

DESIGNING AND IMPLEMENTING A DESALINATION STRATEGY FOR AGRICULTURAL WATER REUSE: INSIGHTS FROM THE SALT'EAUX DEMONSTRATOR

CONCEPTION ET MISE EN ŒUVRE D'UNE STRATÉGIE DE DESSALEMENT POUR LA RÉUTILISATION DES EAUX AGRICOLES : ENSEIGNEMENTS DU DÉMONSTRATEUR SALT'EAUX

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ABSTRACT

Coastal agriculture is increasingly affected by water scarcity and soil salinization, requiring innovative strategies capable of meeting both the quantitative and qualitative requirements of irrigation water. The SALT'EAUX project, implemented in the Sète Agglopôle Méditerranée (SAM) region in southern France, develops an integrated approach to desalination and agricultural water reuse in coastal environments exposed to saline groundwater intrusions and the influence of the Thau Lagoon. Initiated in 2023 as one of the territorial demonstrators of the France 2030 Call for Expressions of Interest programme, the project combines treated wastewater reuse with upstream and downstream salinity management for vineyards and diversification crops.

The strategy is based on fit-for-purpose desalination adapted to local agronomic and hydrological conditions. At the Mèze site, sewer network rehabilitation and selective demineralization reduce treated wastewater salinity to approximately 1.5 dS/m, enabling the irrigation of 90 hectares of vineyards and diversification crops such as olives and onions. At Marseillan, where soils and groundwater are already saline, treated wastewater with salinity levels between 1.5 and 3.5 dS/m is combined with hydraulic drainage rehabilitation, controlled irrigation, and adaptive salinity management over 70 hectares of vineyards.

The methodology integrates continuous salinity monitoring, predictive modelling, adaptive irrigation management, and high-resolution soil salinity mapping using geophysical surveys and machine-learning-based inversion methods. These tools support the optimization of irrigation volumes, water quality, and drainage practices according to crop tolerance and seasonal variability.

Preliminary results from the maturation phase demonstrate that targeted desalination strategies can achieve both quantitative irrigation objectives and qualitative soil preservation goals. The SALT'EAUX project highlights the importance of combining technological solutions with agronomic and hydrological understanding to develop operational, economically realistic, and transferable desalination strategies for sustainable coastal agriculture.

Keywords: Water scarcity and soil salinization; geophysical surveys; controlled irrigation; desalination strategies; sustainable coastal agriculture.

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RESUME

La pénurie d'eau et la salinisation des sols touchent de plus en plus l'agriculture côtière, exigeant des stratégies innovantes capables de répondre à la fois aux exigences quantitatives et qualitatives de l'eau d'irrigation. Le projet SALE'EAUX, mis en œuvre dans la région de Sète Agglopôle Méditerranée (SAM) au sud de la France, développe une approche qui intègre le dessalement et la réutilisation des eaux agricole dans les environnements côtiers exposés aux intrusions d'eaux souterraines salines et à l'influence de la lagune de Thau. Lancé en 2023 comme l'un des démonstrateurs territoriaux du programme d'appel à manifestation d'intérêt France 2030, le projet unit la réutilisation des eaux usées traitées avec une gestion de la salinité en amont et en aval pour les vignobles et les cultures de diversification.

La stratégie s'appuie sur un dessalement adapté aux conditions agronomiques et hydrologiques locales. Sur le site de Mèze, la réhabilitation du réseau égout et la déminéralisation sélective réduisent la salinité des eaux usées traitées à environ 1,5 dS/m, permettant l'irrigation de 90 hectares de vignobles et la diversification des cultures telles que les olives et les oignons. À Marseillan, où les sols et les eaux souterraines sont déjà salins, des eaux usées traitées avec des niveaux de salinité compris entre 1,5 et 3,5 dS/m sont combinées à une réhabilitation du drainage hydraulique, une irrigation contrôlée et une gestion adaptative de la salinité sur plus de 70 hectares de vignobles.

