO_2 inner layer between the stainless steel substrate and the outer coating and the combination of the high activity of boron and the lead oxide in order to develop SS/TiO_2/PbO_2-B anode using sol-gel-spin coating.

The developed solution has demonstrated a satisfactory performance and to promote the test on real wastewaters (urban or/and pharmaceutical effluents). All details are developed in the study of Ben Osman, Y. et al. [3].

2.1.2. Perspectives

At the end of the training session, the CERTE InTheMED project team and the industry representatives agreed to sign a framework agreement drafted by CERTE to continue the collaboration and to benefit from the expertise of the InTheMED project team in Tunisia in the implementation of the new processing technologies.

The industry representatives had shown great interest in adopting the developed electrochemical processing technology in their industry at Grombalia and asked our experts from CERTE for collaboration to roll out this technology in their industrial branch in Korba (Nabeul-Tunisia).

2.2. Konya case study, Turkey

2.2.1. Capacity building on innovative remediation technologies

2.2.1.1. Planning and designing of Living Lab

We adopt the system dynamics (SD) approach in all the living lab activities. Objectives of SD approach are understanding the underlying cause of a problematic dynamic behavior or trend within the system, diagnosing the structural foundations of such behavior, and identifying and testing leverage points within the system to stop or reverse the undesirable trend [4]. Based on the identified problem and the model's intended use, models created using this method concentrate on the behavior of important variables over time and the feedback structure that generates the observed behavior. To detect and capture significant feedback loops, appropriate stock and flow structures are constructed, and their relationships are represented with mathematical expressions [5].

It is mostly beneficial to involve stakeholders in practical sustainability research. To incorporate stakeholders in system dynamics research, academics introduced a concept known as Group Model Building (GMB) in the 1980s. GMB, in its broadest sense, is a collection of methods for building system dynamics models for decision-making that involve stakeholders who stand to gain or lose from the decision's outcome [5]. Discovering the potential leverage that stakeholder participation brings to the models is the goal of GMB. The necessity for a deeper level of stakeholder participation is achieved by incorporating them directly in the model-building process, from the beginning with problem identification to the finish with policy analysis [6]. Researchers have the option to elicit stakeholders' assumptions, ideas, knowledge, and mental models through a guided GMB study, which provides an opportunity to build a comprehensive understanding of the linkages between various system components.

The second workshop on February 17, 2022, was intended to build upon the outcomes of the first workshop of the living lab, which took place in Konya on September 30, 2021 (please refer to [7]). First, we created a brief bulletin of the first workshop, outlining its intended purpose, activity structure, intellectual outputs in the form of visual objects, and the discussion on the road ahead. This was done to avoid losing contact with our key informants and stakeholders to the participatory governance analysis during the six months in between the two workshops. Individual participants received this newsletter in their native language, announcing to them that we want to see them again in February 2022.

The "reference modes" from the first workshop were confirmed with data along the road, and our expert team grouped the policy proposals into categories. During the second workshop, these were presented, prior to the main activities of the second workshop. Figure 7 provides an example.

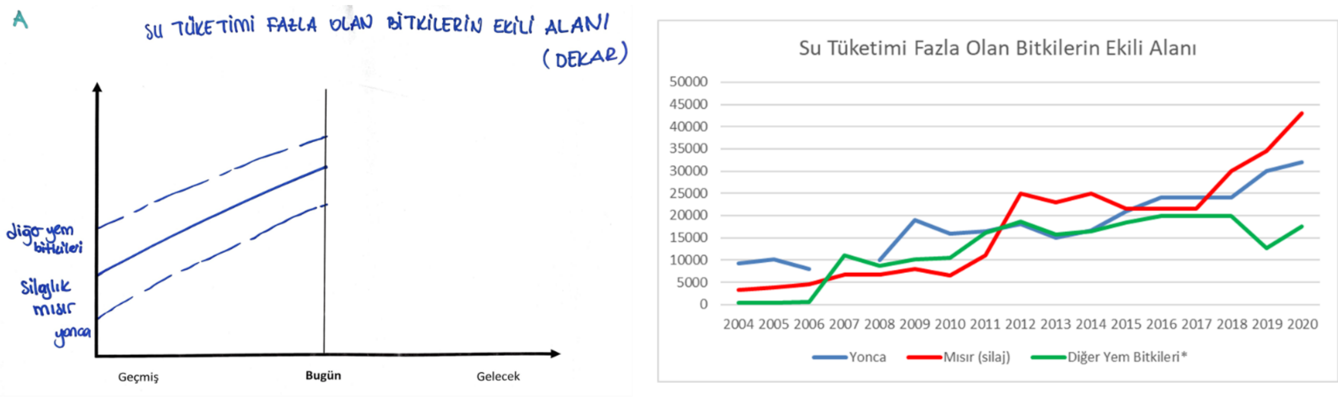


Figure 7. Land allocated to water demanding crops as drawn by the participants (on the left) and observed trefoil (blue), corn (red), and other forage crops (green) cultivated land data (on the right)

To focus on specific and important issues one at a time rather than all at once, we had segmented the topics raised by the participants during the first workshop, while preparing for the second workshop. For that purpose, we created the intended modeling efforts shown in Table 2.

