D.5.2.2 Booklet on adaptation plans put in place at local level

Document Control Sheet

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1 Introduction

The need for Adaptation Plane is one of the Key-Points of 5.2.2 Activity: the transposition at the local scale of the “general” Guidelines has generated three plans that show clearly how they can be applied in different contexts – namely Neretva Delta (HR), Ravenna (IT) and Fano (IT) on both the two sides of Adriatic Sea.

The structure of the three plans presented in the booklets concerns the following aspects (preceded by a preface):

a. involved stakeholders and management of coastal aquifers
b. the need of an adaptation plane: salt intrusion in the area, future scenarios of sea level rise
c. possible solutions for adaptation in the study area: control activities, water resources management, urban, agricultural, natural environment
d. implementation of the adaptation plan

In some booklet, a quantitative – predictive modelling system has been developed, in order to test preliminary and verify the solutions proposed (Ravenna – IT), in particular by artificially recharge coastal retro dunes or the drainage ditches in the agricultural area located in the first inland.

In others cases monitoring network dedicated to upgrade in the understanding of the phenomena has been designed in selected test-sites (Fano – IT); vulnerability analysis of infrastructure system (pipelines, sewerage and similar) should be implemented into the seafront sectors of the city, even allowing more freshwater infiltration.

A diffused issue to solve is linked to the progression of seawater inside the river banks, such as in the case of mobile barriers assumed on the river Neretva (HR); also the attention to the development of irrigation network results high, supported by advanced technologies; into the agricultural areas, a strategic measure is identified into planting/ sowing crops and varieties more resistant to elevated soil salt concentration. Groundwater management systems is needed, through simulation models.

In the following pages are shown tables of synthesis of the most characterizing factors of the booklet.

Case studies areas	SWI (salt-water intrusion) level (knowledge, monitoring and model prediction) and local physical constrain	Impact of SWI on water resources management	Impact of SWI on human activities (U = urban environment, A = agricultural, N = natural environment); 1 = actual 0 = potential
Neretva Delta (HR)	Monitoring since 2006. Trends in salinization of surface and groundwater and agricultural soils in the Neretva Valley. No model prediction. Neretva deltaic area.	High (surface waters = seasonal impact)	A0 = severe impact (yields reduction > 50%; socio-economic damage) N0 = important impact (changes in the biodiversity of wetland)
Ravenna (I)	Monitoring since 20-30 years ago. Model prediction available. Soil elevation: near the average sea level. Subsidence rate (XX century) high.	Important (surface waters = seasonal impact)	A0 = expected impact U0 = low sensitive impact
Fano (I)	Not yet monitored specifically (only in-land short-time piezometric network). No model prediction. Soil elevation: important on the sea level (except within	Very low (for human drinking purposes).	U0 = severe impact on the sea-front side of the city (inflow from channels and rivers, seepage)

	last 1 km from the shoreline).		A0 = expected impact related to pumping rates

Case studies areas	Organizations involved	Relationship of the SWI adaptation plan with other environmental programs	Adaptation actions suggested
Neretva Delta (HR)	Croatian Waters (Hrvatske Vode) Water supply companies	Climate change adaptation strategy of the Republic of Croatia until 2040 Seventh National Report and the third biennial report of the Republic of Croatia under the United Nations Framework Convention on Climate Change (UNFCCC)	✓ Building a knowledge base and capacity data for observation and processing ✓ Information exchange ✓ Development of local and sector-specific action and risk prevention and management at national, regional and local level ✓ Development of GIS, monitoring & nearly warning system, risk mapping & assessment ✓ construction of a mobile barrier on the river Neretva ✓ implement advanced technologies and localized irrigation systems

Ravenna (I)	Municipality of Ravenna Po River Basin Authority Interregional agency for the PO river Regional Prevention and Environment Agency of Emilia Romagna Ente Parchi e Biodiversità-Delta del Po	PAESC (action plan for energy and climate) PUG (general urban plan)	✓ Adaptation of vegetation and crops ✓ Freshwater retention and infiltration ✓ Implement an innovative irrigation system ✓ Hydraulic Management ✓ Coast protection and defence ✓ Protected areas and Awareness ✓ Green and Blue infrastructure
Fano (I)	Hydrographic district of Central Appennine Marche Region Municipalities of Fano ATO – Authority Territory Optimal n°1 “Marche Nord” ASET – local water management and distributions company	Strategic planning “Fano 2030”	✓ Test-sites set-up for monitoring ✓ Planning sustainable water use ✓ Reuse of purified waste water ✓ Control of abstraction rates ✓ Relocation of wells / pumping centers ✓ Desalinization plants ✓ Municipal planning, regulation ✓ Freshwater storage & ponding/infiltration ✓ Active practices against shoreline erosion/coastal design & buffer zones

			✓ Hydraulic barriers and infiltration of freshwater ✓ Progradation of the coastline ✓ Adaptation of underground structures and infrastructures ✓ Innovative & technologic irrigation plants ✓ Adaptation of vegetation and crops

2 Case study 1: Municipality of Fano

This adaptation plan to Saltwater inTrusion in sEa level RIse Scenarios (ASTERIS) aims to support the decision maker to understand, analyze and communicate this specific risk into the municipality of Fano.

Important transient changes in freshwater distribution and availability, as a response to sea ingression/regression phases (eustatic cycles) periodically occurred at the geological time-scale, and during Quaternary period too.

But nowadays, the model of social, economic and touristic development along the coasts of XX century, is under discussion all over the world, not least because of sea level rise due to climate change (both at the global and local scale).

Keeping in account a "Precautionary principle" as a response to the uncertainty of the scenarios designed by environmental modeler's, it is proposed the implementation of different complementary actions, tested all over Europe and in the world, that could foster opportunities and generate multiple benefits.

In particular, this booklet is focused on actions that reduce "priority" risks, namely:

- ✓ growth of groundwater level and saturation of the soil along the coastline during the next decades;
- ✓ degradation of groundwater quality by salts, affecting wells abstractions first and, together, damaging the human presence and related activities (corrosion of technological networks and underground structures of buildings, soil salinization and potential loss of crops).

Considering the understanding and description of the elements of territorial vulnerability, it is focused a related strategy of municipal adaptation. Its intensity ranges between "soft" options (e.g. sustainable groundwater use in the inland, in order to allow sufficient recharge of freshwater to the coast), until "hard" options (e.g. physical/hydraulic barriers, progradation and redesign of the coastline, desalinization and wastewater reuse) in front of the sea.

2.1 Management of coastal aquifer and involved stakeholders

In the present situation, coastal aquifer are generally not recognized as a management unit with specific need of attention regarding the interface with the sea, even if the national law for environmental protections (D.Lgs.152/06) contain a specific article (96) reminding that "it should be warranted the equilibrium between recharge and aquifer abstractions in order to avoid intrusion risk of salt (or polluted) waters". The Water Management Plane of the hydrographic district of Central Appennine (referring to the 2000/60/CE Directive) includes the saline intrusion among the significant impact types, in the analysis "pressures-impacts", but there are not yet further evidences of its evaluation in the GWB – Groundwater Bodies, at least not specifically referred to portions of coastal aquifer. The Protection Water Plan of Marche Region points on the groundwater abstraction limitation in the Metauro and Potenza alluvial plane, in order to avoid salt intrusion. Many measures of the Marche Region Water Plan are oriented to achieve aims strictly aligned with coastal aquifer protection against salt intrusion, for example:

Measure n° B.3.3.2 – Equilibrium of water balance and withdrawal re-arrangement

Measure n° B.3.3.3 – Review and monitoring of water – use rights

Measure n° B.3.3.4 – Optimization of water resource for agricultural utilizations

Measure n° B.3.3.5 – Use of treated waste-water for civil, agricultural, industrial purposes

Measure n° B.3.3.6 – Systems and devices for water saving

According to national and regional regulation, the ATO – Authority Territory Optimal n°1 "Marche Nord" provides with the local manager ASET to Integrated Water Service in terms of reconnaissance of infrastructure, program of interventions, management and organizational model and economic and financial planning. In the following page a list of stakeholders is structured according to their public or private nature and referring to the scale (from national to municipality). In this framework, the involvement of the stakeholders could improve the quality and duration of the decisions, since the goods and services related to groundwater resources in the coastal zone depend on the right of use and to the style of management. Some key-question is therefore related to the degree of acceptation of the solutions proposed by the experts, the willing to accept and give up for the general interest; but also to bring out different aims related to groundwater use, understanding the style of interaction between the stakeholders (positive or conflict) and social impacts related to coastal aquifer managing.

PRIVATE

National level

Trade associations

Industry, agriculture associations (ANBI)

(promoters of water saving devices)

Regional & Provincial Level

Managers of integrated water cycle (use of groundwater for human purposes)

Irrigation and Drainage Consortium; Industry & farmer associations (groundwater users)

Drilling companies (aquifer exploitation)

Municipal level

Environmental groups (knowledge dissemination)

Social media (awareness diffusion)

Foundations (financing)

….. (others)

PUBLIC/INSTITUTIONS

National level

District basin authority (management plan of water resources - 2000/60/CE)

Universities/Research centers (technology development and its applications)

Regional & Provincial Level

Environmental Protection Agencies (groundwater monitoring network)

Policy-makers and environmental planners

Regional Parks, Manager of Natura 2000 sites, SIC/ZPS (environmental and coast protection)

Municipal level

Environmental services (direction and coordination)

Strategic planners (land-use modifications)

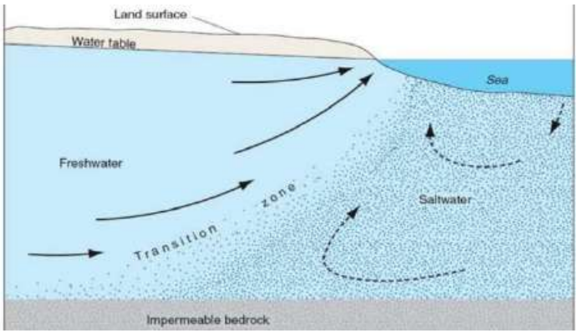
Urban planners (application of guidelines)

….(others)

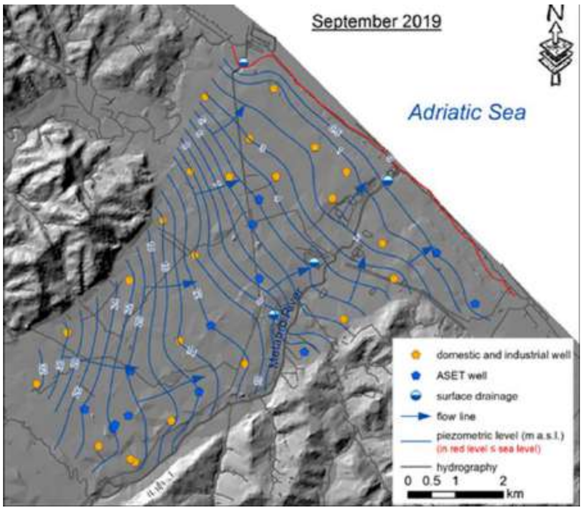
2.2 The need of an adaptation plan

2.2.1 Salt intrusion in the study area

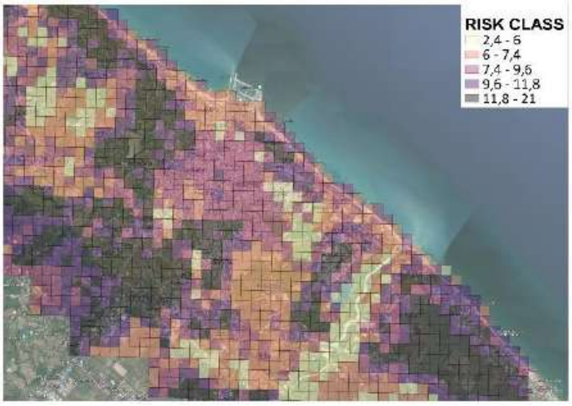
Migration of seawater into freshwater aquifers takes place both as a consequence of excess of wells abstraction, changing the shape of saltwater-freshwater interface, and of sea level rise due to climate change.



Actually, on the basis of monitoring activities during 2009-2020 – measuring hydrochemical parameters in existing wells and piezometric levels - only a few parts of the city land of Fano in front of the sea is subjected to conditions allowing for saltwater intrusion. This occurrence may be critical in particular during summer periods when the piezometric line at 0 meters above the sea tends to move toward inland, as a combined effect of groundwater flow reduction from Metauro aquifer and simultaneous increasing rate of pumping from the wells along the coast.



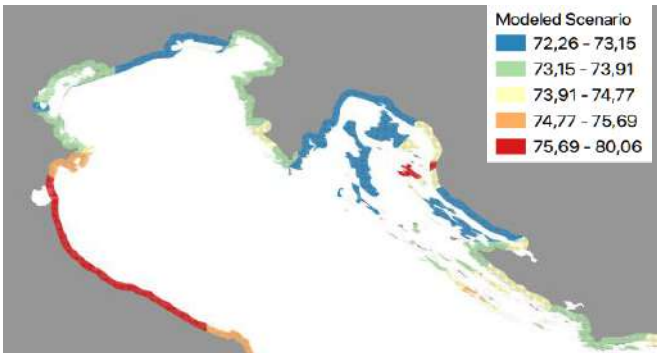
The risk related to salt intrusion in coastal aquifer has been computed with a numerical model, both at the regional and local scale, for different future scenarios (with and without well pumping). In the case of Fano, higher risk classes are related to overexploitation by irrigation, industrial (and domestic) wells; with a general lack of control of the effective pumping rate by private users and without a piezometric network able to detect their depression cones.



Another important way of saltwater ingression is along rivers and inland channels, such as Arzilla River and Canale Albani, with filtration/seepage from the river banks into the adjacent aquifer.

2.3 Future scenarios of the sea level rise

Expected sea level variations at 2100 computed by a numerical model at the global and local scale by University of Urbino ranges between +72 and +80 cm above the 2015 height, as a combined effects of glacial ice melting and volume expansion due to thermic properties of water.



Why should communities care about it and get involved?

In order to reduce restoration costs due to replace/restore salinized water resources, damages to technological networks, underground infrastructures and structures caused by high chloride content; avoid or reduce losses in irrigated land, fruit trees, crops. Preserve geochemical conditions before restore groundwater quality.

What can communities do to prepare for and adapt to salt intrusion in coastal aquifer ?

Protect the beach from sea level rise and frequency of storm surges.

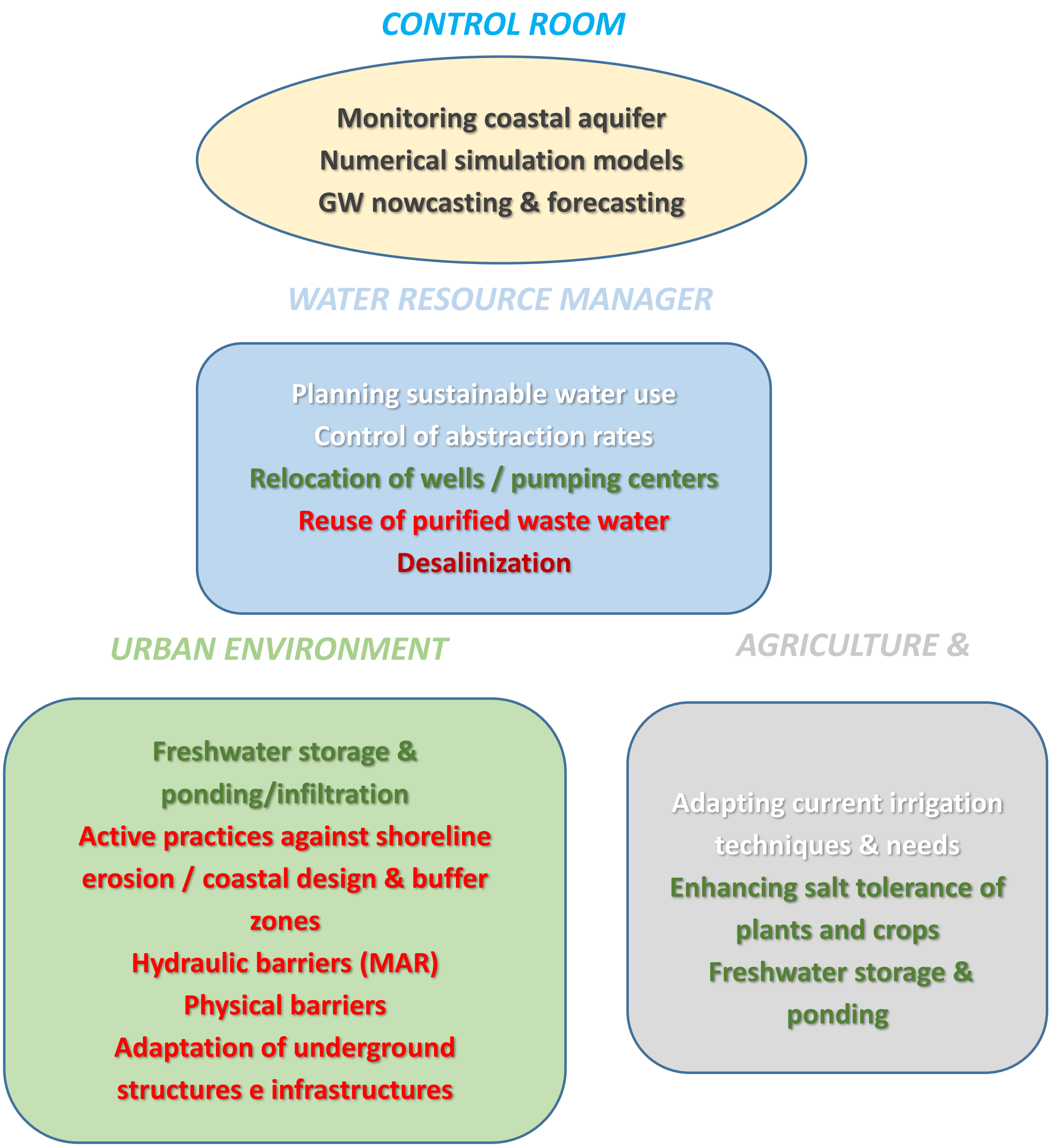
Replace or isolate underground infrastructures (e.g. technological networks, sewers) and buildings (e.g. underground spaces, foundations), in contact with saline and corrosive or brackish groundwater

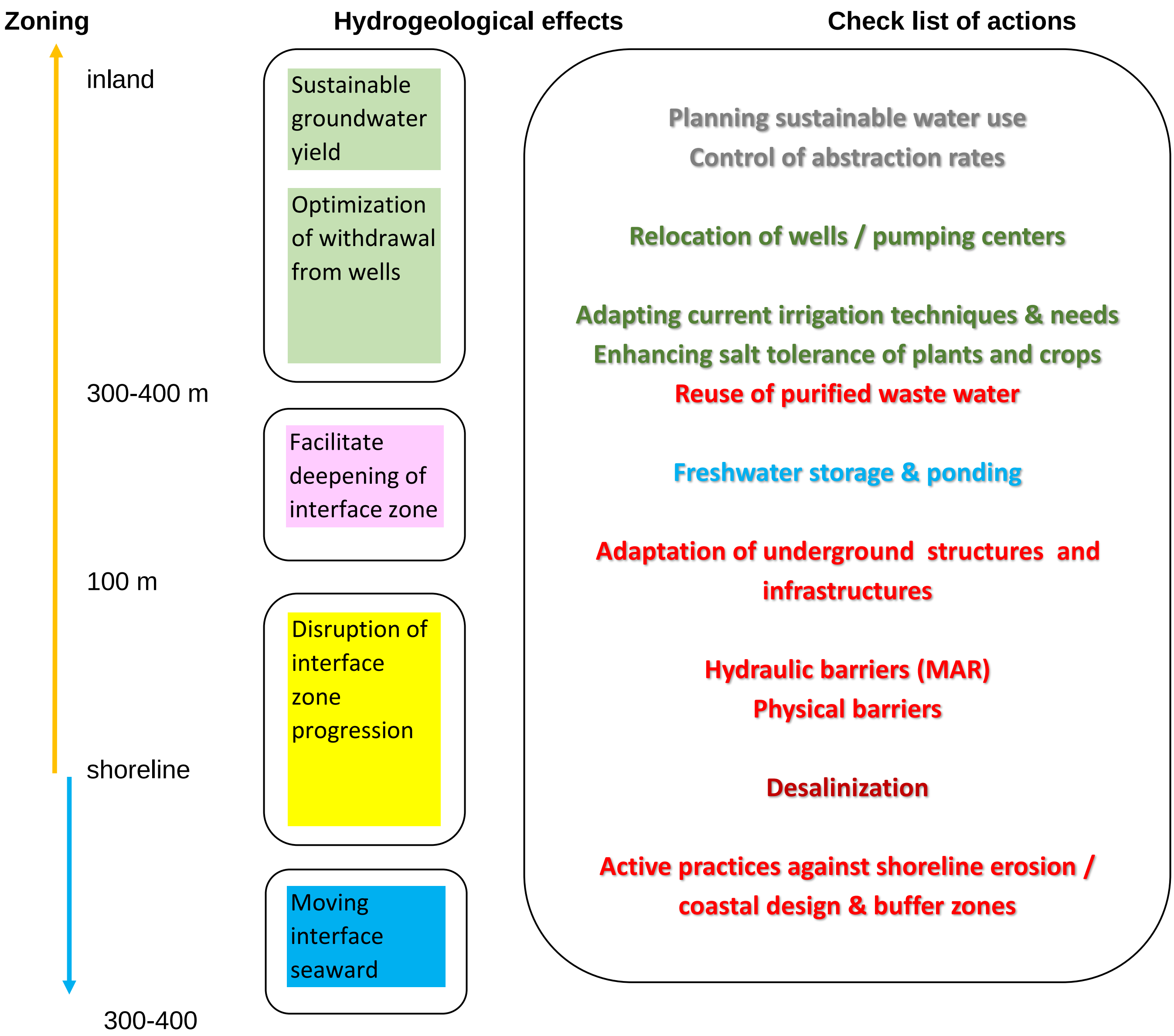
Protect ground water resources for different uses (drinking, irrigation, industrial, domestic)

Protect coastal biodiversity (where applicable / sensitive)

2.4 Possible solutions for adaptation in the study area

The adaption plane provides a framework of actions, which intensity is related in space and time to the severity of SWI, concerning both management aspect and physical realizations & land transforming. Spatially distributed actions have a specific relevance in terms of hydrogeological effects, and their temporal setting follows the progression of SWI and prevention of expected losses/damages.




