Project of the interventions to mitigate saltwater contamination in the Italian site

Deliverable D_3.1.8

Contributing partners:

LP – UNIPD DICEA

TABLE OF CONTENTS

1. **Introduction**

Seawater intrusion in coastal aquifers is a worldwide problem caused by natural processes but significantly worsened by aquifer overexploitation for drinking water supply and irrigation, land subsidence, sea levels rise, and climate changes, which contribute to the reduction of groundwater natural recharge (*Todd,* 2005). There is still need for a better understanding of these processes, in order to define effective countermeasures capable to reduce the negative effects of seawater intrusion on coastal and island communities. Within the framework of MoST (MOnitoring Sea-water intrusion in coastal aquifers and Testing pilot projects for its mitigation the University of Padua, involved as Lead Partner, focused on a study area located at Ca' Pasqua, in the southern part of the Venice lagoon, Italy, as a pilot site to develop and test possible solutions to issues of coastal seawater intrusion. The main purposes is to reproduce the effects of saltwater intrusion in the study site by means of a numerical model, laboratory analyses and field campaigns and to assess the effectiveness of possible countermeasures.

2. **Case study**

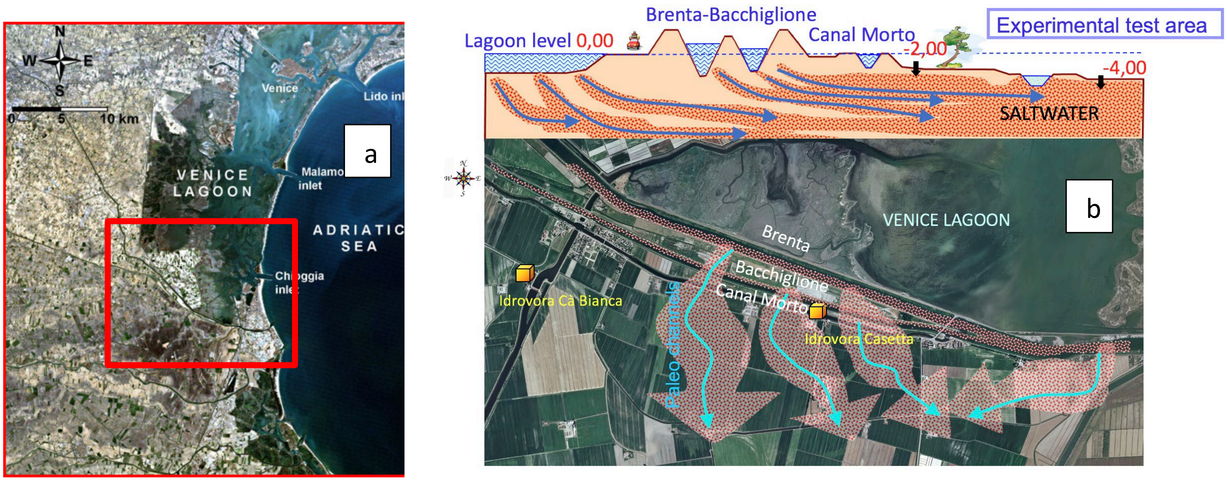

Figure 1. a) General view of the case study in the southern part of the Venetian lagoon. b) Plan view and typical cross-section of the study area, located next to the Casetta pumping station, indicating the main drivers and dynamics of the seawater intrusion.

The study area is complex due to the interplay of different physical elements (e.g. *Carbognin and Tosi,* 2003): the Bacchiglione and Brenta rivers cross the study area just before flowing into the Adriatic Sea; the Morto channel, whose water level is controlled by a lock gate system, collecting reclamation waters by an upstream pumping station, flows inside the study area, parallel to the Bacchiglione river, while the Venice lagoon lies in the north-east boundary of the domain and in the south-west side there are mainly agricultural fields (Figure 1, panel a) and b)). Seawater intrusion in this reclamation area is mainly due to the water level of the aquifer being lower than the water level in the lagoon, generating a reverse hydraulic gradient. Moreover, the ground surface is below the mean sea level due to land subsidence and the water level in the aquifer is controlled trough a complex system of drains, ditches, and dewatering pumps, to prevent flooding and control agricultural irrigation. In addition, during dry periods, the Bacchiglione and Brenta rivers are affected by saltwater intruding from their mouths and traveling upstream. This causes saltwater to intrude in the domain through seepage fluxes from the rivers to the reclamation area.