La méthodologie intègre une surveillance continue de la salinité, une modélisation prédictive, une gestion adaptative de l'irrigation et une cartographie à haute résolution de la salinité des sols à l'aide d'études géophysiques et de méthodes d'inversion basées sur l'apprentissage automatique. Ces outils soutiennent l'optimisation des volumes d'irrigation, de la qualité de l'eau et des pratiques de drainage selon la tolérance des cultures et de la variabilité saisonnière.

Les résultats préliminaires de la phase de maturation démontrent que des stratégies ciblées de dessalement peuvent réaliser à la fois les objectifs quantitatifs d'irrigation et les objectifs qualitatifs de préservation des sols. Le projet SALE'EAUX souligne l'importance de combiner des solutions technologiques avec une compréhension agronomique et hydrologique afin de développer des stratégies de dessalement opérationnelles, économiquement réalistes et transmissibles en ce qui concerne l'agriculture côtière durable.

Mots-clés : Pénurie d'eau et salinisation des sols; Enquêtes géophysiques; Irrigation maîtrisée; Stratégies de dessalement; Agriculture côtière durable.

INTRODUCTION

Agricultural systems located in coastal regions are increasingly confronted with structural water stress and progressive salinization of soils and water resources. Climate change is amplifying these pressures through increasing temperatures, prolonged drought periods, and reduced freshwater recharge. In Mediterranean environments, these phenomena are particularly critical because agricultural production already relies on limited and highly variable water resources. In parallel, population growth and tourism intensify competition for freshwater between urban, industrial, environmental, and agricultural uses. As a consequence, many coastal agricultural territories are searching for alternative water resources capable of sustaining agricultural production while preserving environmental balances.

The reuse of treated wastewater for irrigation has progressively emerged as one of the most promising solutions to address quantitative water shortages in coastal areas. Unlike conventional freshwater resources, treated wastewater offers the advantage of being continuously available and locally produced close to agricultural areas. Numerous studies have highlighted the potential of water reuse to improve water security, reduce pressure on aquifers, and support agricultural resilience under climate change conditions. Nevertheless, the implementation of reuse schemes in coastal environments remains challenging because the quality of treated wastewater is frequently affected by elevated salinity.

In coastal sewer systems, saline groundwater intrusions can substantially increase the electrical conductivity of collected wastewater before treatment. This issue is particularly acute in areas characterized by shallow saline aquifers, aging sewer networks, and hydraulic interactions with lagoons or marine environments. Under such conditions, conventional wastewater treatment processes do not remove dissolved salts, resulting in treated effluents whose salinity may exceed agricultural tolerance thresholds. This limitation constitutes one of the main barriers to the deployment of agricultural water reuse in coastal territories.

The impacts of saline irrigation water on agricultural systems are complex and depend on multiple interacting factors. Elevated salinity may induce osmotic stress in plants, reduce nutrient uptake, and impair physiological functioning, resulting in lower growth rates and reduced yields, or even plant death. Long-term exposure may also alter soil structure through clay dispersion and reduced infiltration capacity, eventually leading to irreversible soil degradation. However, these effects strongly depend on climatic conditions, soil texture, crop species, rootstock tolerance, irrigation practices, and groundwater dynamics. In sandy coastal soils, winter rainfall may contribute to salt leaching, whereas in finer textured soils salinity accumulation may become more persistent.

Conventional desalination technologies such as reverse osmosis are technically effective in producing low-salinity water, but their implementation for agricultural purposes is often limited by high energy consumption and operational costs. Moreover, such technologies are usually designed to maximize salt removal without necessarily considering the actual tolerance of crops and soils. In many agricultural contexts, complete desalination may therefore represent an unnecessary economic and environmental burden. This raises the question of how desalination strategies can be designed to specifically meet agricultural needs in both quantitative and qualitative terms.