Zoning
Hydrogeological effects
Check list of actions
inland
300-400 m
100 m
shoreline
300-400
Sustainable groundwater yield
Optimization of withdrawal from wells
Facilitate deepening of interface zone
Disruption of interface zone progression
Moving interface seaward
Planning sustainable water use
Control of abstraction rates
Relocation of wells / pumping centers
Adapting current irrigation techniques & needs
Enhancing salt tolerance of plants and crops
Reuse of purified waste water
Freshwater storage & ponding
Adaptation of underground structures and infrastructures
Hydraulic barriers (MAR)
Physical barriers
Desalinization
Active practices against shoreline erosion / coastal design & buffer zones

2.5 Control room

2.5.1 Monitoring coastal aquifer

Adequate knowledge is the key point for the best planning: they will occur integrated monitoring devices of coastal water resources, headed by coordinated environmental control agencies, ensuring continuous data-flow by instruments disposed along significant coastal transects:

- ✓ Aquifer phreatimetry / pressure;
- ✓ Salinity, hydro-chemical and physical characteristics of water (isotopes, age, temperature);
- ✓ Tidal measurements;
- ✓ Geophysical measurements.

Purposes:

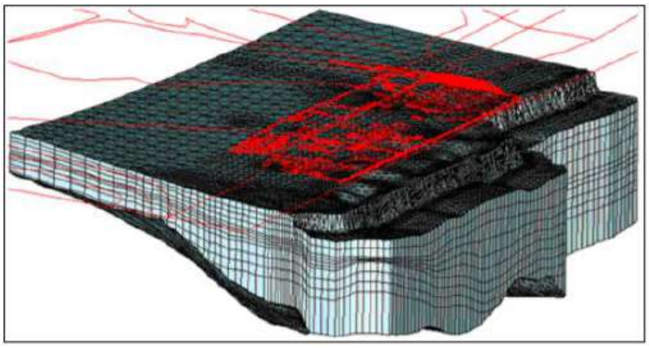
- ✓ Dissemination of information to the population also in accessible language;
- ✓ Elaborate knowledge on the responses of the aquifer system to natural and anthropogenic forcings;
- ✓ Verify the mineralization of aquifer levels at increasing depths, discriminate the nature and origin of saline waters with isotope (and age) analysis;
- ✓ Monitoring the evolution of the interface and intrusion following the implementation of “Best practises” (increase or decrease of salinization).

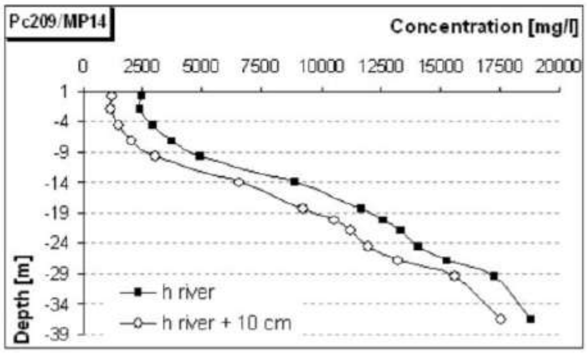
Numerical simulation models: GW nowcasting & forecasting

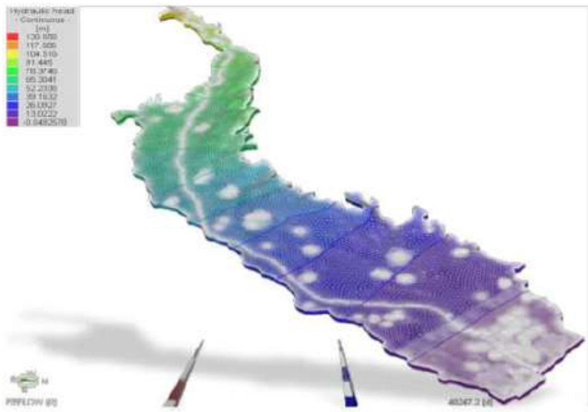
The knowledge of the dynamics of saline inlet in the coastal aquifer, integrated with the monitoring described above, is summarized through the continuous updating of a simulation model of the groundwater flow and of the variations in position of the fresh-salt water interface.

The simulation model dynamically considers the effects of remedial actions, in response to the progressive sea level rise, such as to changes in the flow rate and position of the wells, the introduction of physical and hydraulic barriers, the change of infiltration rates in urban areas or the re-introduction of purified water into the aquifer.

The model provides periodic reporting that reproduces the current state of affairs and foresees the expected scenarios, to support decision makers and to evaluate the results obtained with the actions taken.





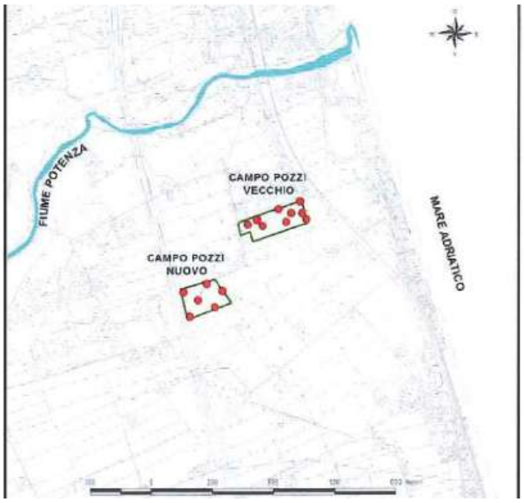


2.6 Water resource manager – Planning sustainable water use

- ✓ Review of water concessions according to risk of aquifer salt intrusion; reduction/optimization of abstraction rates.
- ✓ Introduction of limitations in the use of deep wells
- ✓ Preserve the use of fresh groundwater bodies for valuable uses; encourage alternative water supplies for less-valuable uses

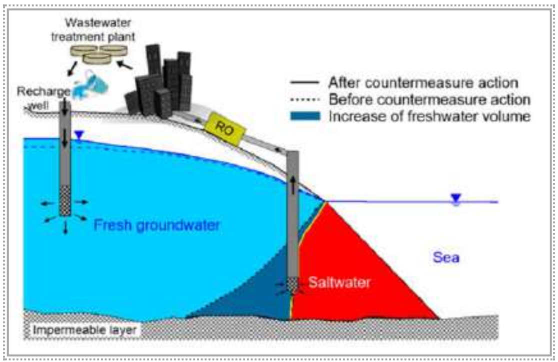
Control of abstraction rates

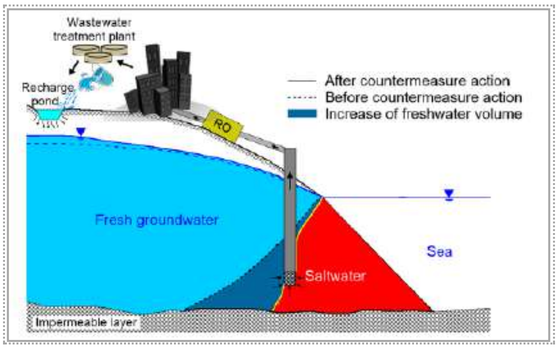
Relocation of wells/pumping centers



Reuse of purified wastewater

Aquifer recharge based on treated waste-water for less valuable purposes, (directly by injection wells or recharge pond), is specifically suitable as a possible contrast action to salinization risk of coastal aquifer and of the irrigation wells in the agricultural zone of Metaurilia, on the SE side of River Metauro. Eventually coupled with continuos abstraction of saltwater & desalinization (with reverse osmosis plant) – see below.





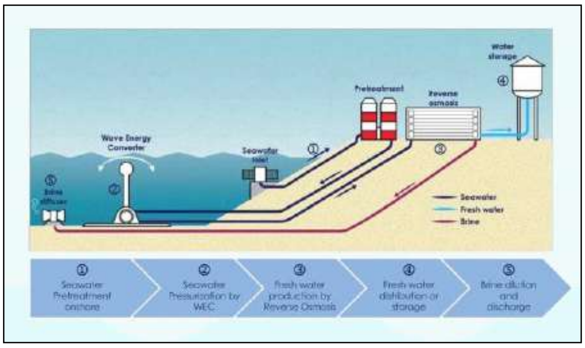
Desalinization

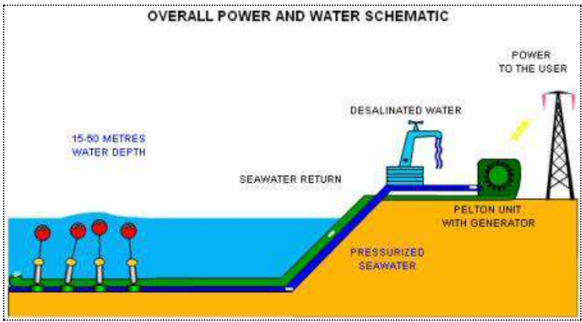
Desalinization may become a necessary option, when the aquifer is significantly affected by salt intrusion from the seaside.

It consists of elimination of salts and minerals from sea or brackish water to obtain drinking water (or other purposes).

The main technique used is reverse osmosis using membrane filters that remove particles, ions and various molecules from the water.

For drinking purposes, the minerals necessary for humans eliminated by reverse osmosis must be "reintroduced" into the water produced by OI.

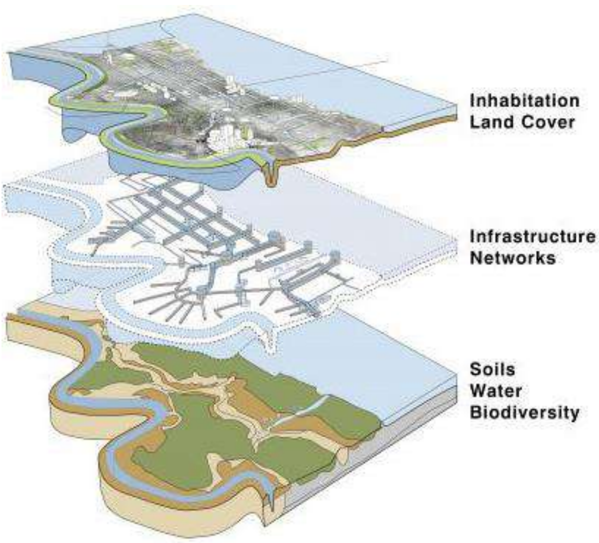




2.7 Urban Environment

2.7.1 Municipality planning, regulation

In this chapter a series of adaptation interventions to saline intrusion in an urbanized environment will be mentioned.



They represent a vision and projects that can be promoted by cooperating actors, in order to increase in awareness.

These measures represent a guidance for urban policies, that are in accordance with the urban policies of the Strategic Plan Document “Fano 2030”.
One of the finalized interventions to achieve the general objectives of the “Fano 2030 Plan” is the creation of a “green crown, where must be favored reforestation actions and policies, but also the creation of greenways and more rest areas made of environmentally friendly materials and enhancement of the territory through the use of urban gardens”.

Within the urbanized area, the Plan sets some objectives:

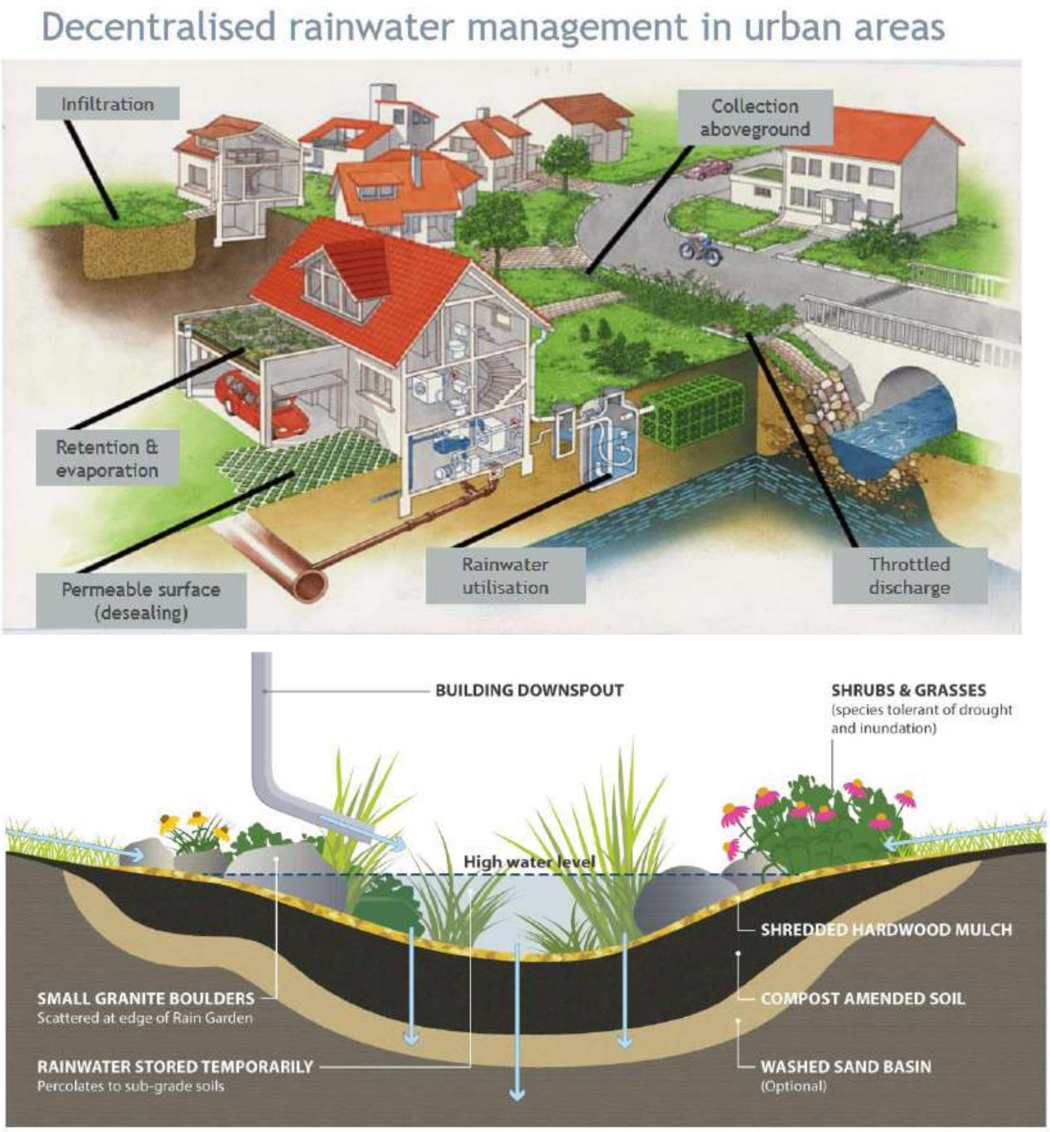
- ✓ improve the quality of public and private spaces;
- ✓ encourage the recovery and completion of assets existing building, also by pursuing their functional adaptation;
- ✓ protect buildings of historical, environmental and architectural value;
- ✓ favor the permeability of urban open areas central; is. the design of the public city as form and objective of the new Plan.

These measures could be tuned at a good level of harmony with the adaptation solutions listed here.

Freshwater storage & ponding/infiltration

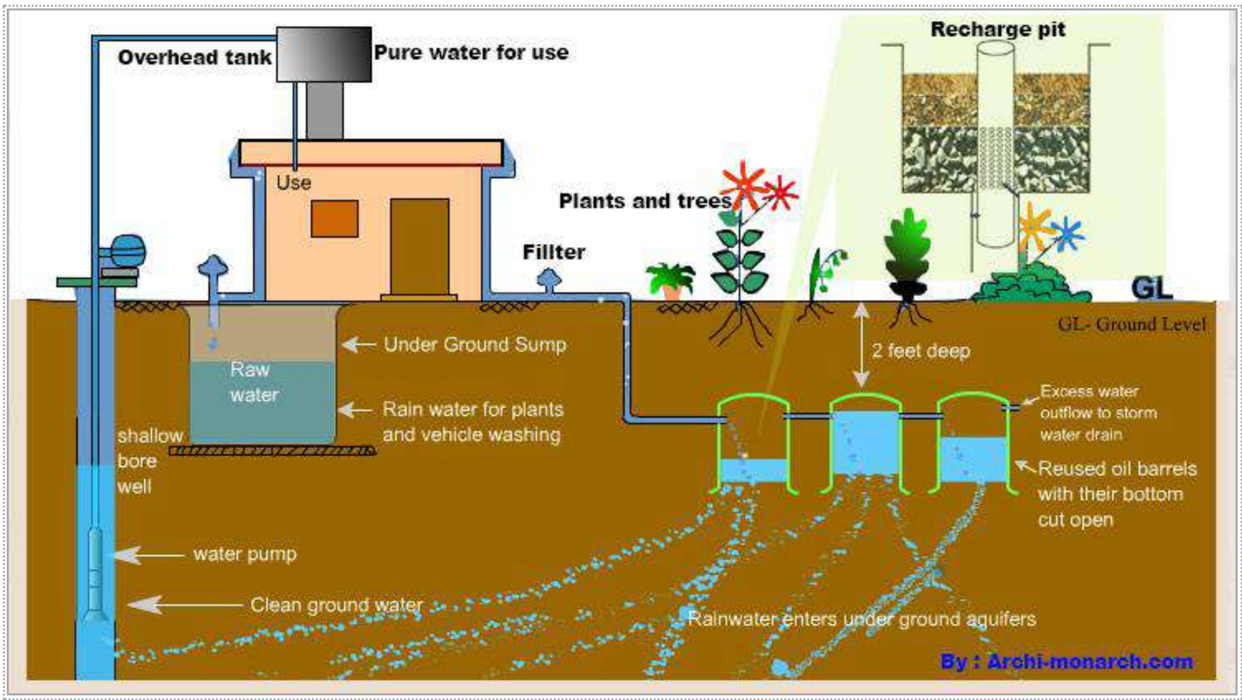
In the coastal lowland zone, with continuous urbanization almost in front of the shore, the key-action is to maximize the infiltration rate of surface (rain) water, facilitating deepening of the interface zone.

Collection and storage of rain, rather than allowing it to run off. Rainwater is collected from a roof-like surface and redirected to a tank, cistern, deep pit (well, shaft, or borehole).