3. Data and methods

The MoST project consists of two main phases: i) the first phase of the work is devoted to the collection of hydro-geophysical information and data in the study area and to mimic the dynamics of the relevant processes in laboratory experiments. In the second phase, ii) appropriate countermeasures (e.g., underground barriers, recharge wells, recharge drains, cut-off walls) will be considered to limit or mitigate the seawater intrusion/contamination and their efficiency will be tested.

The numerical finite difference model Seawat (*Langevin,* 2009) is used to simulate the seawater intrusion process. The variable-density coupled flow and transport equations are solved with an implicit procedure and with an appropriate spatial and temporal grid discretization. Transient boundary conditions are implemented in the model to simulate realistic physical features and changes over time (*Zeng and Wang,* 1999*, Harbaugh,* 2005).

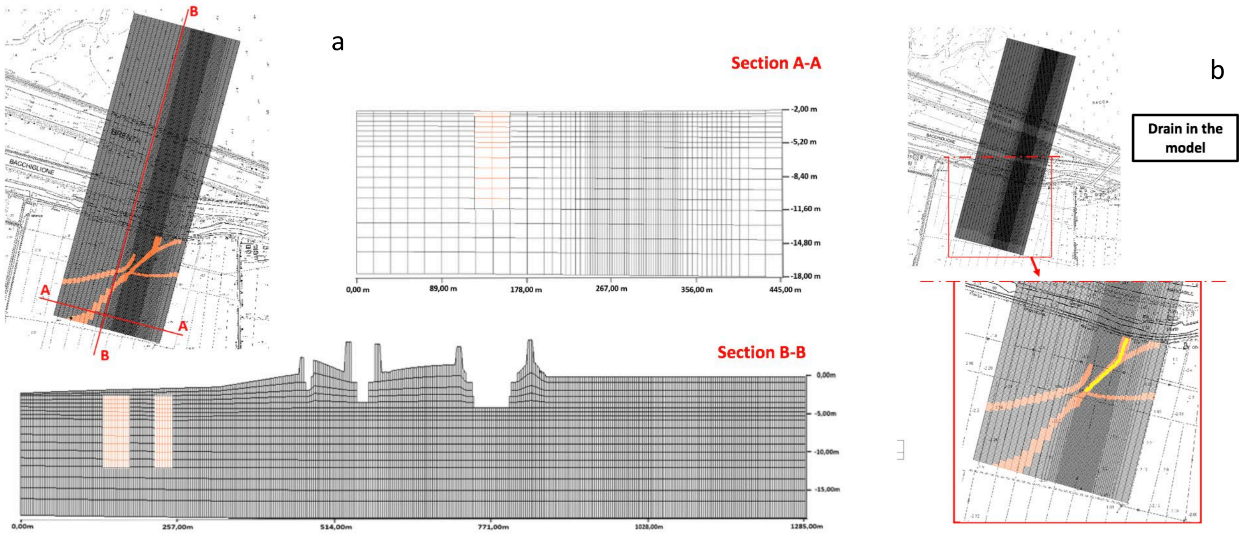

Figure 2. a) Plan view and cross-sections of the mesh applied in Seawat with indication of the paleochannels (in orange), where a drain (in yellow, on the right) (panel b)) is located and tested to mitigate the seawater intrusion.

The model is set up by integrating information derived from in-situ monitoring and observations of precipitation, rivers hydrometric heads, evapotranspiration and tide levels for a period of about 10 years. Stratigraphic, hydrogeological and geoelectrical data are available together with measurements of water table in a number of piezometers. A number of different scenarios with different countermeasures are modelled and compared, allowing the prediction of the resulting seawater intrusion mitigation and its uncertainty.