Table 2. Planned Modelling Activities

Planned Modeling Activities			
	I (Morning)	II (Afternoon)	III (To be completed by the research team)
Groundwater Level	×	×	×
Number of Wells	×	×	×
Yield	×		
Green Plants vs Cereals Area		×	
Traditional vs Modern Irrigation			×

Our aim was to discover the relationship between groundwater supply and demand in the morning, taking agricultural product yields and groundwater wells into consideration. We wanted to explore crop selection in the afternoon, excluding yield. We had planned a similar flow for the morning and afternoon sessions (Table 3), where we would first build consensus with the participants on the problem definition and basic model template. After that, we would thoroughly examine the topic at hand to improve the diagram, add new variables as needed, and uncover the connections between those variables.

2.2.1.2. Living Lab conduction

The attendance to the second living lab and the day plan are presented below in Tables 3 and 4.

Table 3. Attendance to the second workshop of the living lab

Affiliation	Title / Occupation
Alibeyhüyüğü Irrigation Cooperative	Manager
	Assistant Manager
Ankara University	Academic
Çumra Irrigation Union	Manager
	Officer
Chamber of Agriculture in Çumra	Agricultural Engineer
DSİ	Geophysics Engineers (2)
	Surface Waters Department Manager
Hydropolitics Association	Academic
Konya Commodity Exchange	Officer
Konya Plains Project Regional Development Administration (KOP)	Project Development Coordinator
	Engineer
Konya Leader Farmer Association	President
	Agricultural Engineer
	Farmers (4)
Turkish Foundation for Combating Soil Erosion (TEMA)	Officer
Total Attendance:	20

Table 4. Day Plan

Morning	**09:00 AM**	**Greeting**
	09:30 AM	**Opening:** Meet & Greet Recap of the first workshop
	10:00 AM	**1st Session:** Agreement on problem definition & model diagram
	10:30 AM	Coffee Break
	10:50 AM	**2nd Session:** Conceptual Model Building Model-based discussion on policy proposals
Afternoon	1:00 PM	Sample Model Simulation
	1:30 PM	**3rd Session:** Agreement on problem definition & model diagram
	2:00 PM	Coffee Break
	2:20 PM	**4th Session:** Conceptual Model Building

		Model-based discussion on policy proposals
	3:30 PM	Closing

The welcome and summary of the first living lab were followed by the opening session, which concentrated on creating basic causal loop diagrams. Participants were instructed by the facilitator to think of variables as stocks and flows. Modelers concurrently transferred the whiteboard's contents into the modeling program Stella Architect and reflected them on the large projection screen as the debate was being led by the facilitator, who also translated what was being spoken to the whiteboard. Following that, just like in the previous workshop, a simple simulation model was created on Stella Architect to acquaint newcomers with the software and to refresh the memory of returning participants (Figure 8).

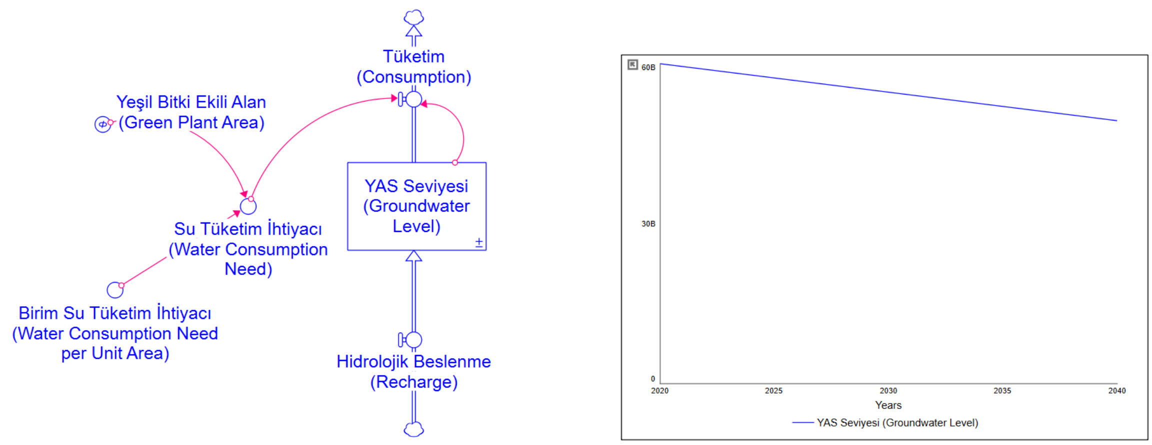


Figure 8: The simple model simulated in the first workshop

Groundwater level and the quantity of operational wells were depicted as stock variables during the first session (Figure 9), and the facilitator then initiated a conversation about the appropriate flow variables. We had a brief break after settling on the physical model and the initial stock-flow template before starting the second part of the workshop.