The SALT'EAUX project was developed in response to these challenges. Initiated in 2023 as one of the territorial demonstrators supported by the France 2030 CEI led by the Banque des Territoires, the project aims to establish an integrated framework for agricultural water reuse and salinity management in coastal environments. Rather than considering desalination as an isolated treatment process, the project approaches salinity management through a combination of upstream infrastructure interventions, adapted treatment technologies, agronomic management practices, and decision-support tools. The project focuses on two sites located within the Sète Agglopôle Méditerranée territory in southern France, Mèze and Marseillan, where vineyards are increasingly threatened by salinity and/or water scarcity.

This paper presents the conceptual framework, methodology, and preliminary results of the SALT'EAUX demonstrator. Particular attention is given to the design of desalination strategies adapted to agricultural constraints and to the operational integration of water treatment, irrigation management, and soil salinity control.

STUDY AREA AND CONTEXT

The SALT'EAUX demonstrator is implemented in the Sète Agglopôle Méditerranée territory, located along the Mediterranean coast in southern France (Figure 1). The study area is situated between the sea and the Thau Lagoon, a large saline coastal lagoon connected to the Mediterranean Sea. This territory is characterized by strong environmental, agricultural, and socio-economic interactions between coastal ecosystems, urban areas, tourism activities, shellfish farming, and viticulture.

Viticulture constitutes a major component of the regional identity and economy. The vineyards of the territory form part of a historical and cultural heritage that has shaped the landscape for centuries. However, wine production is increasingly affected by climate-related pressures, including drought stress, rising temperatures, and salinization of soils and groundwater. Securing the long-term sustainability of viticulture therefore represents both an economic and social challenge for the region.

The project focuses on two sites presenting contrasted environmental conditions: Mèze and Marseillan. At Mèze, vineyards are located inland from the lagoon in an area currently less affected by salinity but

lacking access to freshwater irrigation resources. Agricultural land includes vineyards as well as abandoned or underutilized parcels with potential for diversification. The objective at this site is to preserve soil quality while enabling agricultural transition through secure access to irrigation water.

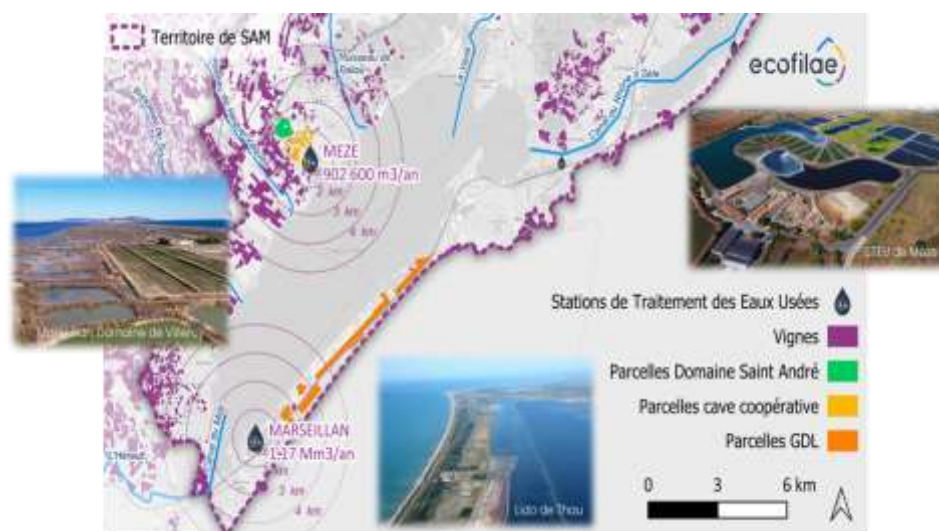


Figure 1. Location of the SALT'EAUX demonstrator project

At Marseillan, vineyards are located on a narrow sandy lido directly exposed to marine and lagoon influences. The saline groundwater table lies less than one meter below the soil surface in some areas, resulting in chronic salt exposure within the root zone. The vineyards have progressively adapted to these conditions, but increasing salinity threatens both productivity and long-term soil functionality. In this context, the objective is not to eliminate salinity entirely but to manage it within acceptable thresholds compatible with agricultural production.