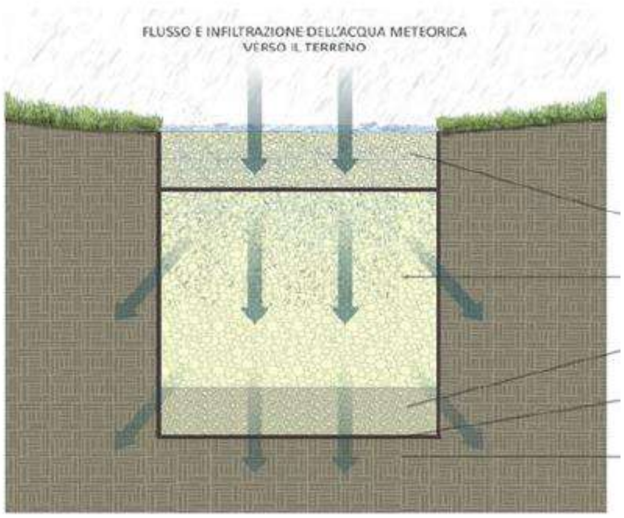
(Source: Toronto and Region Conservation Authority; https://trca.ca/news/complete-guide-building-maintaining-rain-garden/)

Raingarden

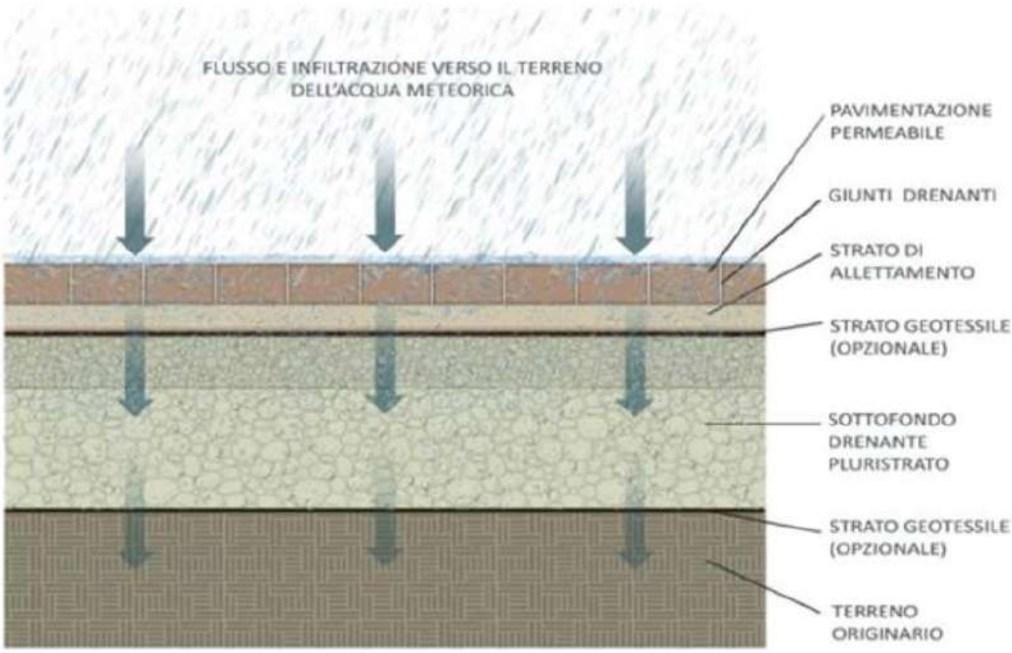


Vegetated bio-retention areas

Infiltrating trenches

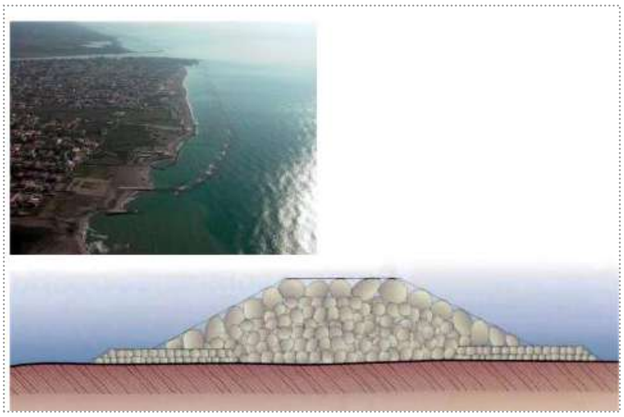


Permeable flooring



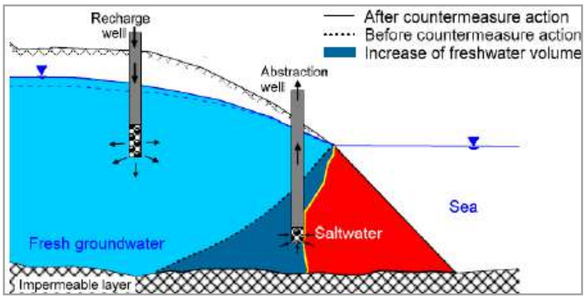
Active practices against shorelines erosion/coastal design & buffer zones

Coastal engineering structures, coupled with requalification of on-shore ecosystems and green coastal redevelopment, contributes to reduce the impact of salt-intrusion phenomena.

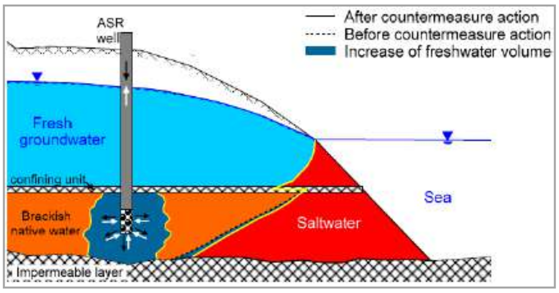


Hydraulic barriers and infiltration of freshwater

Hydraulic barriers, consisting of lines of recharge or extraction wells (or coupled systems) contribute to control saltwater intrusion. Specific knowledge is already available in the municipality of Fano, even if since now the main function of MAR (Managed Aquifer Recharge) is oriented to diluition of nitrate pollution in the Metauro aquifer system; from an energetic point of view, it is desirable adopt solutions with low-emission pumping systems (e.g., solar powered pumps).

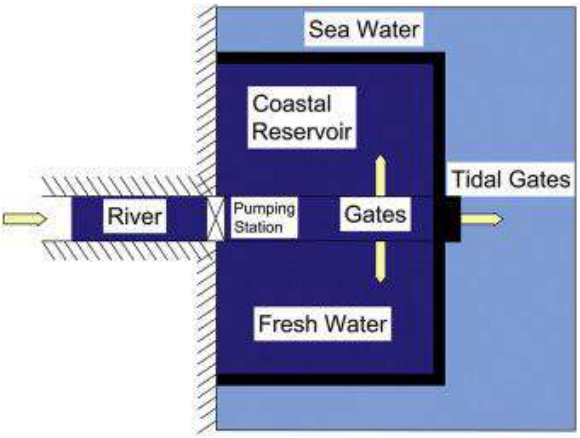


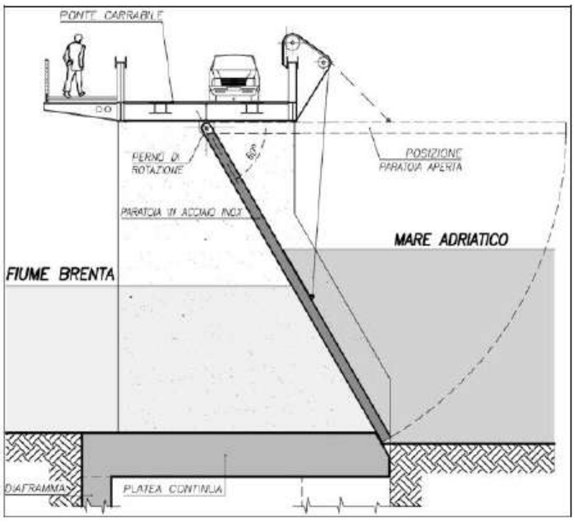
Especially in the case of confining layers, it will be possible designs ystems of Cyclic Recharge with injection of freshwater during wet season followed by pumpings in the dry season. The percentage of water extracted for suitable use, referred to injected volume, defines COP of the system.



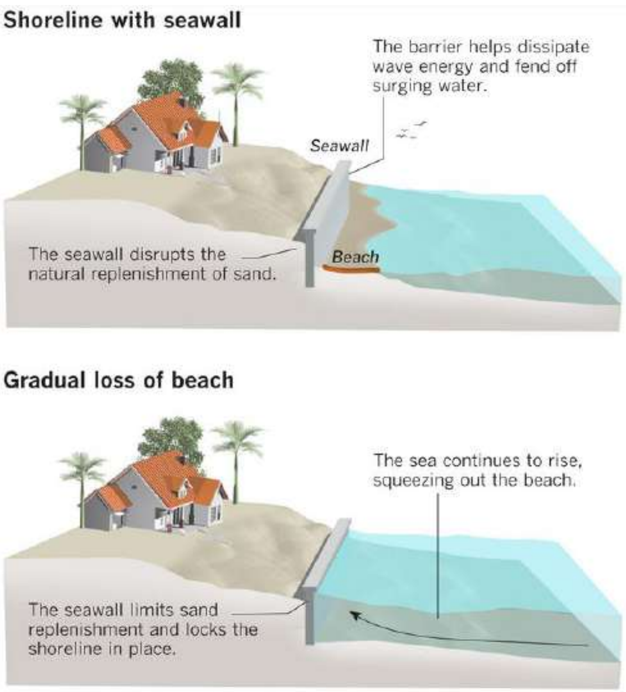
Physical barriers & Geochemical cutoff wall

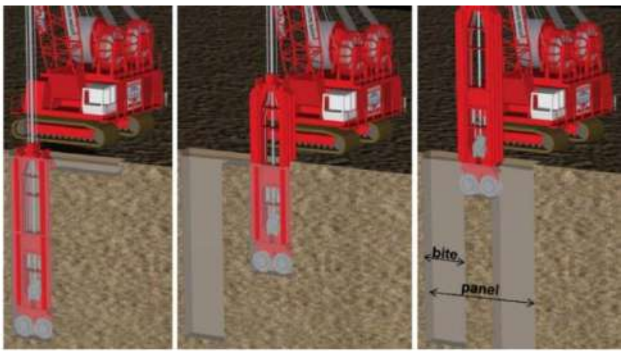
Physical barriers may become necessary next to the shoreline, both on the land surface – especially to regulate river flows and sea ingression during storm surges, and to ensure protection of more exposed structures not removable. But also underground, in order to interrupt the interface zone with diaphragm walls.





Bridges with mobile weir (against river salt wedge)

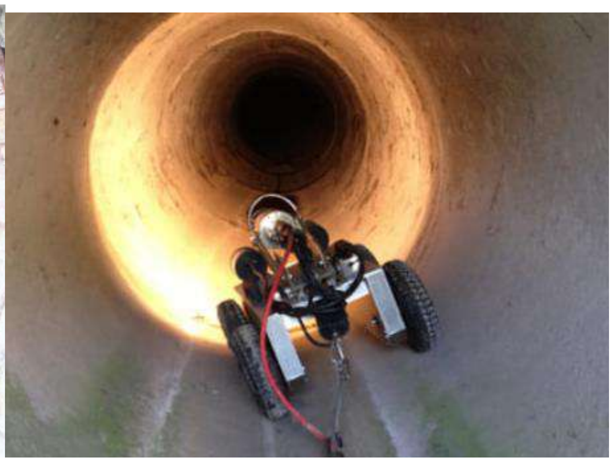




Diaphragm walls construction

Adaptation of underground structures and infrastructures

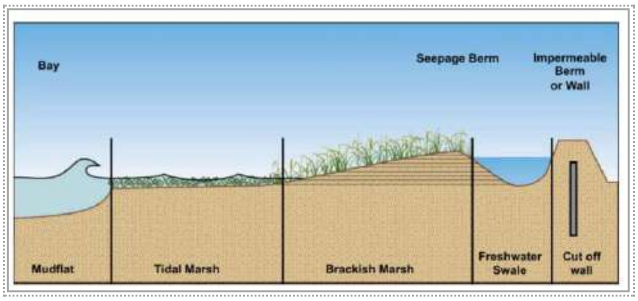
The first action for the adaptation plane by the infrastructure managers consists of a systematic inventory and mapping on the field (with video-inspections), preceded by an archive research, in order to get a full knowledge of the network geometry and materials properties.



Secondly, on the basis of this preliminary activities, a remediation program should be setup, in order to modify, if necessary, the existing materials with others having a higher resistance to salt water corrosion.

Progradation of the coastline

A prevention action against the progressive sea level rise could is prograding the coast line toward the seaside, settling new emerged lands in low-depth water, taking in account impact on the aquatic environment. The new coast-land performs a multi-purpose task, since it could also become an important buffer zone for storm-surge, and a wetland ecosystem.


Bay
Seepage Berm
Impermeable Berm or Wall
Mudflat
Tidal Marsh
Brackish Marsh
Freshwater Swale
Cut off wall


Levee
Brackish Marsh
Tidal Marsh
Tidal Mud Flat
Shallow Bay
THE HORIZONTAL LEVEE
Coastal Storm-Surge Barrier

2.8 Agricolture & Irrigation

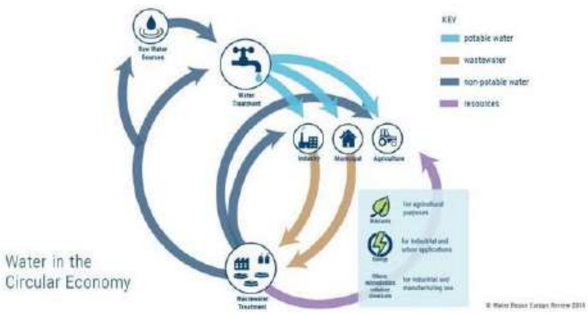
Innovative & technologic irrigation plants

Macro-sprinkling irrigation with new generation pivot (increasing of efficiency and reduction of needs)

Macro-sprinkling irrigation

Sprinkler irrigation

Re-use of purified wastewater as a support to irrigation



Adaptation of vegetation and crops

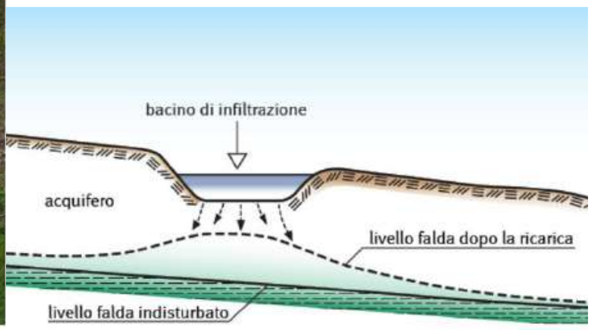
Planning proper agricultural soils use through:

- ✓ reasonable shifts in agricultural practices;
- ✓ selection of plants and crops which can be tolerant to various salt limits and to alternating wetting and drying irrigation practices;
- ✓ design of irrigation pipelines for freshwater transport
- ✓ optimization of wells distribution for irrigation.

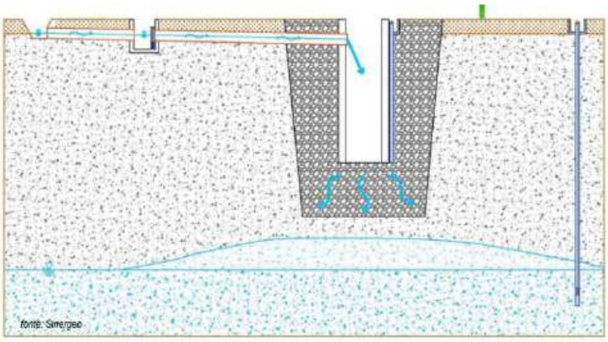
Freshwater storage & ponding/infiltration

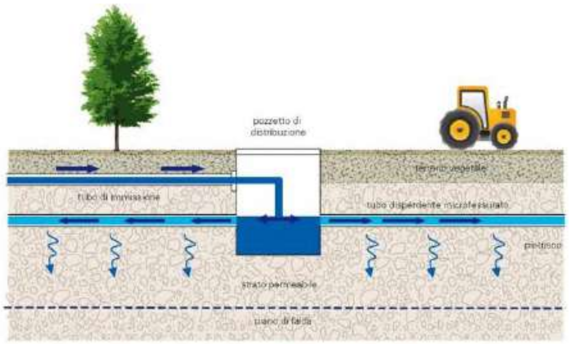
Infiltration stripes or forest ponds

Infiltration ponds



Infiltrating wells





Infiltration tunnels or drains

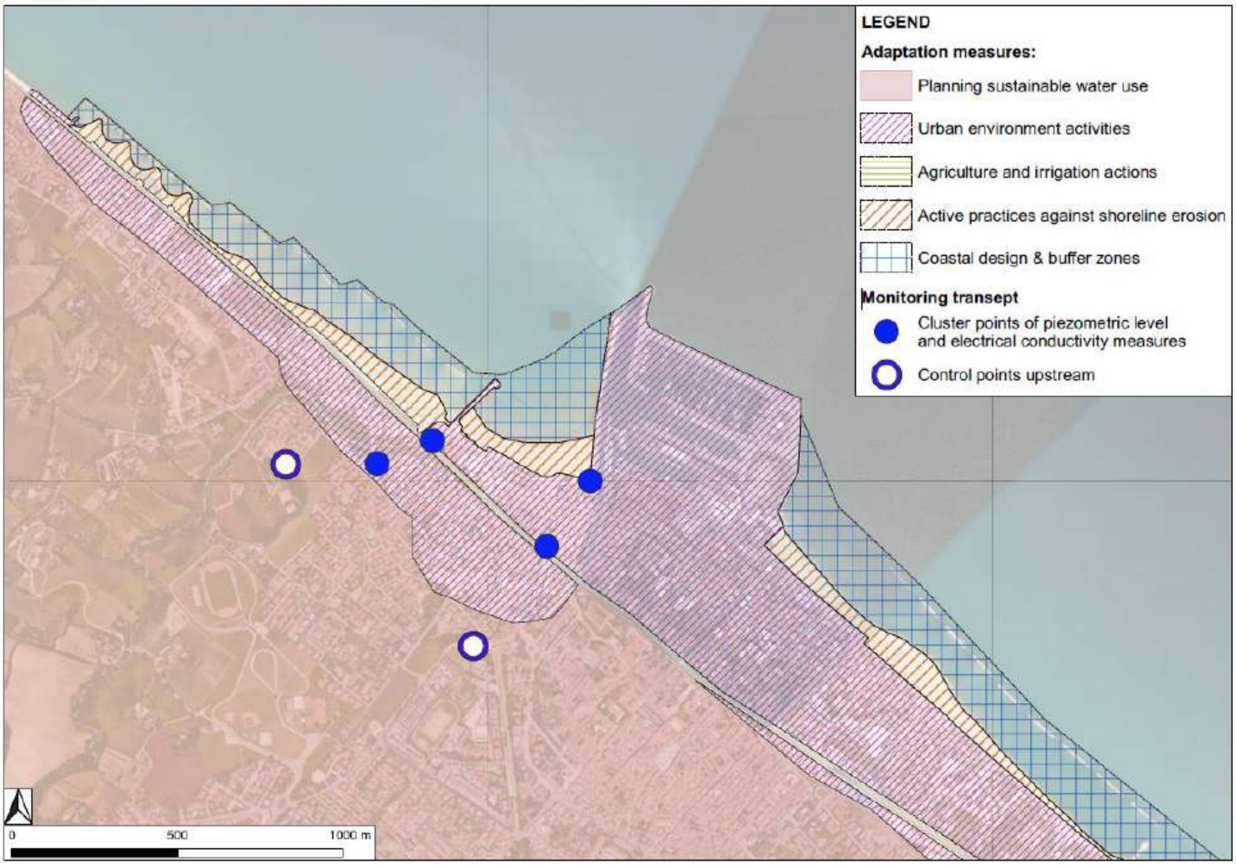
2.9 Implementation of the adaptation plan

2.9.1 Test sites, pilot areas: where, when & why?

In the framework of actions above specified, the adaptation plane identifies several selected "transects" of priority interest for their experimental application. A transect is an ideal line orthogonal to the coastline, along which a zonation of the risk level due to Salt Water Intrusion is expected. Each transect is provided by installations of monitoring devices, distributed between the emerged beach and the inland. The test-sites are related to specific land-use settings, and differs in reason of the solutions to be tested.

Test-sites "Torrente Arzilla" and "Channel Albani"

Two transects are placed in the zone of influence of River Arzilla & Albani channel, along which salt water intrusion will take place in relation to exchange between surface water and surrounding aquifer. Expected measures need to be focused in the field of physical barriers (surface & underground).

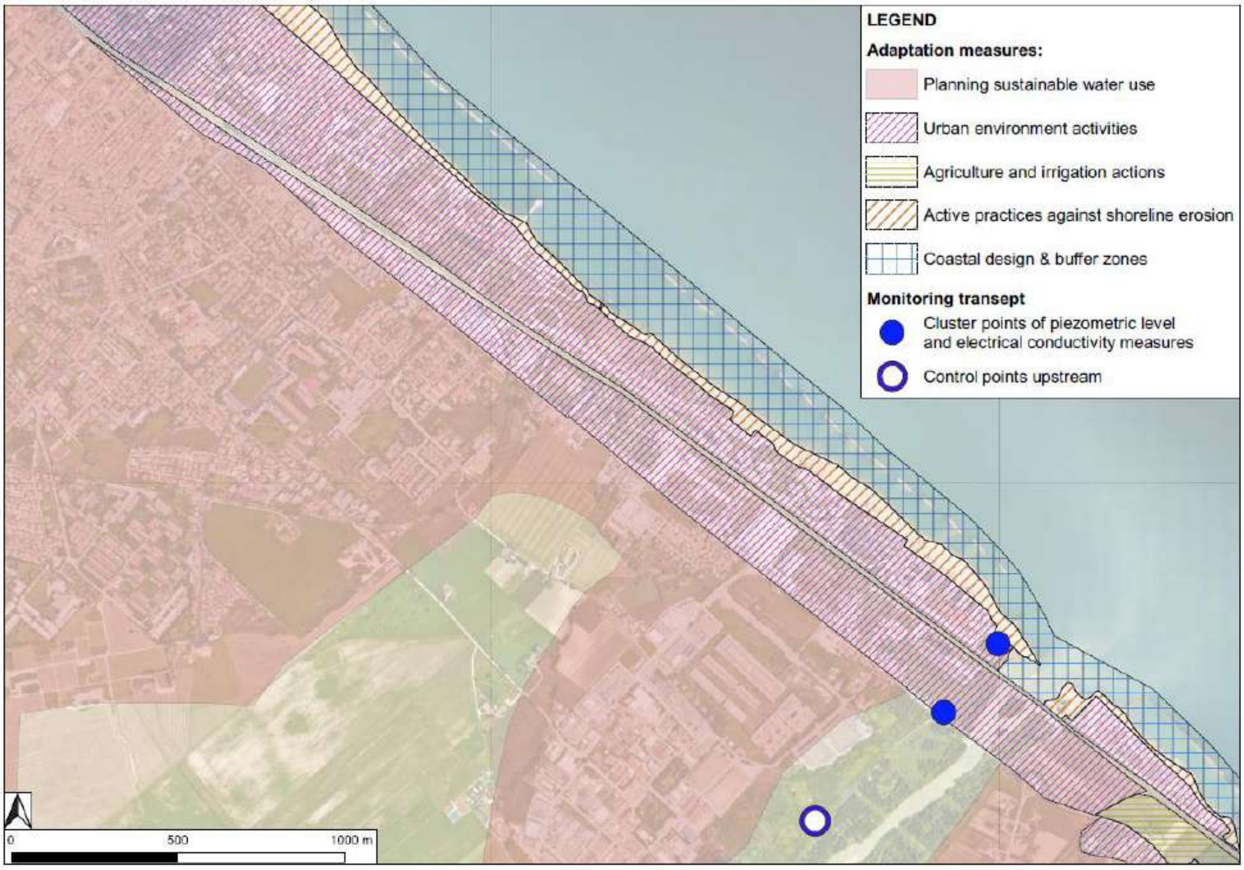


Test-site "Metauro River"

In Metauro River test site, the interest is concentrated in the evaluation of the maintenance of sustainable groundwater yield in the alluvial aquifer (in order to guarantee the freshwater flow towards the coastal zone).