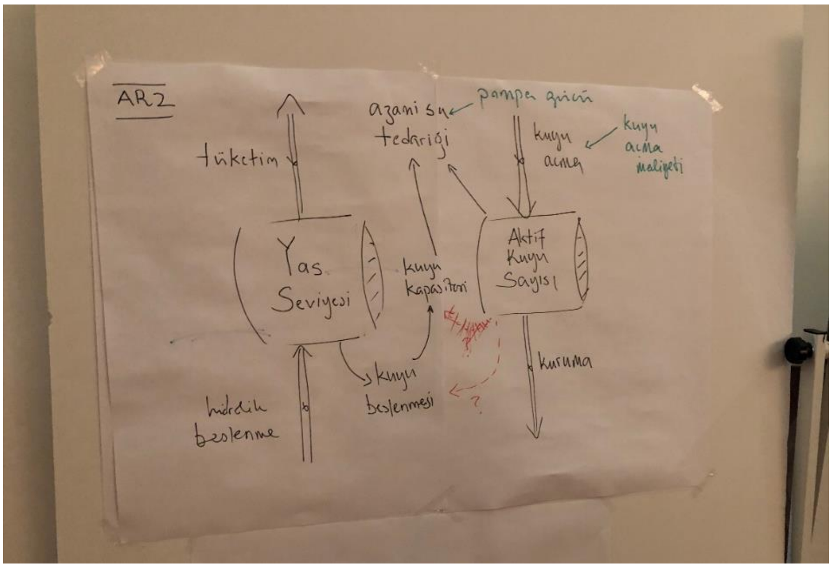


Figure 9: Stock-flow representation of groundwater level and number of active wells

The second session started with the following questions and focused on these topics: "what causes an increase in groundwater levels?" and "what causes a decline in the number of active wells?". The procedure was interrupted by the arguments and miscommunications in the group. We had a discussion on well pumps, their power, and well flow rates, following the discussion on the capacity of the groundwater supply. The plenary dispersed for the lunch break after the session ended with a commitment to tackling the "demand side" of the issue in the afternoon, which was anticipated to shed more light on the factors that influence shifting groundwater demand.

The presentation on the morning's simulation experiments, for which the model was still incomplete, had to be cancelled after lunch because the morning session had been more contentious and demanding than the research team had initially expected. Instead, we focused on groundwater demand to avoid further complications with the supply discussion and to complete the awaited interactions between supply and demand. We then began discussing the yield, assuming the farmers solely grow maize, a green crop with a high water requirement. The facilitator's whiteboard drawing of the session's progress is shown in Figure 10.