To test the potential effects of one of the aforementioned countermeasures, a recharge drain is located in a sandy paleochannel, which could represent a preferential pathway for saline intrusion but can also be used to convey freshwater to reduce soil salinization (Figure 2).

4. Results

The simulation period spans from 2012 to 2018 and it is divided into three sub-periods: the first period is devoted to warm-up the model to obtain proper initial conditions for the rest of the simulations; in this phase, only the natural seawater and fresh water infiltration processes are considered from the lagoon to the aquifer; then, a second phase begins where evapotranspiration and precipitation are applied as atmospheric boundary conditions to assess their seasonal effects. Finally, in the third phase different countermeasures are applied, tested and compared.

Figure 3 reports the simulation results in the same cross-section at different time steps. The results suggest that the main drivers of seawater intrusion are the river's seepage fluxes: the Bacchiglione and Brenta seepage fluxes strongly influence the propagation of salt inside the domain, while the lagoon have only a marginal role, having a lower water level compared to the rivers. The simulated processes are strictly dependent on the seasonal variations and on the hydrometric levels in the river and on the associated concentration as confirmed by experimental field data. The Morto channel, which is never salty, seems to act against saline intrusion, as a natural barrier.

Once the preliminary simulations were performed, a comparison was made between scenarios with and without suggested countermeasures. In particular, we report the results of a scenario whereby a drain located in the paleo-channels is used to convey freshwater into the aquifer. The drain has been designed with a flow rate of about 5 l/s and a depth ranging about 1.5-2 m below the ground surface. The results show that the drain reduces the effects of the saline intrusion, but freshwater keep on partially moving downstream inside the paleochannel (Figure 4, panel a); the simulations further show that the application of the drain allows a salinity decrease in the area and thus a possible increase in the crop productivity. Furthermore, the analysis suggests that a combination of the drain (Figure 4, panel b) and a cut off wall near its end would improve the performance and the efficiency of the countermeasure as a whole. These preliminary results warrant a detailed sensitivity analysis and uncertainty quantification to obtain a cost-based design approach of the potential countermeasures

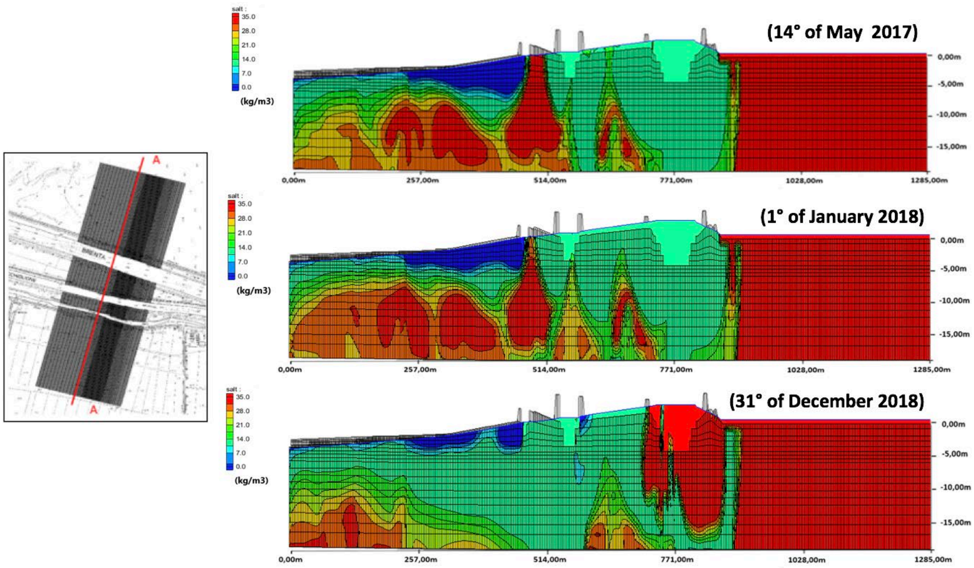

Figure 3. 2D sections of the seawater intrusion (in red) at different time steps of the simulation time.