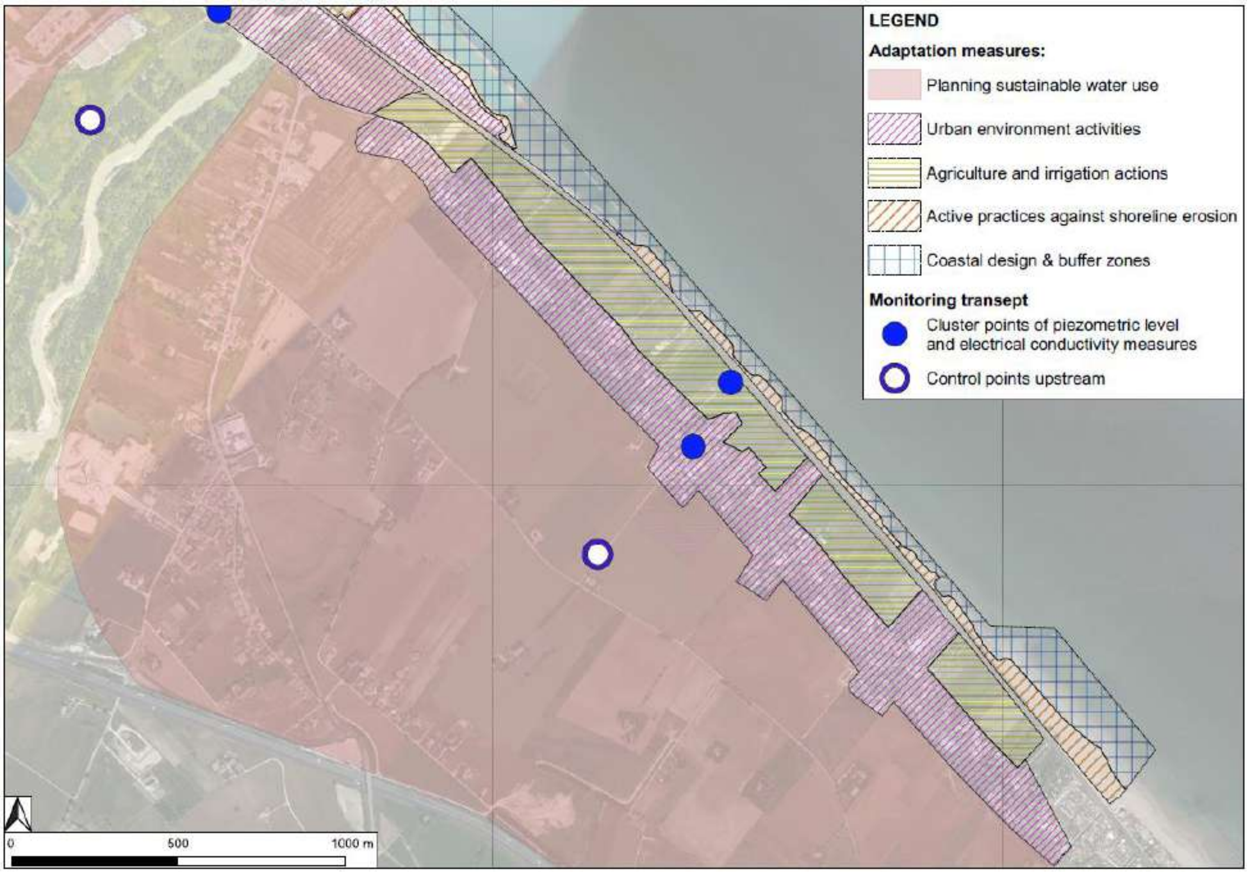
Furthermore, techniques of hydraulic barriers (also with injection of treated waste water) can helpfully be tested into the back-shore.

Supported by sedimentological studies and simulation models of coastal transport processes, the above-mentioned actions could be coupled with active practices against shoreline erosion; if environmentally sustainable, coastal progradation too in the estuary of Metauro River zone could be tested.



Test-site agricultural zone "Ponte Alto"

Furthemore, it could be experimented possibility of deepening of interface zone in the urban stripe, increasing the rain interception and infiltration capacity, as a further barrier to salt intrusion toward the irrigated inland crops.



Control thresholds

The continuous monitoring performed in correspondence of the transects allows to keep under control the short and long-term oscillations of the measured parameters. It is therefore easy to check in a timely manner if the monitored values exceed the thresholds considered "at risk".

In order to promptly identify the real or potential impact of saline intrusion, it is therefore useful to introduce control thresholds of:

- specific electric conductance, as a parameter representative of mixing water salinity;
- piezometric level, as a representative parameter of flow into the interface zone.

POTENTIAL IMPACT	Specific electric conductance (□S/cm)
HIGH	>5000
MEDIUM	3500-5000
LIGHT	2000-3500
NONE	<2000

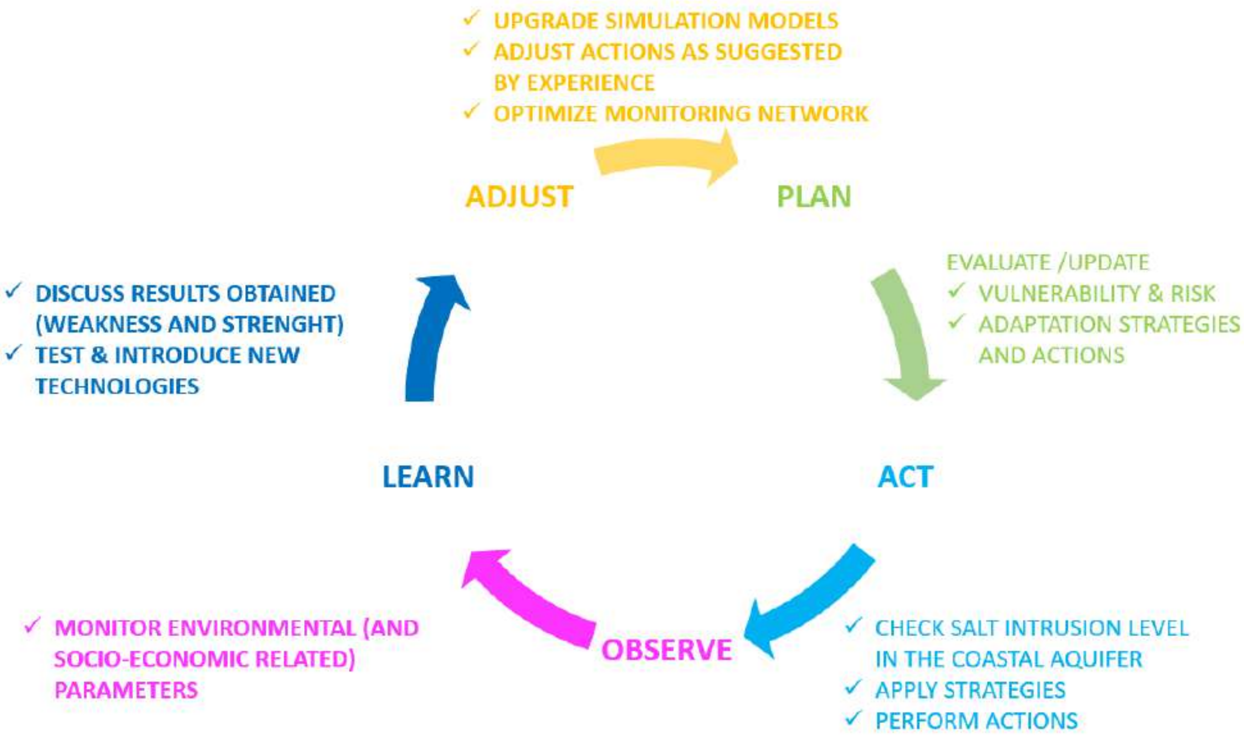
POTENTIAL IMPACT	Piezometric level (m a.s.l.)
HIGH	< 0 (static)
MEDIUM	< 0 (dynamic)
NONE	> 0 (dynamic)

As regards, the piezometric level thresholds are potential impacts, which must be verified together with the electrical conductivity values, before they can be classified as real impact.

When the values are detected, the warning systems are activated; on the basis of the impact class, this can go from the verification request to the temporary blocking of a specific group of wells (or activation of hydraulic barriers and so on).

2.9.2 Monitoring, evaluation and optimizing of adaptation plan: how to improve?

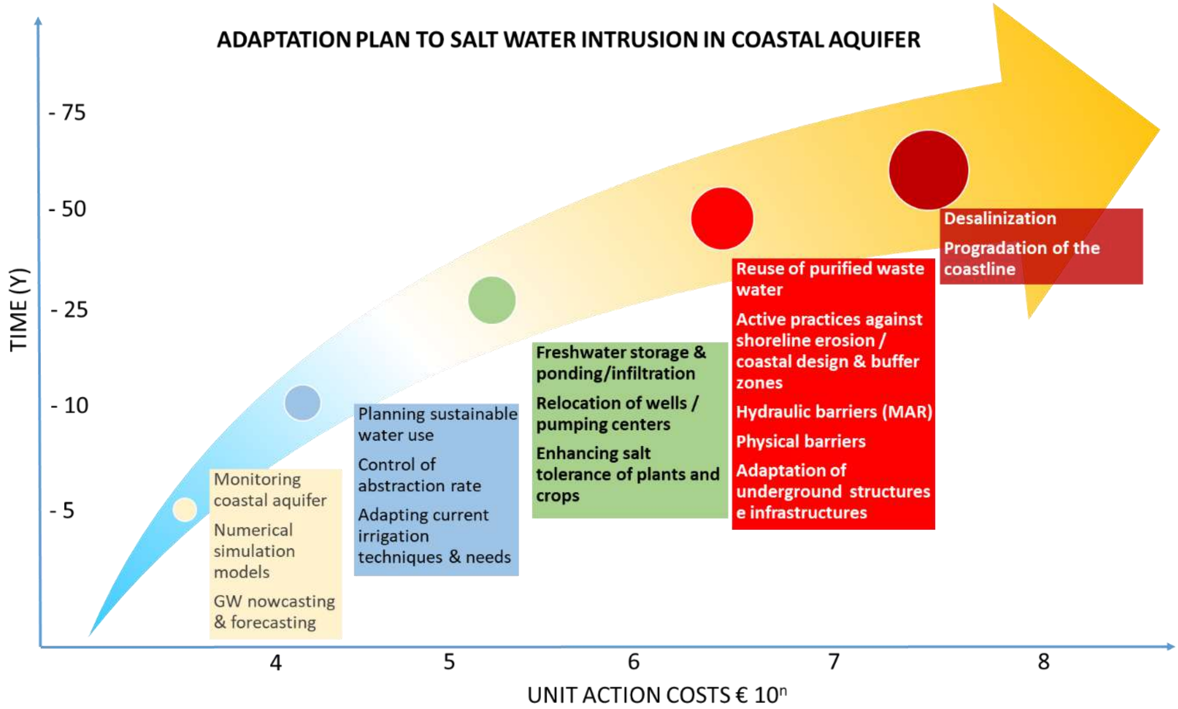
The above-mentioned test sites give the chance for the application of the so-called “observe & learn” method. The Work Package of ASTERIS have assessed the salt risk intrusion into coastal aquifers, related to sea-level rise due to the global warming. The Guidelines and Best Practices have focused a set of possible mitigation and remediation solutions. Targeting in perspective at year 2100, a continuous adjustment process should be started until now. Firstly, considering monitoring network data trends, and periodically checking the results obtained with the application of the different strategies and actions. See the diagram reported below



2.9.3 Extensive run of adaptation plans: what's the goal

The adaptation plan will select the strategies with the best balance between costs and benefits (socio-economic and environmental) for the community. Starting from a situation at present time (2020), showing very small incidence of salt water intrusion in the coastal aquifer of Fano, it's possible to delineate the set-up of first "low intensity" actions, testing more radical solutions in the test-sites.

With the awareness that progressive sea-level rise will occur over a time-scale of centuries, structural engineering solutions could be designed, tested and put into operation during a scenery of some dozens of years.


ADAPTATION PLAN TO SALT WATER INTRUSION IN COASTAL AQUIFER
TIME (Y)
- 75
- 50
- 25
- 10
- 5
Monitoring coastal aquifer
Numerical simulation models
GW nowcasting & forecasting
Planning sustainable water use
Control of abstraction rate
Adapting current irrigation techniques & needs
Freshwater storage & ponding/infiltration
Relocation of wells / pumping centers
Enhancing salt tolerance of plants and crops
Reuse of purified waste water
Active practices against shoreline erosion / coastal design & buffer zones
Hydraulic barriers (MAR)
Physical barriers
Adaptation of underground structures e infrastructures
Desalinization
Progradation of the coastline
4
5
6
7
8
UNIT ACTION COSTS € 10n

3 Case study 2: Neretva Delta

Throughout history, the alluvial valley of the Neretva has been largely transformed into polder-type aricultural area at the river delta by extensive hydrotehical agro-ameliorative interventions. This means that within polder, the groundwater level is maintained by pumping station systems, the operation which prevents flooding of agricultural parcels. The system of hydraulic water transport within the polder consists of a network of drainage channels, pumping stations and floodgates by which water from the area is drained and discharged into the sea. Excess water drained from the polder originates primarily from precipitation and can be reduced by evapotranspiration and vertical seepage. The hydrogeological structure of the alluvial valley of the Neretva in such conditions is very complex and conditions complex water movement processes. Due to the close proximity of the sea and the karst limestone rocks of the river aquifer, the intrusion of sea water into the Neretva valley is very pronounced and up to several 10 km. This results in occasionally or permanently saline water sources used for irrigation, which can have a number of negative consequences for the delta agrobiocenosis. The amount and distribution of precipitation are very important factors in the hydrology of the area, but also in the intensity of salt transport and pollution within the system.

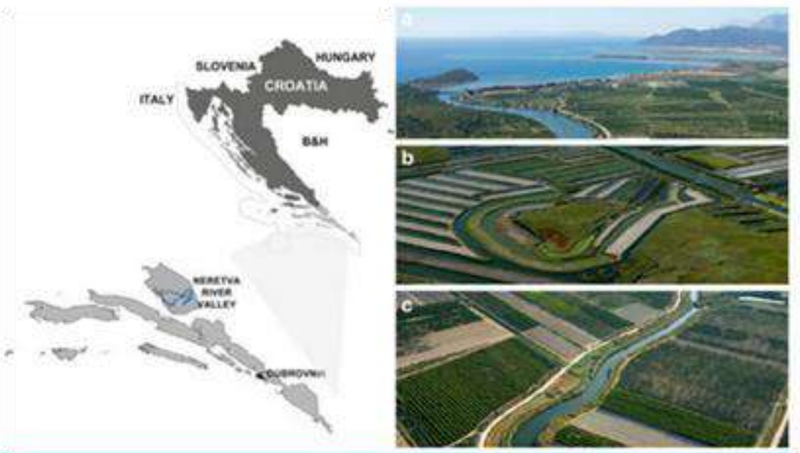


Figure 1. Geographic location of the case study area, and panoramic views of the:
a Neretva river estuary;
b polder type land; and
c land on fluvial terraces along watercourses

3.1 Management of coastal aquifers and involved stakeholders

The National Water Act (OG 66/19) and Directive 2000/60/ EC of European Parliament (Water Framework Directive) are the basic documents for the creation of a framework for action in the field of water policy and they define groundwater as all water below the soil surface in the saturation zone and in direct contact with the soil surface or underground layer.

Groundwater in Croatia is grouped into the so-called groundwater bodies. The initial characterization of groundwater bodies was carried out in 2005 for the basin Black Sea (continental part) and in 2006 for the Mediterranean part. The basis for delineation of groundwater units, in accordance with the requirements of Water Framework Directive, was the analysis of: geological terrain, porosity, geochemical composition, hydrogeological characteristics, geomorphological phenomena, directions and velocities of groundwater flow, springs and well yields, groundwater supply, relationships with surface flows and the position of groundwater units within river basins.

Out of the total 32 groundwater bodies on the entire territory of the Republic of Croatia, 13 belong to the Mediterranean water area. According to the Water Act (OG 66/19), water use is defined as:

- abstraction
- extraction
- use of surface and groundwater for various purposes

The provision of drinking water to the population is in the public interest and has priority over the use of water for other purposes

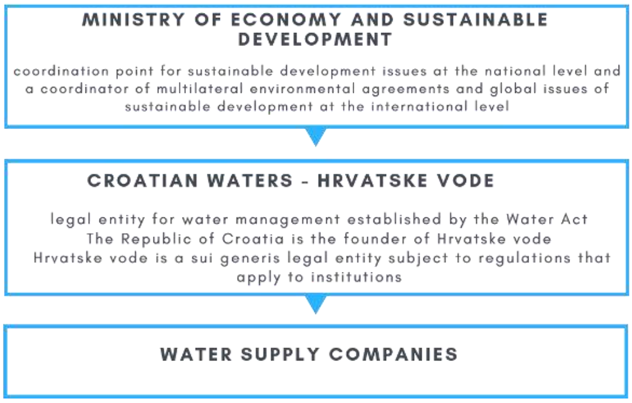
To ensure priority of water use for water supply, Croatian Waters will separately designate in each water district:

(1) all waters used for human consumption that provide more than 10 cubic meters of water per day on average or serve more than 50 persons; and (2) all waters reserved for these purposes in the future.

A public water supplier is a corporation whose sole incorporators are local self-government units in the service area, and exceptionally, the incorporator of a public supplier may be a legal entity whose sole incorporator is a local self-government unit

Figure 2. Institutions involved in water management in Croatia

Both surface and groundwater management and administration on national level is done in the following sequence



3.2 The need for and adaptation plan

The climate change adaptation strategy of the Republic of Croatia until 2040, with a view to 2070, proposes the largest number of climate change adaptation measures for the fisheries and hydrology and water and marine resources management, agriculture, biodiversity, forestry and health sectors. Among the defined priorities of the climate change adaptation strategy is the strengthening of management capacities through a networked monitoring and early warning system and ensuring the continuity of scientific research activities (Figure 3).

The Seventh National Report and the third biennial report of the Republic of Croatia under the United Nations Framework Convention on Climate Change (UNFCCC) (Ministry of Environment and Energy, 2018), among other things, emphasize Water and Marine Resources Management as a vulnerable sector. It is also emphasized that climate change will have significant direct and indirect effects on agriculture due to the trend of rising sea levels and salinization of karst aquifers.

From this aspect, the alluvial valley of the lower Neretva is one of the most vulnerable areas, whose hydrogeological is very complex and causes complex processes of water movement. Previous research has shown trends in salinization of surface and groundwater and agricultural soils in the Neretva Valley. In addition, water systems within the delta as well as the coastal sea are exposed to pressures from agriculture. Changes in the environment are inevitably reflected in the efficiency of agricultural production. Under the conditions of application of saline water for irrigation, yields can be reduced by more than 50%, which directly reduces the economic profit of farmers.

The intrusion of sea water and salinization of the soil, as well as the possible flooding of a part of the Neretva Valley would cause huge socio-economic damage to this extremely important fruit and vegetable area, which, among other things, produces over 95% of Croatian mandarins. The Neretva delta area is the largest potential floodplain in Croatia. This area below the H100 today covers about 81 km^2, and according to the scenario of medium sea level growth may increase to 92 km2 in 2050, and 104 km^2 in 2100 (Report on estimated impacts and vulnerabilities to climate change by sector, 2017. MZOE).