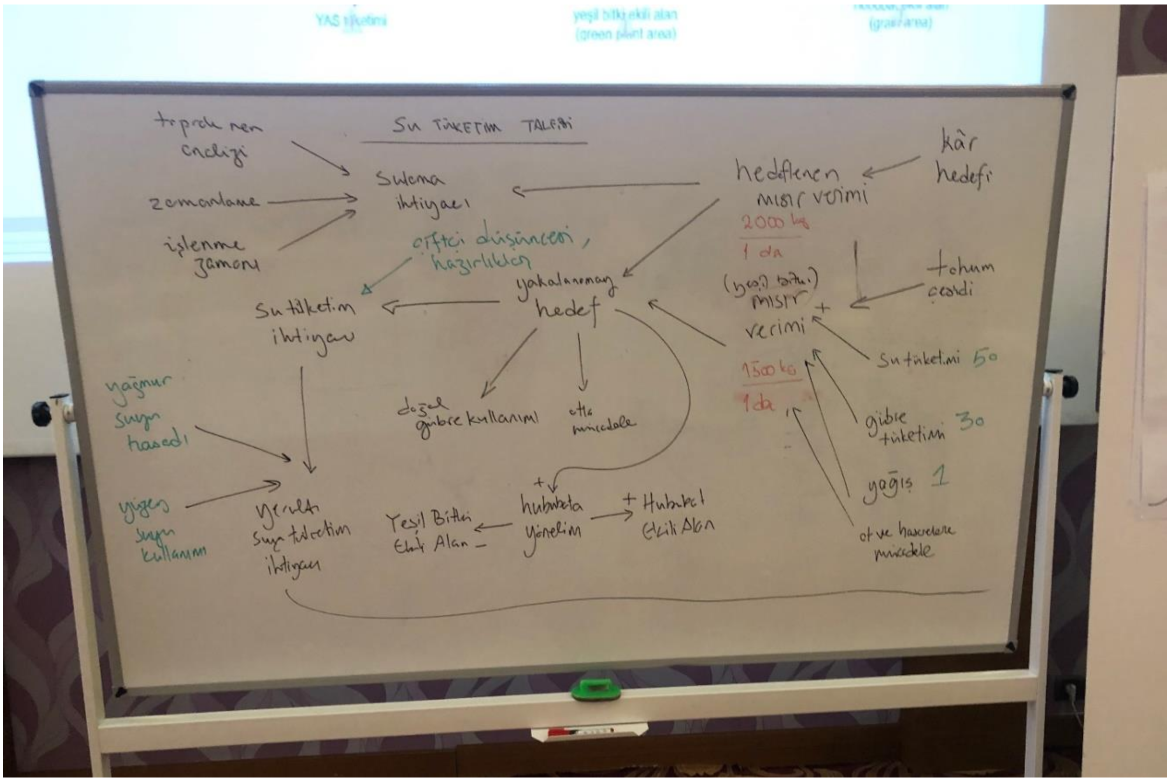


Figure 10: The progress in the conceptual model in the third session

In the final session of the day, we examined the policy proposal about crop choice and arrived at the conclusion that crop rotation strategies would be a better policy proposal for the overall benefit of the nation and in terms of groundwater demand than abandoning particular crops. After that, we talked about the expansion in irrigated land and the factors that led to it.

We decided to conclude the workshop without pursuing all activities in the pre-planned day schedule after observing that the mental effort required of the participants to concentrate on the previously agreed challenges of the modeling exercise had grown to be burdensome.

A fully detailed report on the workshop is provided in *M4.2: Second Living Lab Scrutinizing and Refining the Conceptual Model* [8].

2.2.2. Outputs and perspectives

Prior to the second living lab, we had begun creating a seed model using the knowledge we had gained from the first living lab and previous field trips. The structure of that seed model, combined with the information obtained from the second living lab, is shown below (Figure 11). The assumptions of this model are consistent with the first scenario that we described in

Table 2, column I (morning); we consider groundwater, product yield, and the number of active wells, under the assumption of a single crop type.

We will organize the third and final living lab after the model construction and validation process is complete, engaging more stakeholders this time to hear about the model and its results. A more extensive stakeholder group will be involved in an interactive scenario analysis and participatory policy formulation session. The model will answer participants' queries on policy in the third living lab, and the model will demonstrate the long-term impacts of various policy scenarios.