The wastewater treatment plants serving Mèze and Marseillan each produce approximately one million cubic meters of treated wastewater annually. These treated effluents currently discharge into channels connected to the Thau Lagoon. Their reuse for irrigation represents a significant opportunity to mobilize an alternative water resource. However, the salinity of treated wastewater remains a major limitation. Electrical conductivity values measured at the outlet of treatment plants generally range between 3 and 8 dS/m, whereas irrigation water recommendations for sensitive crops are usually below 1,5 to 3,5 dS/m.

The elevated salinity of treated wastewater is primarily linked to saline groundwater infiltrations into sewer networks. This phenomenon is intensified by the shallow groundwater table, the proximity of saline water bodies, and the aging condition of some sewer infrastructures. Consequently, the design of desalination strategies in the SALT'EAUX project required a detailed understanding of the origins and dynamics of salinity throughout the entire wastewater collection and reuse chain.

CONCEPTUAL APPROACH TO DESALINATION FOR AGRICULTURE

The conceptual framework developed within the SALT'EAUX project is based on the principle that desalination strategies for agriculture should not be designed exclusively from a water treatment perspective. Instead, desalination must be integrated into a broader agro-hydrological system in which water quality objectives are defined according to crop requirements, soil functioning, environmental conditions, and economic feasibility.

The first principle underlying this framework is the concept of fit-for-purpose desalination. Unlike drinking water production, agricultural irrigation does not systematically require extremely low salinity levels. Many crops can tolerate moderate salinity if irrigation practices, drainage conditions, and soil properties

are properly managed. Consequently, the objective is not necessarily to maximize desalination performance but rather to achieve salinity levels compatible with sustainable agricultural production. This approach enables substantial reductions in treatment costs and energy consumption while preserving agronomic functionality.

The second principle concerns the integration of upstream and downstream salinity management. Salinity in treated wastewater is not solely determined by treatment technologies but also by the characteristics of sewer systems and by saline intrusions occurring before treatment. Reducing salinity at the source through targeted rehabilitation of sewer networks may therefore significantly improve the quality of treated effluents and reduce desalination requirements. Similarly, the impacts of saline irrigation water depend on downstream factors such as irrigation scheduling, drainage efficiency, soil texture, crop tolerance, and groundwater dynamics.

The third principle is based on adaptive management supported by monitoring and modelling tools. Salinity dynamics are highly variable in space and time, especially in coastal environments where groundwater levels, evapotranspiration, and climatic conditions fluctuate seasonally. Consequently, desalination strategies must remain flexible and responsive to changing environmental conditions. This requires continuous monitoring of water and soil salinity as well as predictive tools capable of anticipating future risks and supporting operational decision-making.

Finally, the project adopts a systemic governance approach involving water managers, local authorities, agricultural stakeholders, environmental institutions, and scientific experts. This collaborative framework is considered essential for ensuring the operational feasibility, social acceptability, and replicability of desalination strategies in coastal territories.

MATERIALS AND METHODS

Upstream salinity diagnostics

The first stage of the project consisted of diagnosing saline intrusions within sewer systems. This work aimed to identify the origin, magnitude, and temporal dynamics of salinity entering wastewater treatment plants.

Existing monitoring data related to rainfall, groundwater levels, lagoon water levels, pumping stations, and conductivity measurements were first analyzed. Additional conductivity sensors were then installed within strategic sections of the sewer networks. Night-time sectorization campaigns combining flow measurements and conductivity monitoring were conducted across approximately 42 km of network at Mèze and 52 km at Marseillan.

The investigations identified sectors particularly vulnerable to saline groundwater infiltration. Complementary video inspections were performed on approximately 3,2 km of sewer network at Mèze and 9,8 km at Marseillan to characterize structural defects contributing to infiltration processes. Based on these analyses, rehabilitation scenarios were developed to reduce saline inputs into the networks.