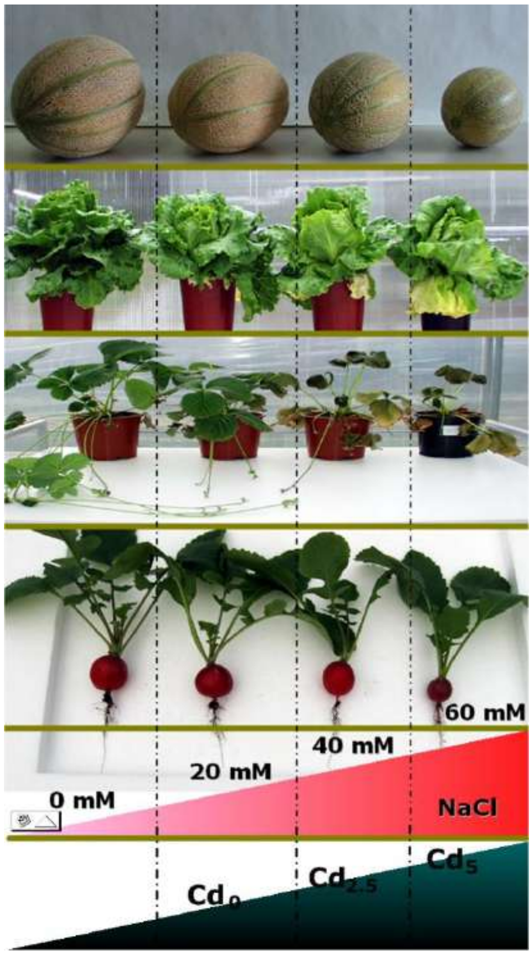

ADAPTATION MEASURES
The main obstacle for successful adaptation to climate change is the lack of knowledge for planning adaptation measures
building a knowledge base and capacity for data observation and processing
information exchange
development of local and sector-specific action and risk prevention and management plans at national, regional and local level
development of necessary tools: geographic information systems - GIS, detection and monitoring systems nearly warning systems risk mapping and assessment
Source: adapted to the SEVENTH NATIONAL REPORT AND THIRD TWO-ANNUAL REPORT OF THE REPUBLIC OF CROATIA ACCORDING TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (UNFCCC)

3.3 Salt intrusion in the study area

In the lower reaches of the Neretva River, two natural directions of saline seawater intrusion have been recorded: the first direction of intrusion is through the riverbed of the Neretva, the second through deeper underground layers. According to the numerical model of stratified flow, it was found that saline water in Metković occurs at a freshwater flow of less than 180 m^3/s, while saline water is completely displaced from the riverbed when the water flow exceeds 500 m^3/s.

Seawater intrusion takes place either at typical coastal aquifers due to over-pumping of freshwater or within delta regions due to drainage of the deltaic areas and reduction in the river flow, due to capillary rise of saline water in the soil profile or due to irrigation with saline water (Romić et al. 2008). The salt-affected soils cannot support vegetation and consequences include salt-induced water deficit, ion toxicity, nutrient imbalance, yield volatility and yield reduction. This leads to some very important indirect effects of salinization: a change in the biodiversity of wetlands, a change in the agricultural production structure and transformation of socio-economic conditions (Romić et al., 2010).

The Neretva River valley in the Mediterranean part of Croatia faces similar situation. Within this region there are around 6,000 ha of intensively used agricultural land made up by reclamation of flood plain and drained with open channels. Agricultural production is becoming more endangered because of periodical or temporal soil and water salinization (Ondrašek et al., 2011). Salinization in the area naturally occurs by sea water intrusion through river mouth and by costal aquifer through underground. In addition, the changes in hydrological conditions affected by numerous water engineering schemes and facilities within the Neretva basin contribute to intensified sea-water intrusion, causing severe groundwater salinisation. Several factors can affect surface and groundwater quality, such as climate, terrain and subsoil properties. Another factor is the overall land management, the intensity and relevance of which depends on the specific local environmental characteristics (Romić et al., 2008). Physical proximity to the sea is another important factor to consider when dealing with salinization risk (Zovko et al., 2018). Soil salinity, especially increased concentration of dissolved chloride (Cl^-) ligands, significantly influence Cd solubility and thus bioavailability and phytoaccumulation (McLaughlin et al., 1994; Weggler et al., 2004). Hence, growing crops on saline soils with increased Cd content has a potential of increasing Cd entry into the human food chain.



Ondrašek, G., Romić, D., Rengel, Z., Romić, M., Zovko, M. (2009): Cadmium accumulation by muskmelon under salt stress in contaminated organic soil. Science of the Total Environment. 407 (7): 2175-2182

3.4 The future scenario of sea level rise and subsidence rates

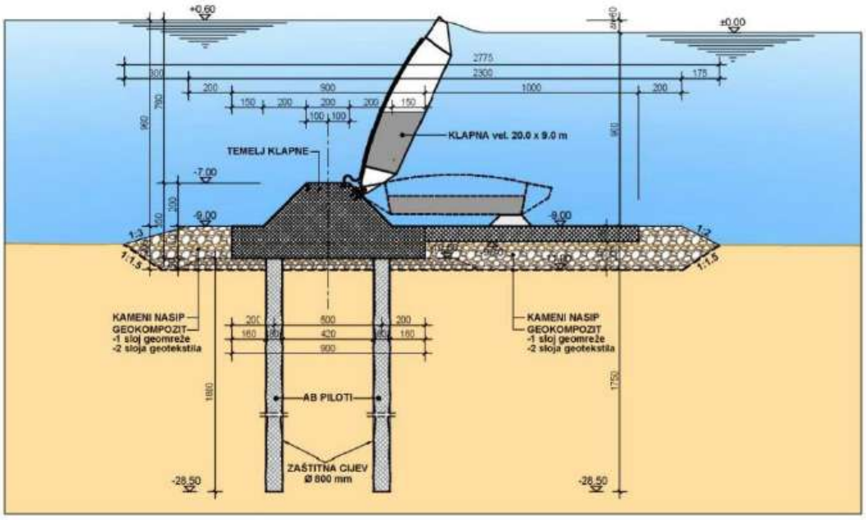
One of the key strategic documents related to climate change in the Republic of Croatia is the previously mentioned SEVENTH NATIONAL REPORT AND THE THIRD TWO-ANNUAL REPORT OF THE REPUBLIC OF CROATIA ACCORDING TO THE UNITED NATIONS FRAMEWORK CONVENTION Croatian.

The average rise in the mean sea level at the global level was recorded throughout the 20th century, but there are some indications that this process has intensified towards the beginning of the 21st century (Domazetović et al., 2016). According to Church (2004), the average annual rise in global sea level in the period 1950-2000. was 1.8 mm ± 0.3 mm, estimates for further average global growth by the end of the 21st century range from just 0.18 m to above 1 m compared to today's level (Church et al., 2013; Doyle et. al., 2015; Pfeffer et al., 2008).

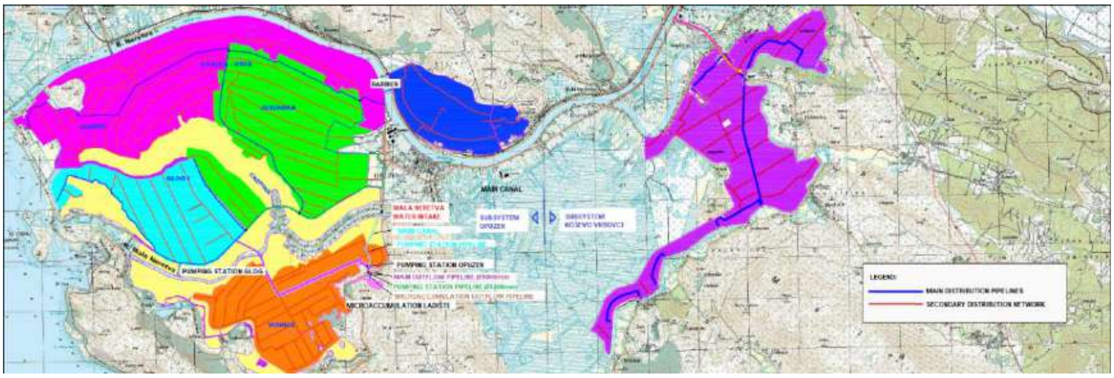
However, the lower coastal areas, estuaries and islands are most endangered. In addition to the submergence of part of the coastal area as a direct consequence of rising sea levels, sea level rise has a long-term impact on more frequent coastal storms, increased coastal erosion and seawater intrusion, ie soil salinization (Nicholls et al., 2011; Gornitz, 1991) and coastal aquifers (Antonellini et al., 2008; Chang et al., 2011). What is particularly worrying in the Neretva River Valley area is that estuary and seawater intrusion are closely linked to groundwater and soil salinization which poses a major threat to agricultural production which is of exceptional economic importance for this area. According to Krvavica et al. (2020) measurements of the salinity profile at the mouth of the Neretva River show strong stratification, and the measurements and the developed mathematical model show that the seawater wedge enters the Neretva River as much as 22 km upstream from the mouth in late spring to autumn. In the future, with rising sea levels, this phenomenon can be expected to intensify.

3.5 Possible solutions for adaptation in the study area

Seawater intrusion in the Neretva river valley poses a great threat primarily to agricultural production due to the salinization of surface and groundwater, and consequently the salinization of soil. Therefore, the possible adaptation measures that need to be implemented should be adapted to the needs and potential hazards within the pilot area of the Neretva River Valley.
One of the possible solutions is the construction of a mobile barrier on the river Neretva (about 2 km downstream from Opuzen), which would prevent the intrusion of the salt wedge upstream, and at the same time allowing the unimpeded passage of boats and fish.



In order to protect agricultural production as an important economic sector of this area, the measure of irrigation of agricultural areas is also important. The problem is to provide sufficient quantities of good quality water to avoid the harmful consequences of irrigating crops with saline water. This can be realized through the irrigation system Donja Neretva which includes two subsystems, subsystem Opuzen and subsystem Koševo-Vrbovci.



The Opuzen subsystem covers the area of Vidrice, Opuzen Ušće and Luke with a total gross area of 2 769 ha (net 2 199 ha) and the total amount of water that needs to be secured, with the adopted 20-hour daily irrigation, for the entire area in the dry year is 1 746 l/s. The subsystem is defined with the pumping station (CS) Opuzen as the central object, water intake from Mala Neretva, microaccumulation (MA) Ladište in which all water for irrigation is located and pressure distribution network. The Koševo-Vrbovci subsystem covers 707 ha of gross agricultural area (net of 595 ha), and includes the areas of Koševo, Vrbovci, Mislina and Metković. The total amount of water that needs to be secured, with the adopted 18-hour daily irrigation, for the entire area in the dry year is 673.5 l/s.

In addition to the construction of planned irrigation systems that will bring quality irrigation water to end users, ie their agricultural land, it is necessary to implement advanced technologies and localized irrigation systems on agricultural land (mini-sprinklers, drip). Advanced technologies can also include monitoring the state of soil moisture using increasingly accessible sensors and connecting them to an irrigation system in which it is possible to implement sensors to monitor the electrical conductivity of the used water.

Finally, adaptation measures may also include planting/ sowing crops and varieties more resistant to elevated soil salt concentration, but also the use of interstock and mycorrhization of citrus fruits which are one of the most dominant crops grown in the Neretva River valley. Since mycorrhization of fruit trees can be carried out relatively easily and cheaply at any time during the life cycle of fruit trees, it is necessary to explore the potential of mycorrhiza in reducing damage from salinization on citrus fruits and other fruits grown in the Neretva River Valley. Mycorrhizal citrus fruits under salinization conditions show better growth due to improved uptake of water and minerals and increased release of hydrogen ions into the rhizosphere leading to soil acidification.

In addition, mycorrhizal plants have improved photosynthesis, transpiration and other important physiological processes that are significantly reduced under salinization conditions, and this is a strong contribution to their resistance to stress that causes salinity.

4 Case study 3: Municipality of Ravenna

The implementation of adaptation measures is largely a responsibility of governments and local communities. While the extent of climate change knows no borders, its effects are local and can vary greatly from one territory to another, depending on that territory's level of vulnerability. Each system, whether urban, rural or natural, is a unique combination of interconnected geographical, physical, socio-economic, political and environmental factors. These parameters will determine the vulnerability of territory to climate change, which according to Ademe is "a function of the nature, extent and rate of climate variation (also known as exposure) to which the system in question is exposed and the sensitivity of the system to this climate variation" (Ademe, 2013, p.5. Italic is ours). Quenault et al. (2011) add a third factor to this equation – the adaptive capacities of the system, defined by the IPCC as "the ability of natural or human systems to adjust in response to climate change (including climate variability and extremes) to mitigate potential effects, exploit opportunities, or cope with consequences" (Quenault et al., 2011, p. 153). The Adriatic region is highly vulnerable to the adverse impacts of climate change.

Detailed knowledge of the particular characteristics of a territory is therefore essential to prepare for the necessary long-term transformations imposed by climate change, with their share of uncertainties for the future.

The territory of the coastal Ravenna area has been studied intensively over the past 20-30 years and many studies, monitoring and analysis are available to highlight the fragilities and problems that climate change can only accentuate in the next few years.

The Ravenna study area is located in the Northern part of the Adriatic Sea (Italy). This area is a combination of extended naturalistic and preserved areas near the urban area of Ravenna and an extensive zone dedicate to agricultural activities.

Between climate-related impacts that could affect the coastal area, in the last years the relevance of salt intrusion is increased. Coastal aquifers are characterized by a natural gradient towards the seaboard, where groundwater discharges into the sea. A saline wedge normally exists below lighter freshwater.

The interface between freshwater and heavier seawater is in a state of dynamic equilibrium and the interface is a transition zone of mixed salinity. This equilibrium can be affected from multiple directions: from above due to inundation or storm surge, laterally due to encroachment of the freshwater/saltwater interface, and from below due to upcoming saline groundwater caused by pumping (Klassen and Allen, 2016).

The Italian and Croatian coasts are subject to the influences of touristic pressure, entailing the increasing extraction of groundwater in peak periods, and its effect on salt ingression, as well as the effects of pumping for agriculture during drought, which are often not taken into account in the management plan for water catchment.

The Adaptation plan to Saltwater in inTrusion in sEa level Rise Scenarios (ASTERIS) it is necessary to support the decision and strategies to minimize and contrast the effect of climate change in the Ravenna municipality especially for the problems of sea intrusion that strongly affect this area. As the average sea level rises, the effects of salt intrusion in this area will be even more extensive and pronounced in the near future.

4.1 Management of coastal aquifer and involved stakeholders

The management of coastal aquifers is regulated by numerous entities that implement different laws and directives for each control level (from international to local).

The involving stakeholders can be split into public/institutional or private stakeholders with different roles in the management of aquifers in the Ravenna area.

An important role for the European country was made **European Directive 2000/60/EC "Water Framework Directive"** that the Italian legislation implemented through the **D.Lgs n.152 of the 03/04/2006**. The **European Directive 2006/118/EC "on the protection of groundwater against pollution and deterioration",** that the Italian legislation implemented through the **D.Lgs n.30 of the 16/03/2009**, establish a framework for Community action in the field of water and have determined an innovative approach into European water legislation, both from an environmental and administrative-management point of view. After the legislative decree n° 152 (**European Directive 2000/60/EC)**, the Italian territory was divided into 7 District Authorities replace the previous Basin Authorities. These District Authorities are supervised at the national level by the Minister for the Environment, Land and Sea (Civita et al., 2017). Also universities and research center play an important role as a stakeholder (e.g. for research project e development, national and local application, etc.).

From the private side, at a national level, there are different stakeholders involved: Industrial and Agricultural associations, trade associations, environmental associations, etc.

At the regional level, several public Authorities are involved in the groundwater governance of the coastal area of Ravenna depending on the different uses of water, such as supply to the population, wastewater treatment, farmland irrigation and drainage, wildlife management and biodiversity protection. ADBPO (Po River Basin Authority), AIPO (Interregional agency for the PO river), ARPAE (Regional Prevention and Environment Agency of Emilia Romagna) and Ente Parchi e Biodiversità-Delta del Po (environment and biodiversity protection) are identified as the main competent actors in the local (regional) management of groundwater and surface water. From the stakeholders involved on the private side, at a regional level, we can report the irrigation and drainage consortium, drilling and Withdrawal Company (for gas/oil and water), Industrial and agricultural users, etc.

At the municipal level, we can recognize the local Environment services, urban and strategic area planners and similar actors for the public stakeholders.

At the local private level, there are multitude of actors involved starting from the final users of the water resource (including farms, industries and artisan settlements, environmental groups, foundations, etc.).

Finally, the D.Lgs 30/2009, that implements the Directives 2000/60/EC, 2006/118/EC and integrates and partially modifies D.Lgs 152/2006 about the characterization and identification of groundwater bodies, establishes the threshold values and quality standards to define the good chemical status of groundwater. Moreover, defines the criteria for quantitative monitoring and classification of groundwater bodies or groups of them.

In particular, it defines:

a) criteria for the identification and characterization of groundwater bodies;

b) quality standards for certain parameters and threshold values for other parameters necessary for the assessment of the good chemical status of groundwater;

c) criteria for identifying and reversing significant and lasting trends in the increase in pollution and for determining the starting points for such reversals;

d) criteria for the classification of the quantitative status;

e) arrangements for the definition of qualitative and quantitative monitoring programs.

A complete review of the Management of coastal aquifers and their administration from the International to the local level is reported in the deliverables of WP4 of the ASTERIS project (Report 4.2).

4.2 The need for an adaptation plan

4.2.1 Sources of groundwater salinity

Salinity in groundwater may come from many processes such as dissolution of rocks containing chlorides, irrigation drainage, seawater intrusion in coastal aquifers, and saltwater up coning of ancient seawater (connate water). Also, it may come from the application of fertilizers or pesticides, the effluent of wastewater treatment plants and industrial waste and lateral movement of saline groundwater from upgradient areas of the aquifer, or upward movement from connected aquifers. Heavy pumping led to water-level declines and changes in flow directions in the aquifers.

In some cases, this has induced saline water from the sea or deep brines, to move into and contaminate an aquifer. The sources of groundwater salinity can be divided into two naturally occurring pollutants and pollutants produced by human activities. Typical sources of salinity in groundwater are illustrated in Figure 1.

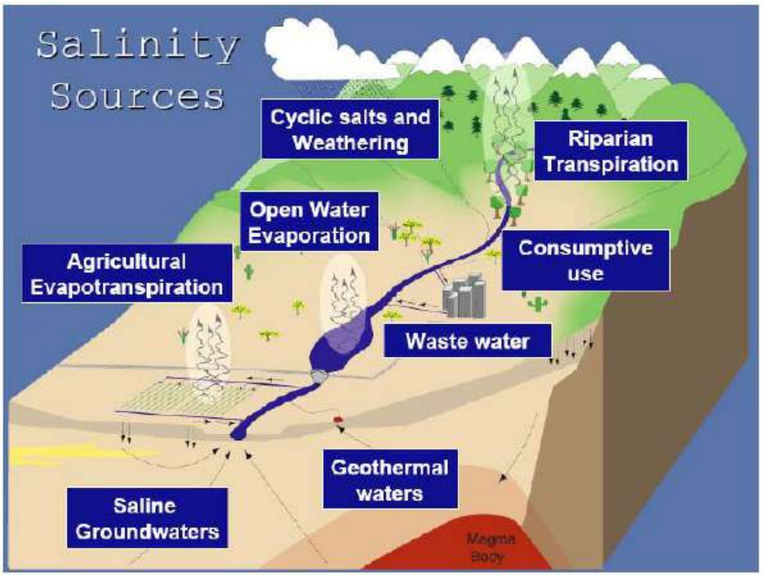


Figure 1 – Typical sources of salinity in groundwater

The natural sources of groundwater pollution are the following:

1 seawater intrusion in the coastal plain where surface water is not enough and groundwater is limited, increasing water demand for the tourism sector, in addition to irrigation and domestic water supply. When groundwater is overexploited, seawater moves into the aquifer and the quality of groundwater deteriorates. Salt concentration increases;

2 mixing with geothermal waters. The chemical composition of groundwater is determined by that of the porous matrix through which it flows and the residential time. The longer the contact period is, the more minerals are dissolved. Especially, thermal water causes negative effects on fresh groundwater. Thermal waters usually carry more minerals and materials deteriorating fresh groundwater quality if mixing occurs;

3 pollutions originated from geological formations containing salt, gypsum, etc. In some groundwater basins, there are impervious barriers between freshwater-bearing formations and saltwater layers. When erroneous drilling methods are used in these formations, saltwater and fresh groundwater can be mixed and the quality of freshwater can deteriorate.

Pollution sources produced by human activities can be grouped into three general categories: municipal, industrial, and agricultural disposals.

1 municipal disposal pollution sources may be point sources or distributed sources. In a developing country, point sources are mainly municipal disposal due to poor sewerage systems. Rapid and uncontrolled urbanization over the areas that have groundwater potential is an important risk. In some areas, this may be more dangerous because of cracks, fractures and high permeability. Moreover, the volume of municipal disposal is increasing day by day;
2 industrial disposal. Because industrial sites are usually located on flat areas where large aquifer systems are located, unfiltered wastewaters originated from factory effluents have contaminated the groundwater resources in several sites worldwide. To minimize groundwater pollution, appropriate wastewater treatment plants have to be constructed;
3 agricultural pollutants. The use of pesticides and fertilizers in agricultural activities is growing. This may cause large distributed pollution of groundwater resources.