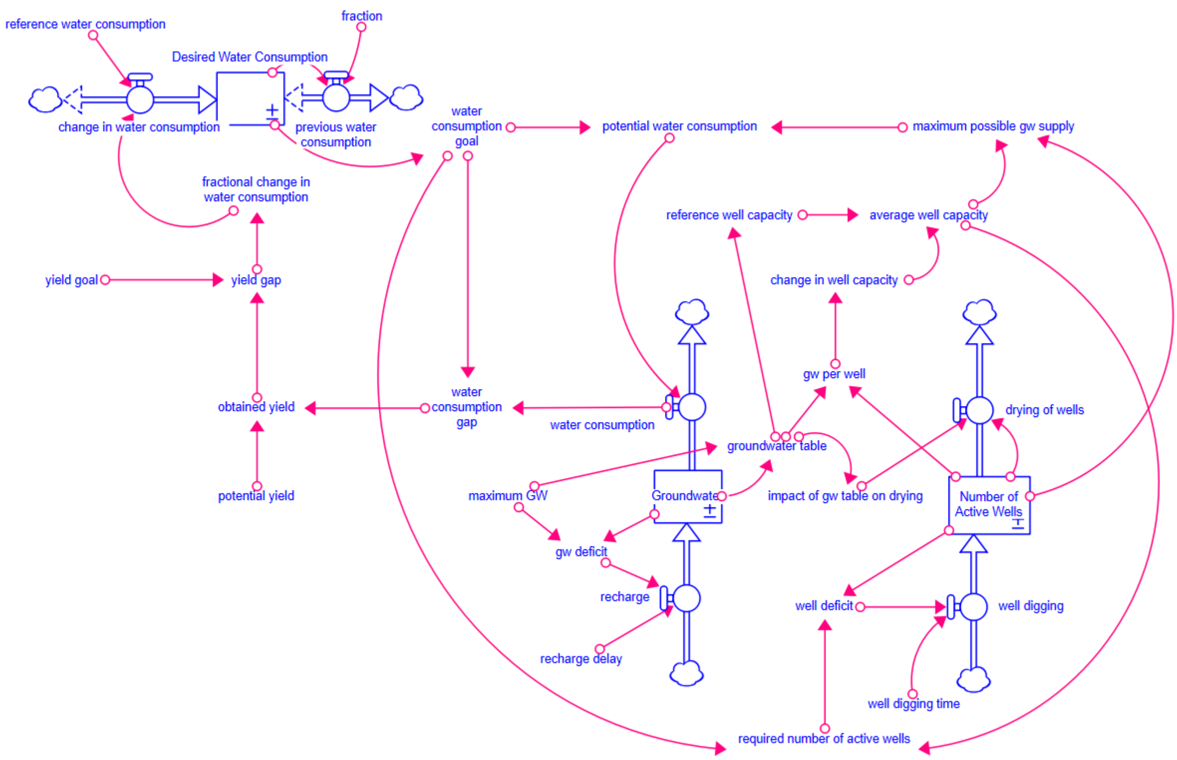


Figure 11: The seed model

2.3. Requena-Utiel case study, Spain

In the Spanish study case, the exploitation of the aquifer over the past two decades has caused the water levels to show a progressive decrease and the aquifer storage balance to be negative, which indicates the emptying of the aquifer. Thus, the Hydrological Plans of the Júcar Water Authority for the 2015-2021 term [9] and for the 2021-2027 term [10] declare the Requena-

Utiel groundwater mass in bad quantitative state and define remediation strategies. The primary strategy was the creation, in December 2016, of the Exploitation Plan for the Requena-Utiel groundwater mass [11]. The Exploitation Plan, which was reviewed and approved in December 2020 [12], is still valid and aims to achieve efficient management and planning to ensure a reliable service to users and to restore the good quantitative status of the groundwater mass. The objective of this Plan is to assign the criteria for the distribution of the reserve established in the 2015-2021 Hydrological Plan [9]. In addition, new water concessions requested after the entry into force of the 2015-2021 Plan have not been accepted. Finally, a variable allocation is determine depending on whether the year is wet, medium, or dry, considering antecedent precipitation.

According to the reviewed version of the Exploitation Plan, a follow-up of the evolution of groundwater and surface resources is published annually. The last follow-up document was published in May 2022 [13], and it shows a certain tendency toward piezometric decrease at some piezometers, but also an increase or a stabilization of the levels is observed in others. On the one hand, it can be due to the very rainy February and March of 2022. On the other hand, it is also showing that efforts to improve the management and groundwater use have had a positive effect. However, a slight increase or the stabilization of the water level after a period of decline is not the desired situation, so additional remediation strategies and tools are still required to overcome the problem.

As highlighted by the stakeholders in the living lab that took place in the study area on the 4th of March 2022 [14], one of the weaknesses in the groundwater management process is the lack of reliable and accessible (i.e., noncomplex) information and tools to monitor the aquifer state. In this sense, based on a numerical model, the Spanish team, together with the Italian one, has developed a smart model by using machine learning, whose basic purpose is to predict water levels in response to changes in recharge and/or pumping. The smart model is reported in the D3.2 [15]. During the evaluation of the smart model, it has proven to be an innovative, accessible, and powerful tool to support stakeholders and managers in assessing the impact of possible changes in groundwater extraction from existing wells and the impact of climate change, translated as rainfall variations, on the aquifer state. This smart model can be implemented on a free webpage to be used by all interested parties in the management of the aquifer. This work was first presented at the Iberian Groundwater Congress 2021 in Valencia, Spain [16], and has been updated and revised since then.

Even though it is extremely necessary to monitor the state of the aquifer with an accessible tool, a strategy to recover the water levels is also fundamental. The most obvious solution to that problem is to reduce pumping; however, the quantitative impact of reduced pumping towards sustainable use of groundwater is anything but obvious. In this sense, we also propose the use of the water balance approach with uncertainty consideration developed at the Kansas Geological Survey [17-19]. The water balance approach is a very successful pumping reduction management technique developed to manage groundwater use in the State of Kansas, United States [17-18], in which storage variation is obtained by subtracting pumping from net input, and a relationship is established between annual pumping and average water decline. From such a relationship, it is possible to assess the sustainability of pumping, the targets of the ongoing management strategies, and the pumping reductions required to recover water levels. This method can provide rapid and valuable information on the condition of the aquifer, as well as its response to pumping reduction scenarios. In addition, its results are easy to understand and communicate to a wide audience. In fact, the Spanish team has already applied the method at the Eastern Mancha Aquifer and presented it at the Iberian Groundwater Congress 2022 [19].

The main weakness of the water balance method is need for sufficient and reliable information on water use and levels. However, the Spanish team is aware that the Direction General for Water has decided to invest in the modernization of their control network by including High-Resolution Monitoring devices, so we believe the proposed method could be fully adopted in a few years. It is also worth mentioning that, in coordination with the Júcar basin Water Authority, the Spanish team tried to install three devices in three abandoned piezometers that were not included in this modernization; however, the degradation of the old piezometers together with the difficulties to access them because they are in private land, prevented the installation of the sensors. The lack of these three piezometers has not affected the deployment of the surrogate model and its application.