Water treatment and desalination strategies

At Mèze, the selected strategy combines sewer rehabilitation with selective demineralization of treated wastewater. Pilot-scale tests using a membrane-based process demonstrated the feasibility of reducing electrical conductivity from approximately 3,5 – 3,8 dS/m to around 1,5 dS/m. This target was defined according to vineyard tolerance thresholds and the requirements of diversification crops such as onions and olives.

The desalination process was intentionally designed to achieve partial rather than complete demineralization. This approach allows operational costs to remain compatible with agricultural economics while delivering irrigation water suitable for long-term use.

At Marseillan, a different strategy was adopted. Because vineyards are already exposed to saline conditions and soils are predominantly sandy with natural drainage capacity, the objective was to manage salinity rather than eliminate it. Treated wastewater with salinity ranging between 1,5 and 3,5 dS/m is therefore considered potentially usable provided that irrigation management and hydraulic drainage are optimized.

An optional demineralization unit remains under consideration at Marseillan in case long-term monitoring demonstrates unacceptable agronomic impacts. However, the project prioritizes low-energy solutions combining upstream salinity reduction, drainage management, and adapted agricultural practices.

Soil salinity characterization and agronomic monitoring

A detailed characterization of soil salinity was conducted on the Marseillan site using electromagnetic geophysical surveys combined with soil sampling. This methodology enabled high-resolution mapping of salinity distribution across the vineyard domain and within the soil profile.

The analyses revealed strong spatial variability in salinity levels both horizontally and vertically. Surface horizons between 0 and 40 cm generally exhibited electrical conductivity values between 2 and 4 dS/m, while deeper horizons between 60 and 120 cm frequently exceeded 4 dS/m and locally reached 8 dS/m. These results confirmed the influence of shallow saline groundwater on root zone salinity dynamics.

Physiological measurements were conducted on vines to evaluate the effects of salinity on plant functioning. Parameters related to vegetative development, reproductive growth, and yield components were monitored under different salinity conditions. The experiments aimed to identify thresholds beyond which productivity declines become significant.

In parallel, diversification crops including quinoa, oats, lentils, chickpeas, onions, and olives were introduced in experimental plots to assess their suitability under saline irrigation conditions.

Development of predictive tools

The project includes the development of several operational decision-support tools. A predictive model of saline intrusion into sewer systems will be developed to anticipate salinity fluctuations at wastewater treatment plant outlets. This tool integrates environmental variables such as groundwater levels, rainfall, lagoon levels, and hydraulic network behaviour.

At field scale, hydro-saline balance models will be developed to simulate interactions between irrigation water quality, soil salinity, groundwater dynamics, and crop response. These tools aim to support adaptive irrigation management by helping farmers determine irrigation volumes and periods compatible with salinity constraints.

RESULTS AND PRELIMINARY FINDINGS

The maturation phase of the SALT'EAUX project confirmed the relevance of combining upstream and downstream salinity management strategies. The sewer network diagnostics demonstrated that saline groundwater intrusions constitute the principal driver of elevated conductivity levels in treated wastewater.

At Mèze, rehabilitation works targeting critical network sections are expected to reduce influent salinity by approximately 1 to 2 dS/m. Combined with selective demineralization, this enables the production of irrigation water with a stable conductivity around 1,5 dS/m. This water quality level is considered compatible with the irrigation of approximately 90 hectares of vineyards and diversification crops using around 100 000 m³ of reclaimed water annually.

At Marseillan, the detailed characterization of soil salinity provided important insights into the functioning of the coastal agro-system. Salinity was found to vary considerably between plots and soil depths, highlighting the need for localized management approaches. Despite these saline conditions, vineyards continue to produce under current practices, indicating a certain level of adaptation of both soils and plants.

Physiological monitoring showed that salinity primarily affects vegetative growth and reproductive development rather than fruit quality itself. Yield reductions appear to result mainly from lower biomass production and reduced cluster formation. These observations suggest that maintaining salinity within moderate thresholds may allow continued production without severe agronomic degradation.