4.2.2 Salt intrusion in the study area

Several natural and anthropogenic features make the coastal area of Ravenna vulnerable to the effects of climate change. For example, Saltwater intrusion in the phreatic aquifer and seawater encroachment inland along the rivers; natural and anthropogenic land subsidence; direct contamination from water bodies open to the sea; modification of coastal dunes and reduction of their barrier effect; land reclamation drainage systems; insufficient freshwater available for groundwater recharge and sea-level rise.

Similar to many other coastal lowlands and deltaic plains, the eastern Po plain, and specifically the Ravenna area, are underlain by a subsiding sedimentary basin.

Groundwater salinization is mainly caused by seawater intrusion due to the hydraulic gradient landwards that is enhanced by land subsidence, land use and drainage allowing for agriculture and settlements.

The combined effect of climate change and anthropic exploitation from the aquifer (water)/reservoir (oil/gas) dramatically increase the effect of saltwater intrusion on the Ravenna coast and in the first inland in the last years.

In this paragraph, we report a general description of the current state of salt intrusion in the Ravenna coastal area also based on the results of monitoring WP 4.1 and previous studies.

A physical survey of the coastal area was carried out in WP4. The sampling sites were selected according to the previous monitoring network developed for other relevant projects in the Ravenna area. Most sites were homogeneously distributed in the area of Pineta San Vitale (north of Ravenna), although a limited number of sampling points were selected along the coast and inland. Three surveys, from July 2019 to November 2020, were carried out in order to perform chemistry and water isotope analysis, physicochemical parameters and water table level. Since July 2019, periodical surveys for water level, temperature, pH, EC and vertical physicochemical logs were focused on specific sites, arranged along two main transects and orthogonal to the coastline.

Two different survey campaigns were carried during the monitoring activity: water sampling surveys (physicochemical parameters, chemical and isotopic analysis) and water level/physiochemical surveys along selected transects.

The geochemical results confirmed that the Ravenna shallow aquifer is significantly affected by the salinization process, as already previously documented (Giambastiani et al., 2007; Antonellini et al., 2008; Antonellini and Mollema, 2010; Laghi et al., 2010; Mollema et al., 2013, 2015; Greggio et al., 2020). The great majority of waters were indeed characterized by both Na^+-Cl^- compositions and high TDS values. In those sites where water samples were collected at two different depths, the shallower layer was always characterized by a lower TDS when compared with that collected at the well bottom, thus confirming a phreatic character of the system favorable to freshwater infiltration. The latter process and its variability over seasons are well evident from vertical logs, which remark the sensitivity of the system to the hydrological regime.

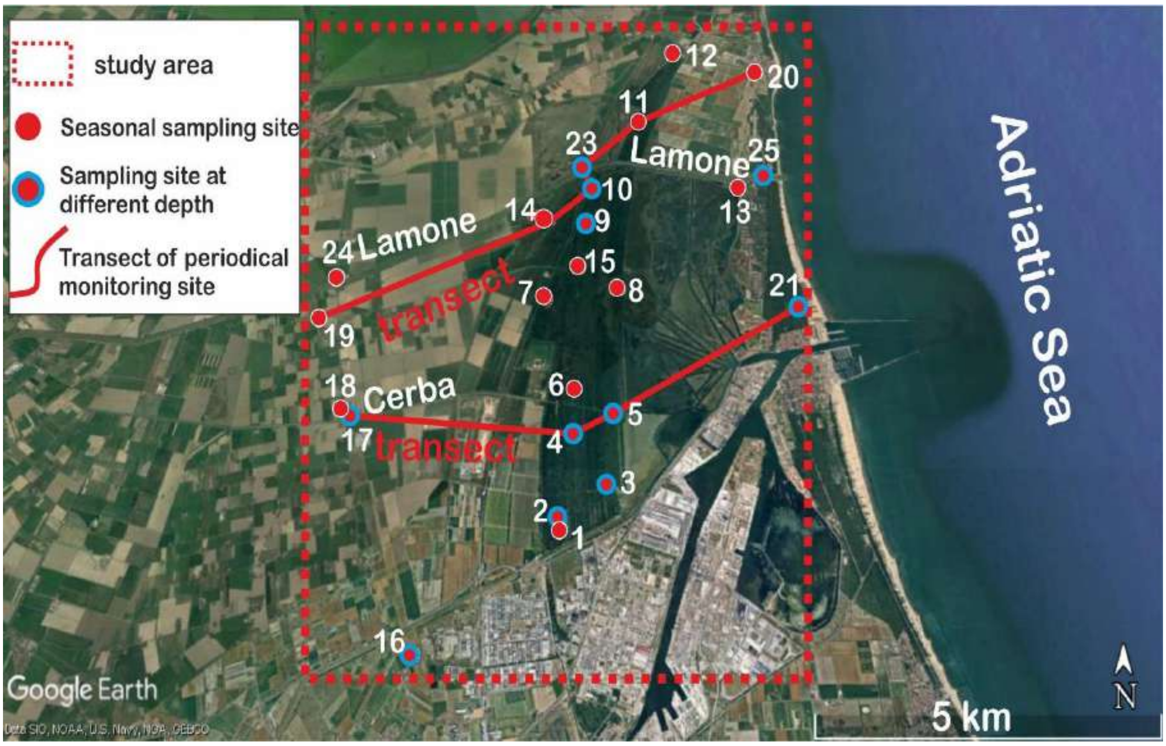


Figure 2 – Location of the study area. The sampling sites and monitoring transects are also reported.

The analyzed data confirm the active process of underground seawater intrusion from the shoreline.

The hydrogeological, physical-chemical and geochemical-isotopic data, as well as their mutual comparison, allowed to recognize the main water components involved in the studied coastal system, and define the principal physical and chemical processes presently occurring. In most cases, the mechanisms that regulate these processes were recognized and new insights into the processes of seawater intrusion and aquifer recharge with respect to the previous studies were provided (see deliverbales of WP 4.1.2.).

A description of a conceptual model for the Ravenna study area was developed in the deliverables of WP 4.1.2.

In Figure 3 is reported the schematic conceptual model of the shallow coastal aquifer in the Ravenna area.

For more detail of saltwater intrusion and monitoring campaign in Ravenna site, we remand to the deliverables of WP 4.1.2.

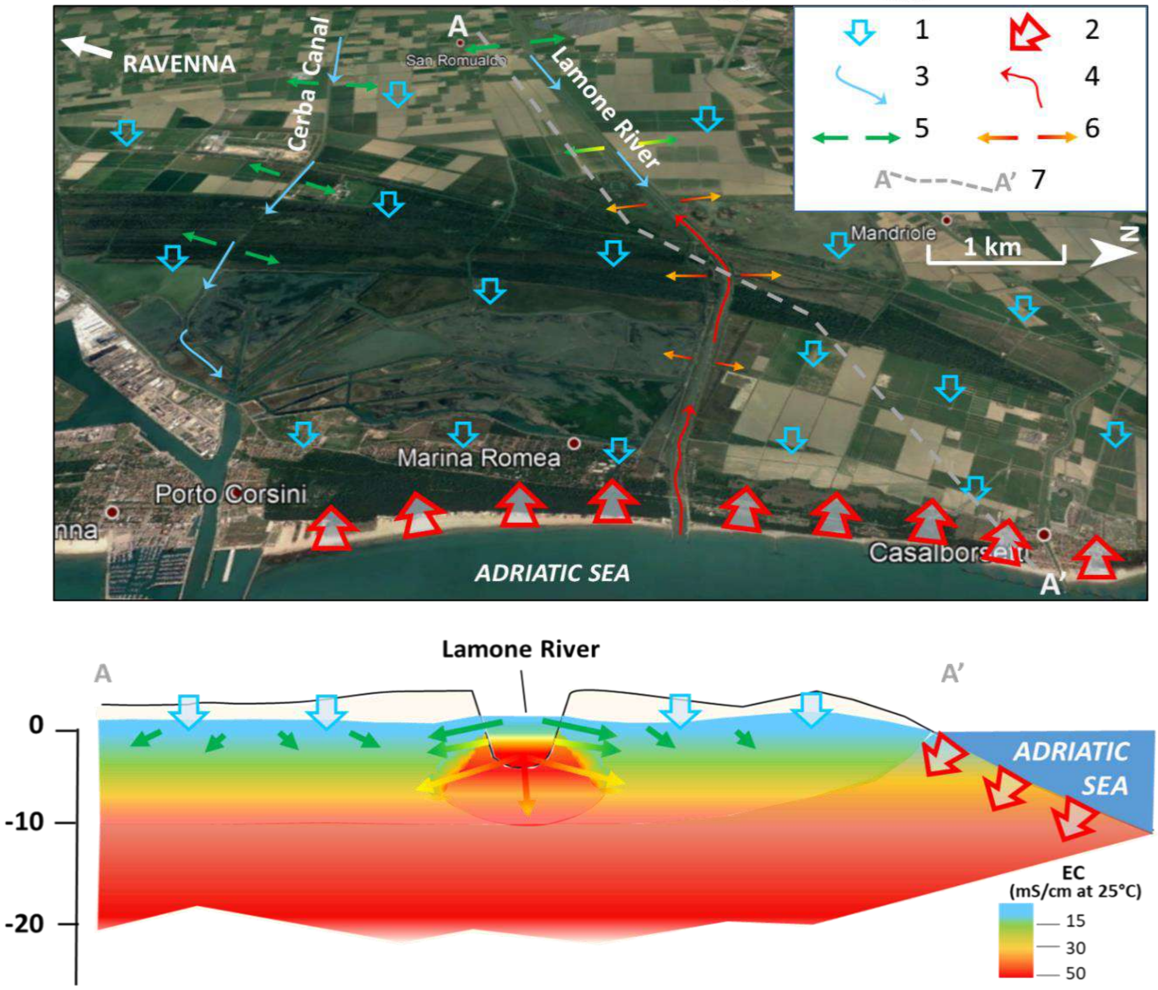


Figure 3 – Schematic conceptual model of the shallow coastal aquifer of Ravenna: 1) local rainfall infiltration; 2) seawater intrusion from the shoreline; 3) freshwater flow in superficial watercourses; 4) seawater intrusion along river beds; 5) transfer of freshwater from superficial watercourses to groundwater; 6) transfer of saline and brackish water from the superficial watercourses to groundwater; 7) trace of the section A-A'. EC= Electrical conductivity

4.3 Future scenario of sea lever rise and subsidence rates

Climate change is enhancing processes affecting salt intrusion; in particular, sea-level rise (forced by changes to atmospheric pressure, thermal expansion of oceans and seas and melting of ice sheets and glaciers) is one potentially significant process that is expected to play a role in seawater intrusion (Werner et al., 2009).

Relative sea-level rise (RSLR), i.e., the superposition of eustatic rise of the sea and land subsidence, represents one of the geologic hazards threatening low-lying coastlands worldwide (Nicholls et al., 1999, 2008). One of these zones is the wide flat plain around the Po River delta, northern Italy, where the study area is located. This coastal region is characterized by the presence of a significant historical heritage(e.g., Ravenna), resorts villages known all over Europe (e.g., Rimini), industrial centers and harbors (e.g., the Ravenna port, the most important one in the Adriatic Sea for merchandise traffic), natural environments such as lagoons, marshes, and reclaimed farmlands generally lying below the mean sea level and kept dried by a dense network of reclamation channels and pumping stations (Fig. 1).

This area is the one at greatest risk in Italy (Bondesan et al., 1995a) since the combined effect of land subsidence and eustatic sea-level rise produced a loss of land elevation with respect to the mean sea level ranging from centimeters to meters over the last decades, and created a significant ecological and environmental impact (Bondesan and Simeoni, 1983; Teatini et al., 2005; Simeoni and Corbau, 2009; Tosi et al., 2009).
Subsidence in the coastal area of Ravenna is due to several natural and anthropogenic activities that have facilitated saline intrusion and salinization of agricultural and marshy lands in the first coastal zone.

The natural subsidence rate, due to natural compaction alluvial deposit, is about 1 mm/year (Selli and Ciabatti, 1977; Pieri and Groppi, 1981).

Unfortunately, land settlement, initially of the order of a few mm/year, dramatically increased up to 110mm/year after World War II primarily due to groundwater pumping and, subordinately, gas production from several deep on-shore and off-shore reservoirs (Teatini et al., 2005).
Figure 4 shows the map of the cumulative land subsidence over the whole period investigated by Teatini et al. (2005). The industrial area of Ravenna has settled by more than 1.5 m during the past century, and a west-east 10-km wides rip (corresponding to about 32% of the municipal territory) including the city center has subsided by more than 1 m.

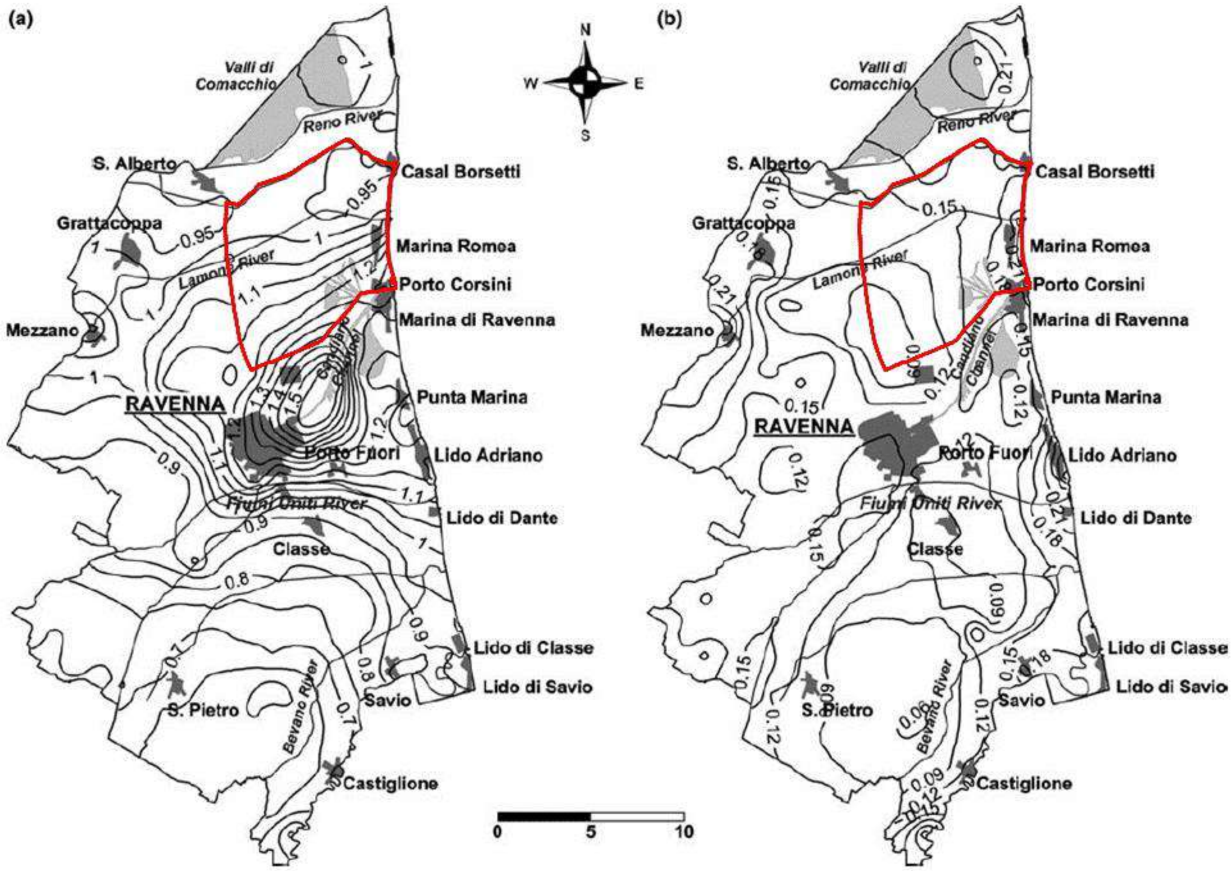


Figure 4 – Cumulative land subsidence (m) in the Ravenna Municipality a from 1897 to 2002 and b from 1977 to 2002 obtained from the GIS processing of the available leveling data. The contouring intervals are 0.05 m and 0.03 m, respectively (modified after Teatini et al., 2005). The study area is represented by a red line perimeter.

The stability of the shoreline is of paramount importance for the safety of the Ravenna coastland whose elevation, behind a discontinuous sandy dune ridge, currently ranges between -1 and 1 m a.s.l. Extending from the Reno River mouth to the north to the town of Cervia to the south, the Ravenna coast has been severely impacted by land subsidence during the past century. Its environmental and geomorphological deterioration can be easily recognized, for example, from both the widespread beach regression and the increasing vulnerability of the coastal tourist towns which have experienced severe floods over the last decade. The time evolution of the cumulative land subsidence along the shoreline is shown in Figure 5 using 1897 as the reference year.

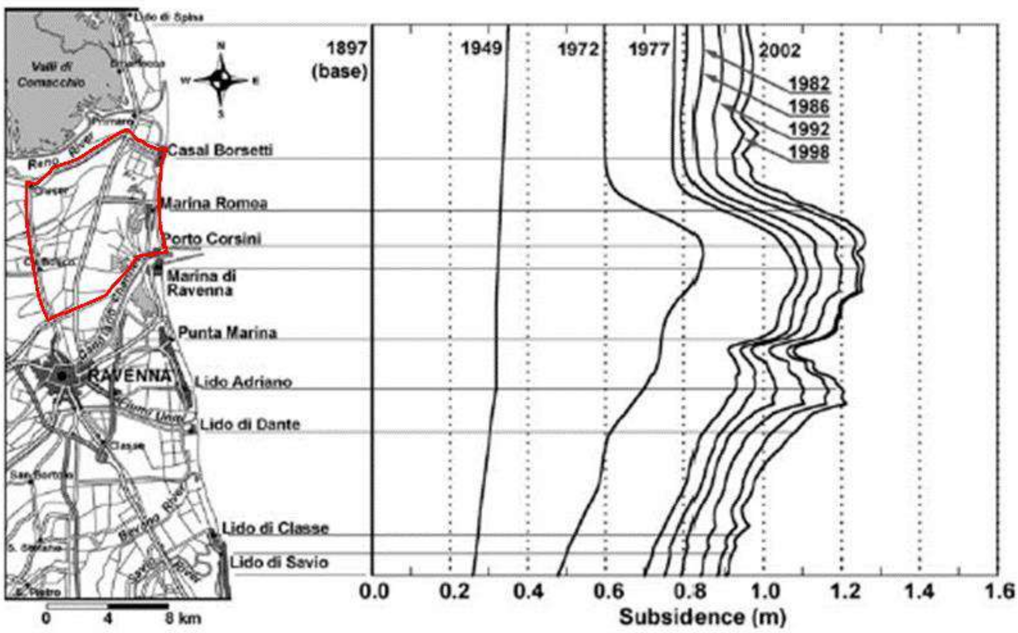


Figure 5 – Land subsidence versus time along the shoreline of the Ravenna Municipality obtained from the GIS slicing of the leveling data (modified after Teatini et al., 2005). The study area is represented by a red line perimeter.

In addition to the problems of subsidence, that increase the ingression of saltwater intrusion on the coastal area, the Ravenna area is subject to a strong risk due to the rise of average sea level. Sea level is currently rising and it is expected to increase from 25 to 100 cm (global average) by the end of the century. Sea-level rise is not uniform but is affected by a strong spatial variability. The Mediterranean Sea, due to its characteristic of a semi-enclosed basin, has not been well represented in global ocean circulation models so far developed, which consider the Mediterranean as a closed Sea, without exchange with the Atlantic Ocean across the Gibraltar Strait.

The developed model and the high-resolution maps of the sea-level scenario are reported in the deliverable of WP 3.3 of the ASTERIS project.

In the activity of WP 3.3, sea-level changes are modeled by taking into account all the interrelated physical mechanisms that characterize glacial isostatic adjustment processes and considering regional variability. As a consequence, the activity will predict regionally varying relative sea-level (RSL) changes that might locally be significantly different from eustatic (i.e., spatially uniform) sea-level variations. Previous studies of saline intrusion in coastal aquifers relied on the eustatic approximation, which implies a globally uniform sea-level rise.

The objective is to predict the actual local RSL changes within the study area and, in a subsequent step, the local response in terms of saline intrusion.

The long-term sea-level variations at a given place and time stem from the combination of several contributions:

- The glacial isostatic adjustment (GIA): describe the effect of the ongoing mass redistribution still caused by the melting of the late-Pleistocene ice sheets.
- Current ice melting:
- Steric component: describes the effects of water density variations. These can be separated into thermosteric and halosteric components, were the first accounts for temperature variations assuming a constant salinity, and the second represents the effect of salinity variations at constant temperature (Jordà and Gomis, 2013).
- Contribution of other factors (including, for instance, sediment compaction, co- and post-seismic deformations and other tectonic effects)

All these components have been modeled to obtain the scenarios for the evolution of future sea level.