2.4. Tympaki case study, Greece

In Tympaki, as identified in the survey of the previous report, the main problem is the overexploitation of the aquifer, that in turn has led to saltwater intrusion. Therefore, the remediation measures that are suggested for Tympaki is to apply a pumping scheme that is based on the optimization of the pumping rates, so as to maintain the water table at an efficient level that is capable of pushing back the saltwater intrusion front (isoline of 3.25 m). In the following pictures, the situation of the Tympaki coastal aquifer is presented for three different cases: a) when the pumping rates fully cover the irrigation needs of the area (Figure 12), b) when the pumping rates are restricted to the values imposed by the licenses of water use that are issued by the Water Directorate (Figure 13) and c) when the pumping rates abide by the results of the optimization procedure (Figure 14). The maps refer to the end of the dry period, in the effort to upgrade by 1 m the hydraulic head in the observation points.

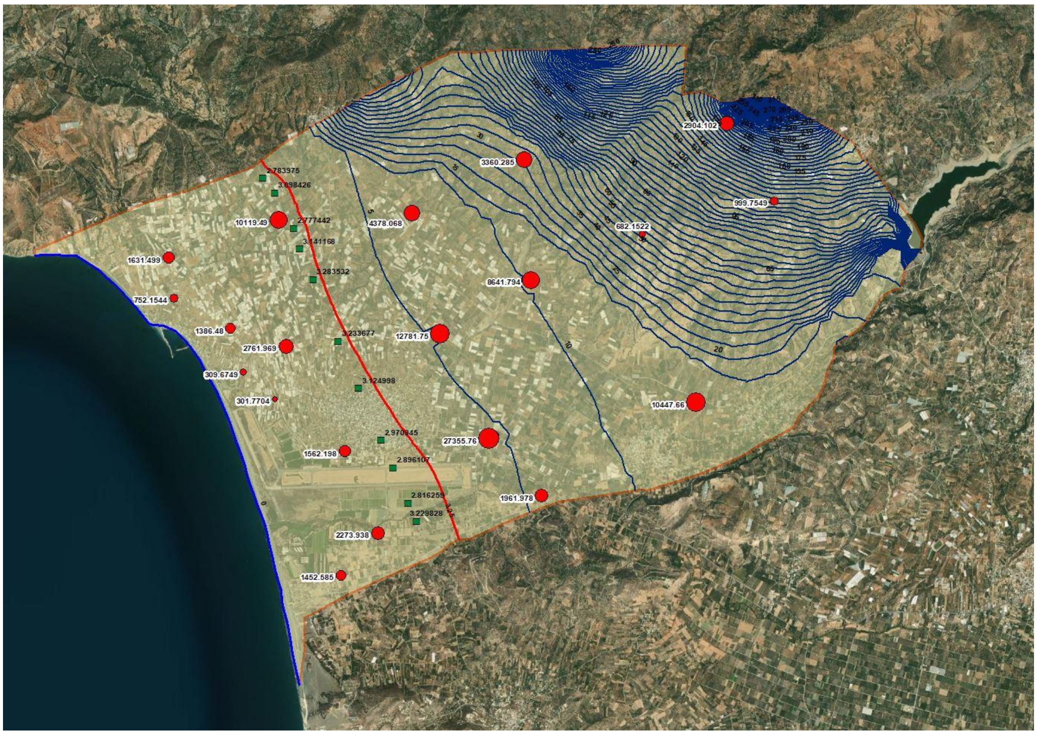


Figure 12: Water table level a.s.m.l for pumping rates equal to irrigation needs

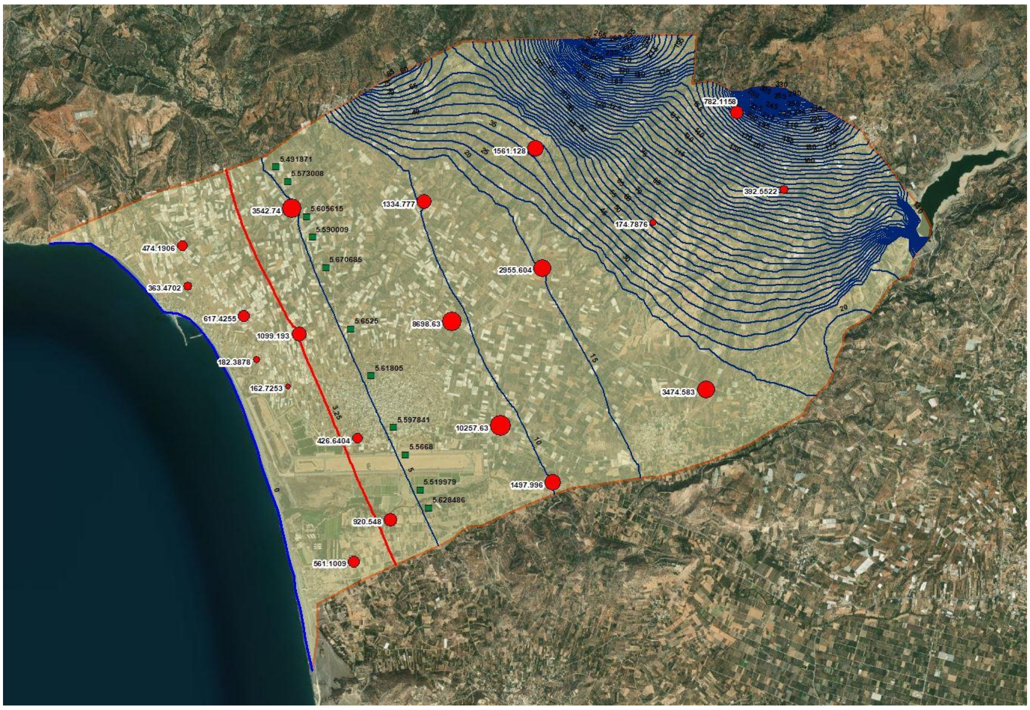


Figure 13: Water table level a.s.m.l for pumping rates equal to the limits of water authorities

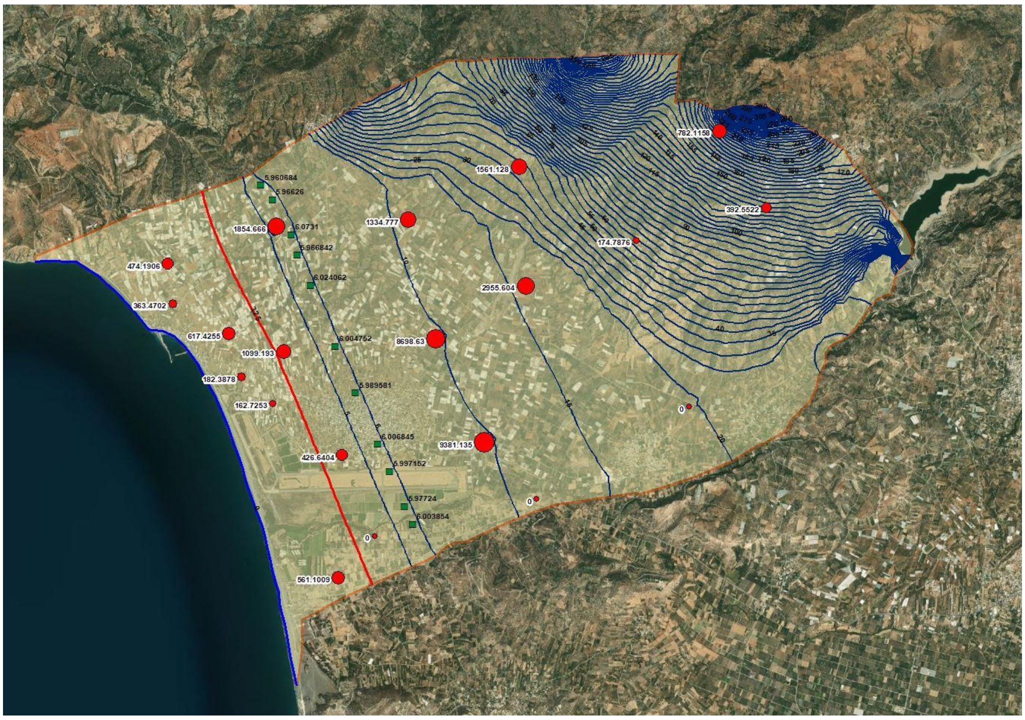


Figure 14: Water table level a.s.m.l for optimum pumping rates

By Table 5, it is obvious that the optimum results, as wells as the limits of the water authorities do not necessarily mean the full coverage of the needs. However, policy makers as wells as researchers would suggest these pumping rates as measure to mitigate saltwater intrusion. For the deficiencies that arise, it is proposed to integrate other water resources such as surface water and treated waste water.