The hydraulic drainage rehabilitation strategy at Marseillan also appears promising. By controlling groundwater levels and facilitating salt leaching during winter periods, drainage may contribute to limiting long-term salt accumulation within the root zone. This mechanism is particularly important in sandy soils where water movement remains relatively rapid.

The project also demonstrated the importance of crop diversification within adaptation strategies. Preliminary observations indicate that some diversification crops exhibit satisfactory tolerance to moderate salinity levels and may contribute to improving agricultural resilience under changing climatic conditions.

DISCUSSION

The SALT'EAUX project highlights several important lessons regarding the design of desalination strategies for agricultural reuse in coastal environments. First, the results confirm that desalination strategies should not be conceived solely as technological treatment systems. Instead, they must integrate the entire continuum linking wastewater collection, treatment, irrigation practices, soil functioning, and crop response.

One of the major findings of the project is that the implementation of various salinity management measures (possibly including partial desalination) could help address the challenges facing agriculture in coastal areas. By targeting salinity thresholds compatible with crop tolerance rather than drinking water standards, the project significantly reduces treatment requirements and associated costs. This fit-for-purpose approach improves the economic feasibility of reuse schemes while maintaining agronomic sustainability.

The comparison between Mèze and Marseillan illustrates the importance of adapting desalination strategies to local environmental conditions. In relatively preserved areas such as Mèze, maintaining low salinity levels is essential to avoid initiating soil degradation processes. Conversely, in already saline environments such as Marseillan, agricultural systems may remain functional under moderate salinity provided that irrigation and drainage are carefully managed.

The project also demonstrates the importance of considering temporal dynamics. Salinity levels fluctuate according to climatic conditions, groundwater behaviour, and irrigation practices. Adaptive management supported by predictive tools therefore represents a key component of sustainable desalination strategies.

From an operational perspective, the integration of multiple stakeholders within the project governance has proven essential. The collaboration between water utilities, agricultural stakeholders, local authorities, environmental institutions, and research organizations facilitated the development of solutions that are technically feasible, environmentally acceptable, and operationally realistic.

Several challenges nevertheless remain. Long-term monitoring will be necessary to evaluate the cumulative impacts of saline irrigation on soils and crop productivity. Economic assessments will also be required to compare the costs and benefits of different desalination scenarios under real operational

conditions. Finally, climate change may further intensify salinity pressures through sea level rise and increased drought frequency, requiring continuous adaptation of management strategies.

Despite these uncertainties, the SALT'EAUX project provides a valuable demonstration of how desalination strategies can be designed to specifically meet agricultural needs in coastal environments. The approach developed within the project may serve as a transferable framework for other Mediterranean and coastal territories facing similar constraints.

CONCLUSION

The SALT'EAUX demonstrator addresses one of the major challenges currently facing coastal agriculture: how to mobilize alternative water resources while controlling salinity risks for crops and soils. The project demonstrates that desalination strategies for agricultural reuse should not aim systematically for maximum salt removal but rather for the optimization of water quality according to agronomic requirements and local environmental conditions.

Through the combination of upstream sewer rehabilitation, selective desalination, adaptive irrigation management, hydraulic drainage, monitoring systems, and predictive modelling tools, the project establishes an integrated framework for sustainable water reuse in saline coastal environments. The contrasted situations of Mèze and Marseillan illustrate the necessity of adapting desalination strategies to local hydro-agronomic contexts.

The preliminary results obtained during the maturation phase confirm that reclaimed water with controlled salinity can contribute to securing irrigation volumes while preserving soil functionality and supporting agricultural diversification. Beyond the technological dimension, the project highlights the importance of systemic and collaborative approaches integrating infrastructure management, agronomy, hydrology, and governance.

The SALT'EAUX project therefore provides both scientific and operational contributions to the development of fit-for-purpose desalination strategies for agriculture. Its methodology and findings may support the replication of similar approaches in other coastal regions confronted with increasing water scarcity and salinity pressures under climate change conditions.

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