a b

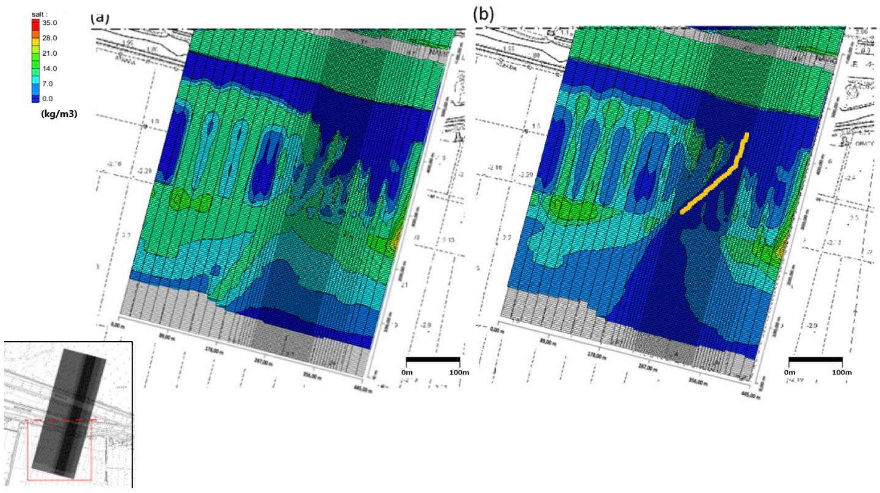

Figure 4. *Plan view at 1.5 m in depth (reference system -2 m a.s.l), 1° of December 2018 without (panel a)) and with (panel b)) the application of the drain. It can be seen, in the right, an increment of the area (in blue and light blue) potentially devoted to agriculture activity and crop productivity.*

5. Summary and preliminary conclusions

In conclusion, the case study area shows a high vulnerability to the saline intrusion phenomenon due to its hydrological and geomorphological features, justifying the need for monitoring and mitigation strategies. In this context, numerical modelling is an efficient approach to analyse, define and test potential countermeasures and their performance.

Results highlight that saltwater intrusion is strongly dependent on seasonal variations, seepage fluxes from the rivers and on the presence of paleochannels which may constitute a preferential pathway for seawater intrusion, on one side, but can also enhance the efficiency of potential countermeasures.

Drains, usually located in the paleochannels, could be an efficient countermeasure to solve this issue together with the application of a cut-off wall. Finally, more accurate investigations (through laboratory tests and fields campaign) could provide more reliable estimations of the main geotechnical and hydraulic parameters and their uncertainty, in order to more accurately assess the best countermeasures in terms of crop productivity increase.

6. References

Carbognin L. and Tosi L., Il Progetto ISES per l'analisi dei processi di intrusione salina e subsidenza nei territori meridionali delle province di Padova e Venezia, CNR-ISDGM, Venezia, 2003.

Ilaria Cunico, “Development of numerical experiments to simulate lab tests and predict field activities in the Most project”, Masster thesis, 2019

Harbaugh, A. W., MODFLOW-2005, the U.S. Geological Survey modular ground-water model–The Ground-Water Flow Process, Tech. and Methods 6–A16, U. S. Geol. Surv., Reston, Va., 2005

Langevin, C. D., 2009, SEAWAT: A computer program for simulation of variable-density groundwater flow and multi-species solute and heat transport: U.S. Geological Survey, Fact Sheet, 3047-2009, Fort Lauderdale, Florida, 2009.

Todd D. and Mays L., Groundwater Hydrology, Wiley, Third Edition. Hoboken, NJ., 2005

Zheng C. and Wang P., MT3DMS, Documentation and User's guide, US Army Engineer Research and Development Center, Vicksburg, MS., 1999