Table 5. Results of the suggested actions

Pumping Well	Water Demand for the Dry Period (m^3/day)	Permitted Water Abstractions for the Dry Period (m^3/day)	Percentage of demand covered by permitted abstractions	Pumping Rates from Optimization Results for the Dry Period (m^3/day)	Percentage of demand covered by optimum pumping rates
1	999.75	392.55	39.26%	392.55	39.26%
2	12,781.75	8,698.63	68.06%	8698.63	68.06%
3	27,355.76	10,257.63	37.50%	9381.14	34.29%
4	309.67	182.39	58.90%	182.39	58.90%
5	10,447.66	3,474.58	33.26%	0.00	0.00%
6	2,273.94	920.55	40.48%	0.00	0.00%
7	682.15	174.79	25.62%	174.79	25.62%
8	1,631.50	474.19	29.06%	474.19	29.06%
9	1,961.98	1,498.00	76.35%	0.00	0.00%
10	4,378.07	1,334.78	30.49%	1334.78	30.49%
11	10,119.49	3,542.74	35.01%	1854.67	18.33%
12	2,761.97	1,099.19	39.80%	1099.19	39.80%
13	2,904.10	782.12	26.93%	782.12	26.93%
14	8,641.79	2,955.60	34.20%	2955.60	34.20%
15	1,562.20	426.64	27.31%	426.64	27.31%
16	1,386.48	617.43	44.53%	617.43	44.53%
17	752.15	363.47	48.32%	363.47	48.32%
18	1,452.58	561.10	38.63%	561.10	38.63%
19	3,360.29	1,561.13	46.46%	1561.13	46.46%
20	301.77	162.73	53.92%	162.73	53.92%
Total amount	96,065.07	39,480.22	41.10%	31,022.53	32.29%

2.5. Castro Verde case study, Portugal

The Portuguese case study is located within a mining concession named Neves-Corvo and operated by SOMINCOR – *Sociedade Mineira de Neves-Corvo, S.A.*, a subsidiary of Lundin Mining. The Neves-Corvo polymetallic base metal deposit is part of the world-class Iberian

Pyrite Belt of southern Portugal and Spain. The mine is situated in the southern region of Portugal, in the Alentejo province, about 15 km southeast of Castro Verde town.

Neves-Corvo mine has been developed as an underground operation, with exploitation in five major polymetallic sulfide orebodies [20]. Within the mine premises, the groundwater is a significant aquifer that connects to water supplies and a significant river that passes close to the mine [21].

2.5.1. Identified problems relating to groundwater bodies

The **problems** identified in the *D5.2 - Report on the procedure for capacity building and the selection of the main hot spots* [1] are resumed in the following points:

- Vulnerability of groundwater to contaminants originating from mining activities and infiltrating the groundwater bodies, mainly due to the presence of a sizeable tailing infrastructure.
- In mining operations, the orebody has a pyrite (iron sulfide) content, so waste rock and tailings have the potential to oxidize and produce acid [20]. Moreover, the explosives used for blasting the orebody induce the elevation in concentrations of nitrogen compounds and sulphates [21].
- Castro Verde aquifer system is exposed to the risks of contamination due to the exploitation of mineral resources and agricultural activities.
- Mining operations are below the water table, impacting the current groundwater level of the system and wells in neighboring regions. The pumping of water from the mine has depressed the water table over a significant area around the mine [20]. As the mine workings deepen, some water supply wells dried up and alternative supplies of water have been provided as appropriate to compensate for this [21].
- As with most mine sites, rainfall runoff is potentially contaminated with suspended solids and dissolved pollutants, including acid, which if uncontrolled could severely contaminate the nearby river system [21].

2.5.2. Proposed water remediation technologies and strategies

The **potential remediation strategies and technologies** proposed to overcome the identified problems are listed below:

- The mining company has implemented a large monitoring network of piezometers, with more than 65 observation points, around the entire infrastructure and more than 200 observation points covering the entire hydrogeological network. Both monitoring networks provide relevant near-real-time information regarding the water depth and the chemical composition of the water.
- Furthermore, the mining company intends to complete a full monitoring study that comprises a hydrogeological numerical model of the aquifer to assess the impact of mining activities and propose environmental actions to restore the pre-exploitation conditions of the aquifer. This model was expected to be delivered within the timeframe of the InTheMED project but did not finish.
- Before discharge into the environment, the industrial effluent is treated in several facilities, such as a Modular Water Treatment Plant, Drinking Water Treatment Plant, Wastewater Treatment Plant, and nano-filtration plant. The latter is the most recent technology implemented at the mining complex and consists of three sequential filtration stages: sand filters, microfiltration, and reverse osmosis.
- There is a potential for groundwater impacts from the Tailings Management Facility (TMF) to be migrating offsite, either via a diffuse plume or via a fracture pathway. As a result, an Environmental Health and Safety Audit recommended the hiring of consultants to assess the existing oil and groundwater monitoring network and to propose improvements to be subsequently incorporated into the closure plan, this work has been initiated by the Mine [20].
- The mine must also prepare annual monitoring reports to be delivered to the Portuguese authorities. Namely, the effluent and surface water quality control program is defined in accordance with the requirements of Environmental License Np. 19/2008, 3rd of March, issued for the Neves-Corvo mining complex [22].
- The mine is supplied by surface water from the Santa Clara reservoir, to avoid the decrease of water level in this reservoir, the mining company increased the use of

recycled water for industrial purposes and reduced the amount of freshwater drawn from the Santa Clara reservoir [20].

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