In this deliverable were reported the results of two different scenarios: The “semi-empirical” scenario and the model-based scenario.

The first scenario is based on the Rhamstorf (2007) equation that calculates the sea-level variation H(t) with respect to a reference time, due to the temperature increase. The results of this model show a sea-level rise of about 47-50 cm by 2100.

The geophysical modeling (model "based" scenario) shows that the three different components produce a sea-level variation scenario at 2100 ranges between 72 and 80 cm above the 2015 height (Figure 6).

This result is of comparable magnitude to that obtained with the “semi-empirical” scenario, which ranges between 47 and 50 cm.

For more details on the analysis of average sea-level rise and the modeling results obtained please refer to WP3 - 3.3.1 "Regional high-resolution Maps of Sea-level".

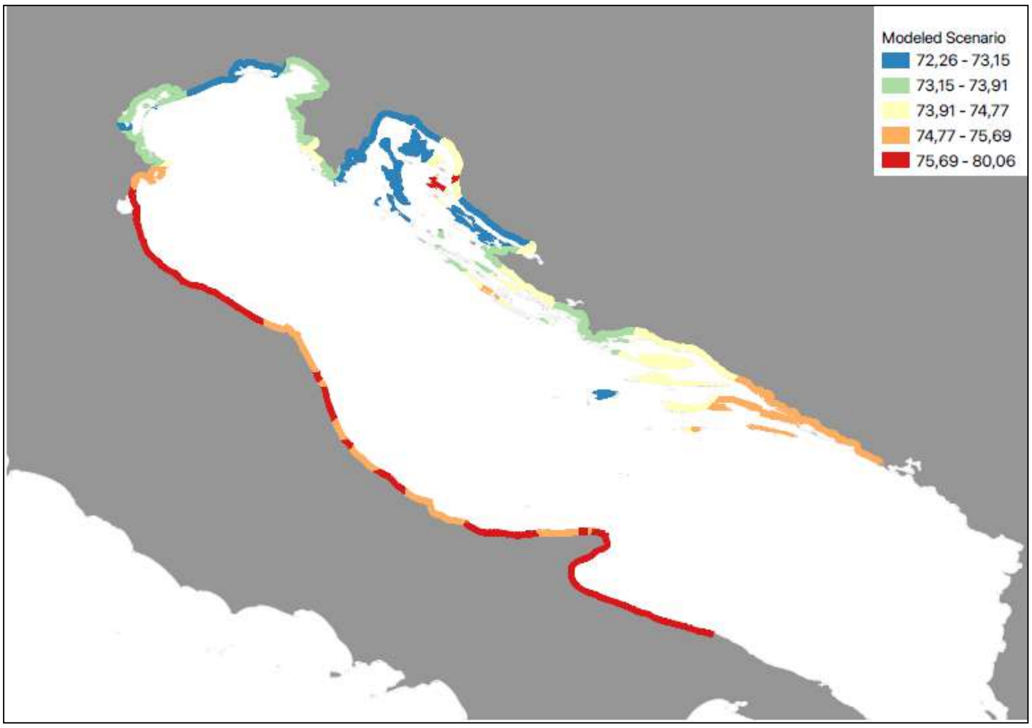


Figure 6 – Model-based sea-level scenario (after D3.3.1 of WP3 Asteris Project)

4.4 Possible solutions for adaptation in the study area

The adaption plane provides a framework of actions, which intensity is related in space and time to the severity of the salt-water intrusion, concerning both management aspect and physical realizations and land transforming.

There are different level of action that can be summarized as follow in four principal activity group:

- Control/Prediction of Seawater intrusion
- Water Resource improvement
- Urban environment activity
- Agricultural and Natural environments activity

4.4.1 Control/prediction of seawater intrusion

Adequate knowledge of salinity conditions in critical areas is among the fundamental points for the correct management and the best planning for the safeguard of these areas.

Environmental monitoring activities of the water and surface resource are essential to understand the current conditions of the affected areas and allow the development of conceptual and numerical models to predict the effects of salt intrusion. It is necessary to implement an integrated monitoring system with the collection of continuous data through appropriate instrumentation placed in main points or transects to obtain a picture of the current criticalities. Data typically collected include groundwater level or pressure in artesian aquifers; soil salinity trends at various elevations of interest; hydro-chemical analysis and physical characterization of groundwater and surface water; tidal measurements, geophysical measurements; etc.

The collected data can also be useful to implement and update conceptual/numerical models of groundwater resource quantity and quality under different scenarios. The simulation model dynamically considers the effects of remedial actions, in response to the progressive sea-level rise, such as to changes in the flow rate and position of the wells, the introduction of physical and hydraulic barriers, the change of infiltration rates in urban areas or the re-introduction of purified water into the aquifer. The model can provide periodic reports that reproduce the current hydrological situation and allow developing expected forecast scenarios to support the decision maker's choice and to evaluate the results obtained with the actions taken.

4.4.2 Water resource improvement

The improvement of water resources passes through a series of activities to control and/or modify the exploitation of the water resource. The extensive use of groundwater resources has created a strong imbalance, which over time, has worsened water quality.

Several activities can be promoted to counter the deterioration of freshwater quality and quantity including:

1) controlling groundwater withdrawal concessions;
2) optimizing or reducing the flow rates emitted from wells;
3) the introduction of limits on the use of deep wells.
4) Alternative use of lower quality water for some uses while maintaining the use of quality water only for valuable activities;

Some effective, but relatively expensive, activities can be implemented to improve groundwater quality and counteract salt wedge intrusion. These include the reuse of purified wastewater (directly by injected wells or recharge pond) and the use of desalinated water in special plants for human use or, less frequently, for irrigation.

4.4.3 Urban Environment activity

The adaptation activities to saltwater intrusion in the urban environment can be summarized as a series of local interventions to preserve/reuse freshwater and/or contrast the saltwater ingression. In the urban area, it is possible to promote some measures regulated by the local political authorities (municipality, reclamation consortia, other local actors...) that can be useful to contrast the salinization of groundwater and soils.

The main adaptation activities are listed below:

1. Freshwater storage and ponding/infiltration: in the coastal lowland zone, with continuous urbanization almost in front of the shore, the key action is to maximize the infiltration rate of surface (rain) water, facilitating deepening of the interface zone. Collection and storage of rain, rather than allowing it to run off. Rainwater is collected from a roof-like surface and redirected to a tank, cistern, deep pit (well, shaft, or borehole);

2. Active practices against shoreline erosion/ coastal design and buffer zone: coastal engineering structures, coupled with requalification of on-shore ecosystems and green coastal redevelopment, contributes to reducing the impact of salt-intrusion phenomena.
3. Hydraulic barriers and infiltration of freshwater: hydraulic barriers, consisting of lines of recharge or extraction wells (or coupled systems) contribute to control saltwater intrusion. In the case of confining layers, it will be possible to design systems of Cyclic Recharge with an injection of freshwater during wet season followed by pumping in the dry season
4. Physical Barriers and Geochemical Separation Wall: physical barriers may become necessary near the surface shoreline to regulate river flows to the sea and saltwater ingression during storm surges, as well as to protect the most exposed non-removable structures. This practice is also useful to intercept and interrupt the interface zone with diaphragm walls.
5. Monitoring/Control and maintenance of underground structures and infrastructures: One of the first actions for the adaptation plan by the infrastructure managers consists of a systematic inventory and mapping on the field (with video-inspections), preceded by archive research, to get a full knowledge of the network geometry and materials properties. The knowledge of the state and the materials of the underground infrastructures allows defining the necessary interventions for their adaptation to a more aggressive environment due to salinity.
6. Progradation of the coastline: a prevention action against the progressive sea-level rise could be prograding the coastline toward the seaside, settling new emerged lands in low-depth water, taking into account the impact on the aquatic environment. The new coast-land performs a multi-purpose task since it could also become an important buffer zone for storm-surge and a wetland ecosystem.

4.4.4 Agricultural and natural environments activity

The agricultural environment is one of the production systems most affected by the effects of soil salinization. Scientific research has enabled the selection and creation of crops suitable for growth in a partially salty environment. Nonetheless, salinity levels tend to increase with the effects of climate change (mid-sea rise, capillary rise, etc.) and due to the poor quality of the water used.

For the same reason, the natural environment is subject to an increase in soil and water/groundwater salinity (wetlands, marshy and lacustrine environments, natural reserves) that can change the ecosystem and biodiversity.
The Lamone and Reno rivers are of vital importance to preserve the biodiversity of the marsh area and to mitigate the salinization on the coastal area and in the first hinterland. Unfortunately, freshwaters of these rivers are used intensively for agricultural practices and human water supply. The area comprises about 500 hectares of wetlands characterized by the presence of freshwater environments that are increasingly difficult to maintain because of the increase of drought periods, meaning the scarcity of freshwater and a quality decrease in terms of physic-chemical parameters, especially over summer. Moreover, the area comprises very extensive woods (about 1,200 hectares) that require the presence of freshwater to counteract the salinization of the aquifers and soils, toxic for the trees, and 1.100 hectares of brackish water lagoon, that need fresh water to keep the right balance with the salty seawater. Finally, there are about 3,000 hectares of agricultural land threatened by the lack of fresh water and the consequent progressive salinization.

In these environments activities and improvement actions that can be undertaken summarized as follows:

1. Adaptation of vegetation and crops: adequate agricultural land use can be planned through reasonable changes in agricultural practice or by selecting plants or crops that are tolerant to varying levels of soil salinity, alternating periods of controlled efficient irrigation with periods of run-off irrigation (with large use of water for “flushing” the soils).
2. Implement an innovative irrigation system: innovative irrigation techniques (macro-sprinkler and sprinkler, drip irrigation) can increase efficiency and water savings.
3. Freshwater storage and ponding/infiltration system: the use of available surface water can be used to recharge the water table with ditches and ponds. This choice is certainly the most economical compared to other infiltration systems through wells, drains/underground tunnels

4.5 Ravenna test sites: conceptual/ numerical modelling

The coastal areas of the Adriatic Sea are highly vulnerable to the effects of climate change and anthropic activity. The problem of salt intrusion in coastal areas has required the study of several activities and guidelines to try to preserve these areas (as reported in the previous paragraph). There are a lot of practices and interventions that can be used to contrast the salt intrusion, and one of these is the possibility to extend the areas of freshwater retention and infiltration.

The idea is to use the water of the Lamone River to artificially recharge coastal retro dunes or the drainage ditches in the agricultural area located in the first inland.

In order to enable the planner to compare alternative modes of action, a tool is needed that will provide information about the response of the system to various alternatives. The necessary information about the system response can be obtained by a "model" that describes the behavior of the considered system in response to excitation

A model for managing aquifer development and/or recharge comprises (Figure 7): i) the geological representation of the system (the so-called "conceptual model"); ii) the mathematical description of the phenomena of interests and the computer program that implements appropriate numerical tools to solve the governing equations (the "computer model program"); and iii) the "simulation model", i.e. the application of the computer code to simulate the specific system.

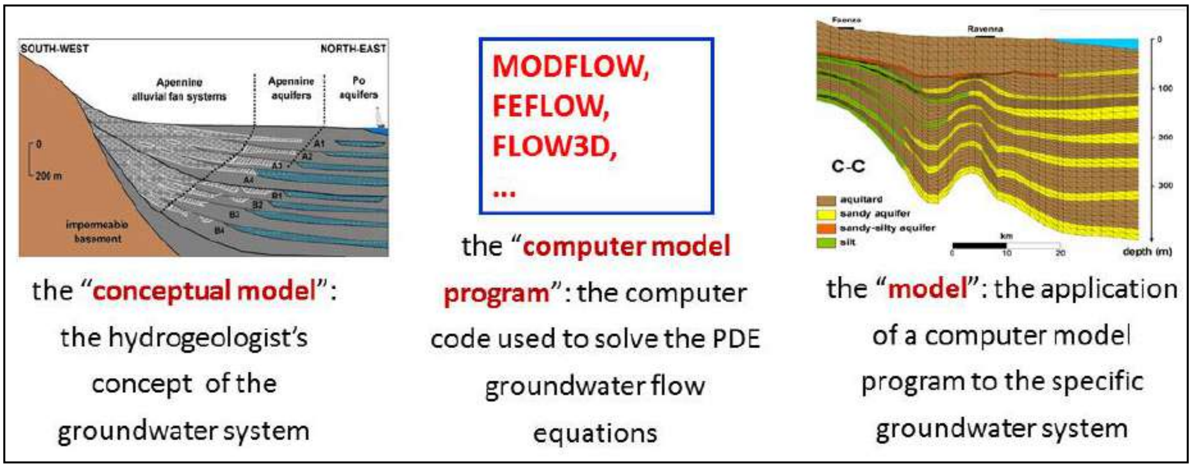


Figure 7 – Sketches representing the three model types that must be developed to simulate and manage groundwater resources and MAR

The building of a simulation model starts from the definition of a conceptual description of the geological layers, including geometry and thus boundaries, rock characteristics and types, subdivision of the system in aquifers and aquitards, and so on. This conceptual description must be based on geophysical data, i.e., a combination of stratigraphic columns, geological sections (obtained for example by seismic, electrical, and radar techniques), well and aquifer test data, etcetera. Following the reconstruction of the subsurface system, one is faced with its translation into proper mathematical models that can be implemented into a simulation code. These models can be solved using numerical techniques yielding results in the form of predictions of the dynamics of the system (water pressure and mass distribution as a function of time and external or internal forcing factors) that can be interpreted as the probable behavior of the subsurface fluid under the peculiar scenario subject of the study.

Thus, a model is built by putting together information at different levels, scales, and sources, including personal believes of the system functioning. A difficulty that faces all individuals attempting to use the results of a model is the development of an understanding of the strengths and limitations of a model analysis without having to reproduce the entire analysis.

4.5.1 Numerical model

The local-scale hydrogeological model has been developed using a density-dependent groundwater flow and transport simulator.

Groundwater flow is simulated through a numerical solution of a fluid mass-balance equation. The ground-water system may be either saturated or partly or completely unsaturated. Fluid density may be constant or vary as a function of solute concentration or fluid temperature. The model tracks the transport of either solute mass or energy in flowing groundwater through a unified equation, which represents the transport of either solute or energy. Solute transport is simulated through the numerical solution of a solute mass-balance equation where solute concentration may affect fluid density. The single solute species may be transported conservatively, or it may undergo equilibrium sorption (Weill, et al. 2011) (through linear, Freundlich, or Langmuir isotherms). In addition, the solute may be produced or decay through first- or zero-order processes. Energy transport is simulated through the numerical solution of an energy-balance equation. The solid grains of the aquifer matrix and fluid are locally assumed to have equal temperature, and fluid density and viscosity may be affected by the temperature. Most aquifer material, flow, and transport parameters may vary throughout the simulated region to account for the measured heterogeneities. Sources and boundary conditions of fluid, solute, and energy may be specified to vary with time or may be constant. The dispersion processes include diffusion and two types of fluid velocity-dependent dispersion. The standard dispersion model for isotropic media assumes direction-independent 6 values of longitudinal and transverse dispersivity. A flow-direction-dependent dispersion process for anisotropic media is also provided. This process assumes that longitudinal and transverse dispersivities vary depending on the orientation of the flow direction relative to the principal axes of aquifer permeability.

4.5.2 Location of test sites

Ravenna is situated in the northern part of Italy in the Pianura Padana region. This area is affected by saltwater intrusion because the soil elevation is near the average sea level.

Figure 7 – Ravenna Study area and local intervention point (red bullet point)

We identify two test zones close to the Lamone River. The first one (Figure 7 – "A") is located in the retrodunes area. This zone is a natural area behind the coastal dunes. The second (Figure 7 – "B") is more inland and it includes large agricultural areas characterized by distributed and parallel drainage ditches.

From a detailed Digital Elevation Model we extract two representative profile sections that describe the geometry of the model domain (Figure 8 and Figure 9).

Profile A-A of Figure 8 is describing the boundary of the first model domain (retrodunes model) with the characteristics of natural dunes behind the coast and a retrodunes closed area that can be used as a pond infiltrate freshwater diverged from Lamone River. Similarly, profile B-B of Figure 9 describes the contour of the ditches model domain.

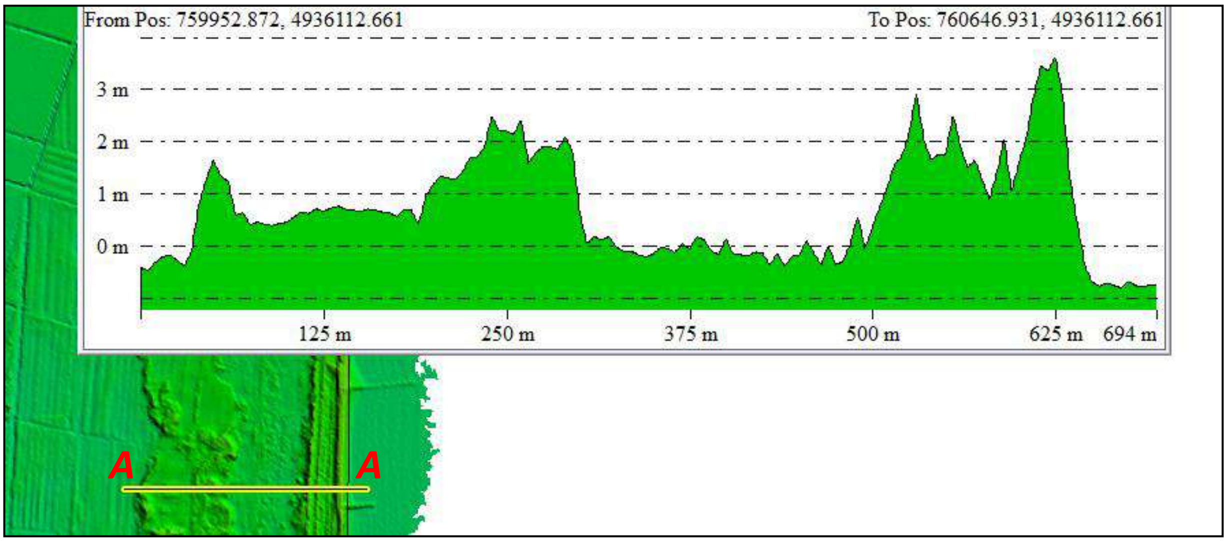


Figure 8 – Representative section profile A-A of dunes and retro dunes area extract from DEM

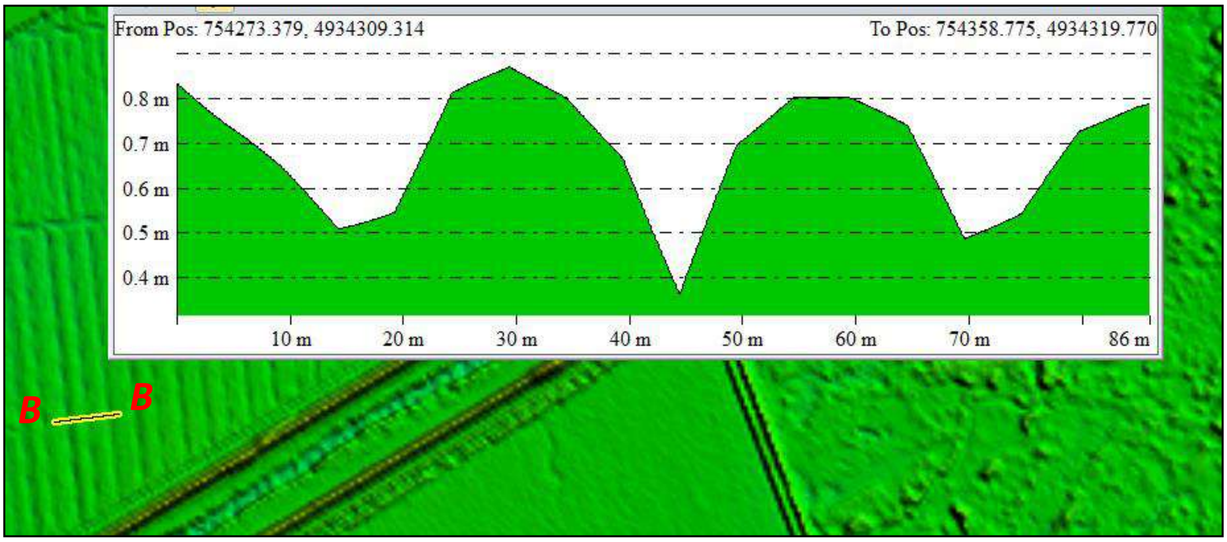


Figure 9 – Representative section profile B-B of agricultural ditches extract from DEM.

4.5.2.1 Conceptual models

We analized two Conceptual models of infiltration recharge to develop the numerical models presented in this work. The retrodune model (model A) was developed considering two layers of sand material with different hydraulic properties as reported in Figure 11.

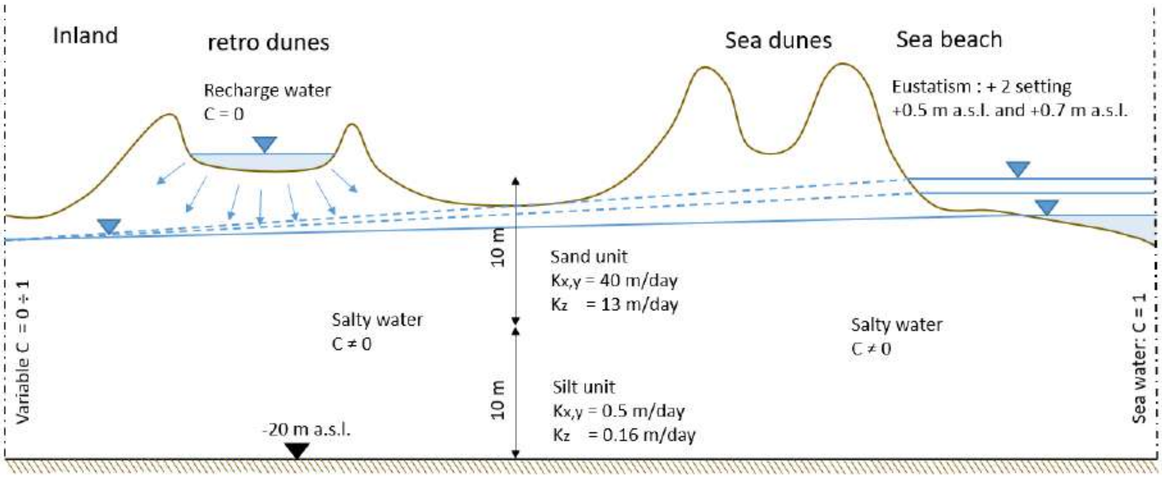


Figure 11 – Model A: Conceptual model of retrodune recharge.

In this model, the sea level is set to 0 m on asl and increase to +70 cm to test different saltwater intrusion scenarios. These values of 70 cm correspond to the worst predicted rise of sea level in the year 2100. The pond water level varies from 15 to 30 cm in the infiltration area with continuous or seasonal recharge for 1 year of simulation time.

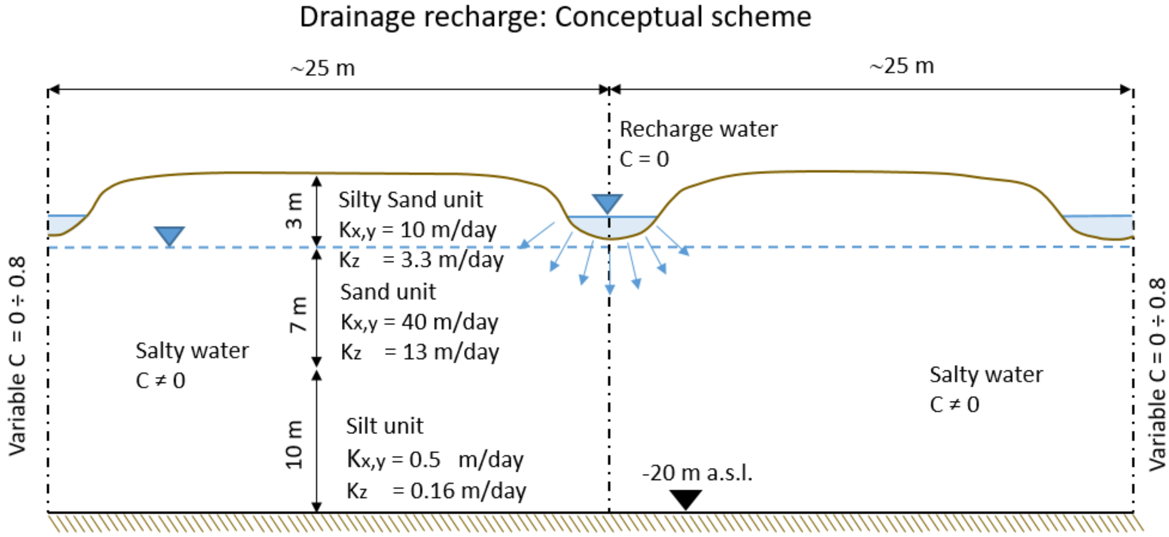


Figure 12 – Model B: Conceptual model of ditch recharge.

The second model (model B) has similar material parameters with three different sand layers. In this model, we test different ditch water levels, from 15 cm to 30 cm, and different recharge setups during the simulations. The water table level is set to -1.00 m asl according to the level imposed by the drainage system.

The initial condition in term of pressure head is represented by:

$$\psi_0(x, y, z) = z_w(x, y) - z(x, y) \tag{2}$$

where z_w is the elevation of water-free surface in a generic point, with (x,y) planar coordinates and elevation z. This means that a hydrostatic pressure has been initially used above and below the water table, taking into account the higher weight of the brackish water with respect to the fresh one.

The value of the salt concentration was initially assumed to be linearly increasing in the top layer from top to bottom, as suggested by the deliverables of the WP4 (D. 4.1.2) of the ASTERIS project. The concentration in the top Sand layer (Layer1) is derived from analyses on collected water samples (D. 4.1.2 ASTERIS Project). NaCl concentration is expressed in term of dissolved mass with a relative value from 0 to 1 (0 freshwater, 1 saltwater):

$$c_{layer}(x, y, z) = 0; \quad i.e., \quad c_{layer}(x, y, z) = 0\ g/l$$

$$c_{layer}(x, y, z) = 0.5\ ; \quad i.e., \quad c_{layer}(x, y, z) = 17.5\ \mathrm{g/l}$$

The average value of seawater solute concentration is assumed equal to 1, i.e. 35 g/l.

The following boundary conditions were prescribed for each model:

1. Dirichlet conditions on the West and East. Hydrostatic pressure has been prescribed using the values of the depth to the water table provided by deliverables of WP4 (ASTERIS project). For model A these values are representative of an aquifer elevation at -1.5 m asl on the west side and varying from 0 to +0.7 m above asl (Sea level increasing scenario at 2100) depending on the modeling scenario. For model B, we imposed a constant water table level at -1.0 m asl that is provided by the drainage systems
2. Neumann condition on the land surface (Net Rainfall, about 500 mm/year, calculated as the difference between Annual Rainfall and Evapotranspiration distributed on the top).
3. Neumann no-flux condition on the domain bottom.

The setup of hydraulic parameters for each model was carried out using data from the literature review and from deliverables of the ASTERIS project as reported in paragraph 4.5.5.

4.5.2.2 Discretization of the model domain

According to the hydrogeological information available from literature, the ASTERIS project and the specific aim of the local-scale simulations, i.e. the analysis of artificial recharge scenarios, the DEM extrapolated sections of interest have been discretized as shown in Figure 13 and 14.
The mesh has been generated using the program ArgusOne from Argus Holdings, Ltd. ArgusOne ensures the construction of unstructured grids, thus providing an accurate numerical solution of the PDE equations.
The two-dimensional grid was "projected" horizontally along the y-axis to generate a three-dimensional finite element mesh of the simulation domain (a “slice” whit 1 m of thick) for each model. For model A, the mesh consists of 2 layers of tetrahedra for a total of 72’033 nodes and 276’522 elements. Similarly, for model B, the mesh of tetrahedral elements is composed by 3 layers for a total of 33’681 nodes and 132’402 elements This setting allows for an accurate reconstruction of the geological formations detected in the area.

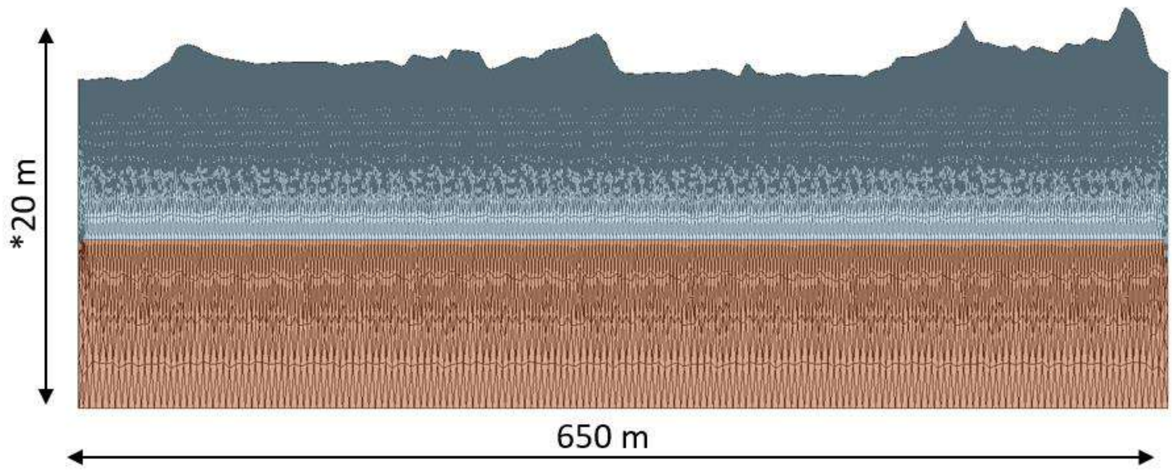


Figure 13 –Slice in the middle of three-dimensional finite element mesh of retrodune recharge model (Model A). The vertical exaggeration is 10.

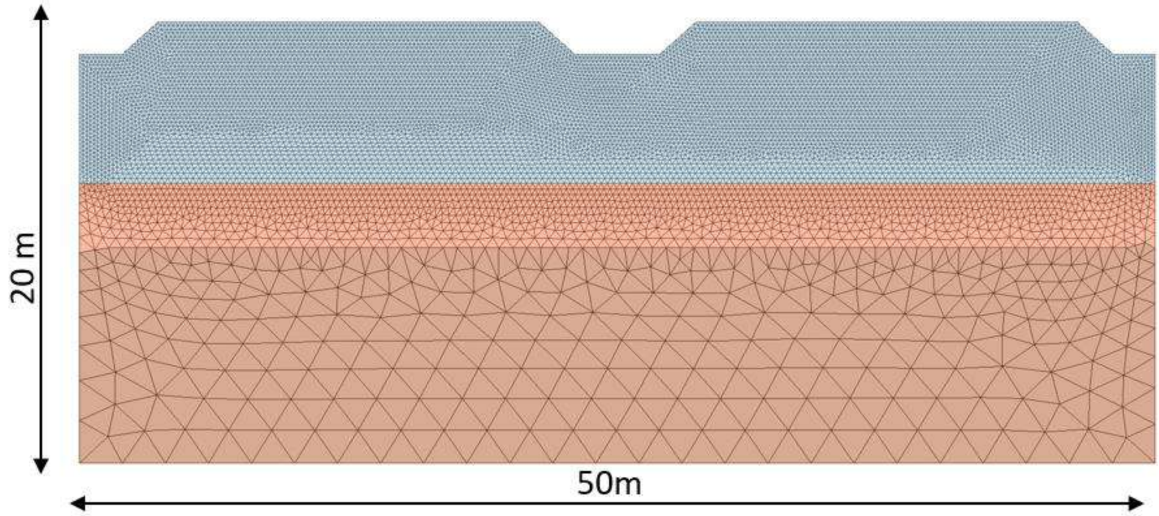


Figure 14 – Slice in the middle of three-dimensional finite element mesh of ditch recharge model (Model B).

A deep impermeable bottom was placed at about 20 m below asl, in correspondence with the middle of the fine sandy unit.

4.5.2.3 Hydrological/soil parameter

Information on the geologic structure and aquifer system was gathered from a review of the scientific literature on the study area. Another fundamental parameter for the simulations (such as load condition, water table level, salinity, etc.) has been collected by deliverables of the previous WP of the ASTERIS project.

Two main sandy units characterize the aquifer's stratigraphy: a relatively thick medium-grained sand shallow unit (from 0 m to -10 m a.s.l.) and a lower fine-grained sand unit of a lesser thickness (from -21 m to -26 m a.s.l.). A clayey-silt and sandy-silt unit (from -10 m to -21 m a.s.l) separates these two bodies. Lastly, the Würmian continental silty-clay basement is at a depth varying from -20 m in the western sector to -30 m at the present shoreline (Veggiani, 1971, 1974) (Figure 15). The lithologic reconstruction of the phreatic aquifer shows a dominant sand composition with high hydraulic conductivity values (about 10^{-3} m/ s). The quantity of sand decreases in the western part, towards the agricultural and reclamation areas. Clay–silt content increases with depth; at 25–30 m depth, a compact grey clay level forms the phreatic aquifer basement.

Monitoring data and geo-electrics resistivity surveys, which were carried out in the previous deliverables of the ASTERIS project, suggest that the brackish–freshwater interface is close to the surface. Its average depth is 5–6 m below the mean sea level, but it can go down to 11 m depth where there are high-infiltration recharge areas, as in the fossil dunes (Sabia et al., 2005). Below 15– 20 m a.s.l. some saltwater saturated lenses of sand, probably in hydraulic connection with one another, reach down to the clay basement. The brackish–freshwater interface does not reach the bottom-confining layer and does not prevent saltwater intrusion into the aquifer.

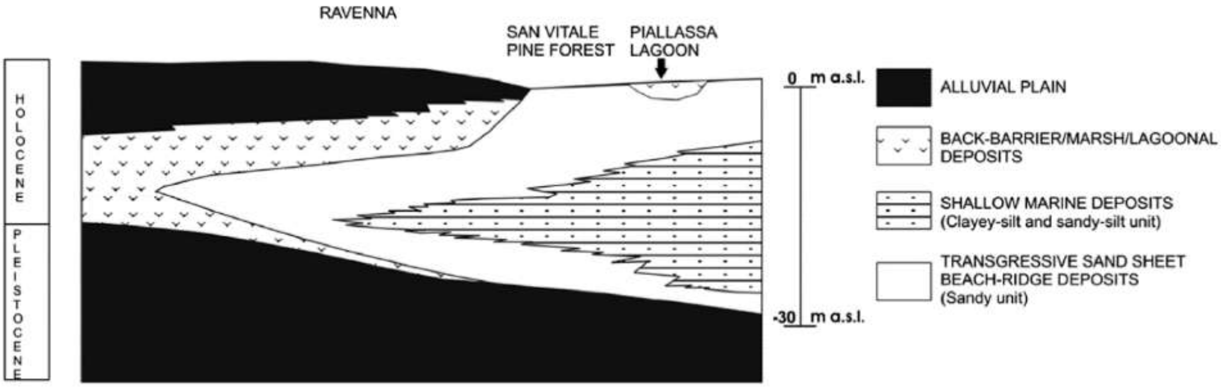


Figure 15 – Lithostratigraphic reconstruction of the study area (modified from Amorosi et al., 1999; Marchesini et al., 2000, Giambastiani et al. 2007).

The water table maps show that the lowest water table is found in the inland part of the study area where drainage is strong in order to keep the farmlands dry. As a result, the hydraulic head is controlled by the drainage system and in the largest part of the aquifer, it is too low to stop saltwater intrusion from the brackish lagoon. The only areas where the water table is above mean sea level are along the embankments of the main rivers.

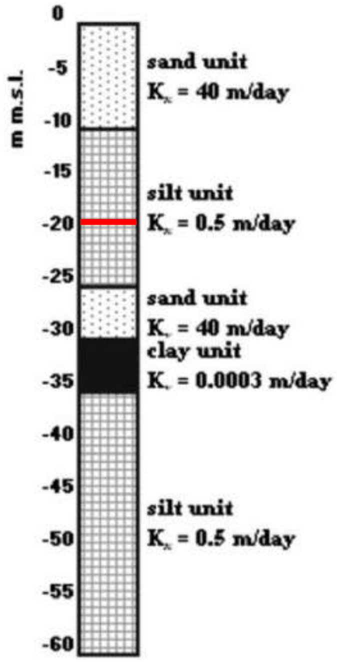


Figure 16 – Simplified subdivision of the permeable aquifer and hydraulic conductivity values (K_x), as used in the numerical model (after Gimbastiani et al. 2007). The red line indicates the bottom layer of the developed model.

Considering geological data (Ermes, 2002), slug tests and the geoelectric resistivity surveys that we carried out in the pine forest (2004–2005), we have characterized the aquifer and its geometry (Figure 16). The figure shows the subdivision of the phreatic aquifer into five main units and reports their hydraulic conductivity K_x and thickness.

The anisotropy ratio, vertical versus horizontal hydraulic conductivity K_z/K_x, is 1/3 for all layers. The effective porosity n_e is 25% (Regione Emilia-Romagna and ENI-AGIP, 1998).

The longitudinal dispersivity a_L is set equal to 0.1 m, whereas the ratio of transversal to longitudinal dispersivity is 0.1. All these values are typical for these kinds of aquifers. For a conservative solute such as chloride, the molecular diffusion for porous media is taken as equal to 10^{-9} m^2/s.

The parameters of the van-Genuchten (van Genuchten 1980) capillary curves used to characterize the hydrologic properties in the unsaturated zone are:

Capillary pressure: -0.765 (m); n = 4 (-); Swr = 0.15 (-); Storage = 0.001 (1/m) (1)

These data were obtained using the Rosetta code. Rosetta is a computer program that implements hierarchical pedotransfer functions for the estimation of van Genuchten water retention parameters, and the saturated and unsaturated hydraulic conductivity using limited (textural classes only) to more extended (texture, bulk density, and one or two water retention points) input data (Schaap, Leij e van Genuchten 2001).

4.5.2.4 Steady-state (initial) condition

Simulations run until steady-state conditions were reached for hydraulic head and salt concentration without any infiltration recharge for each model developed.
The steady-state conditions is shown in Figure 17 for the retro dune model with water table at 0.0 m. A new stationary condition has been analysed by increasing the sea level to 50 and 70 cm above sea level. In second model (Figure 18), is imposed the water table at -1.0 m asl. This level is assured by the local drainage system in this area.

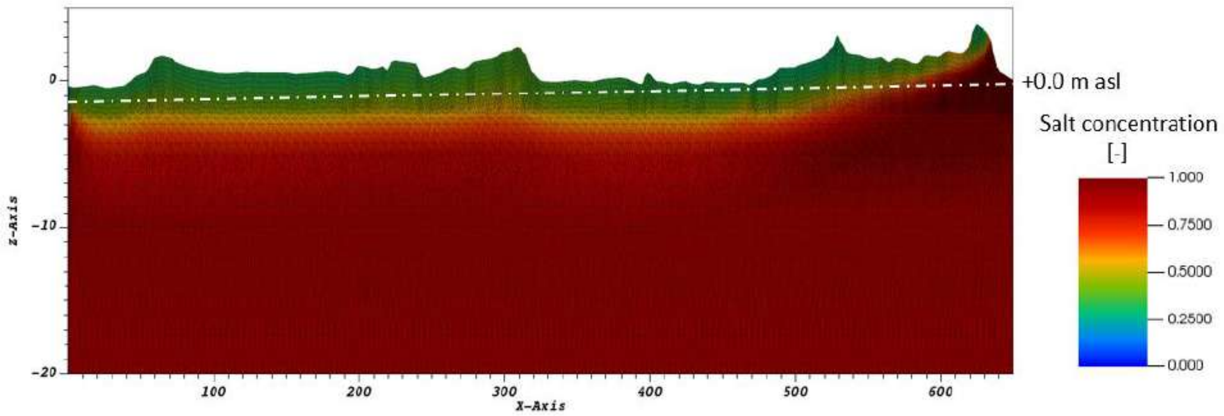


Figure 17 – Steady-State condition of model A, reached after 1 year of simulation. The white line indicates the water table imposed.

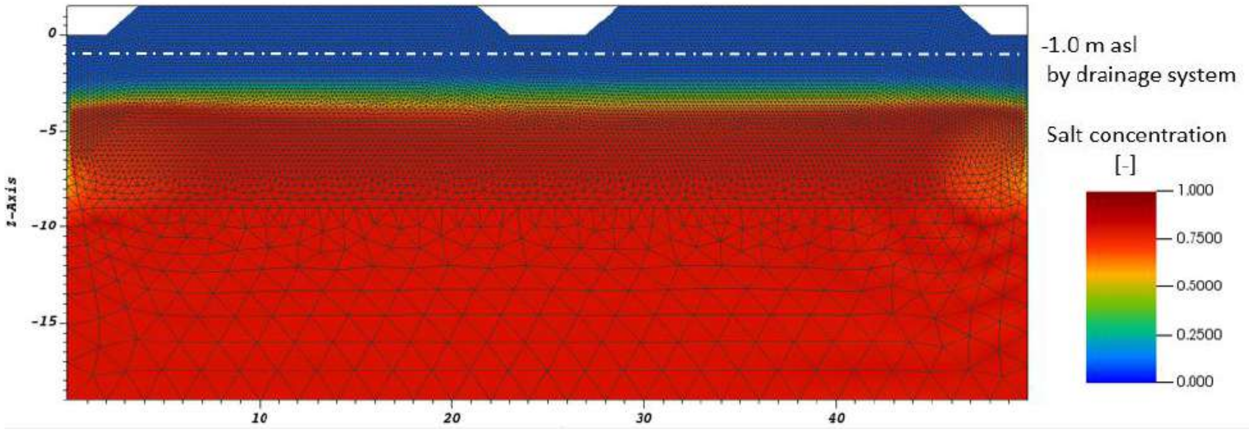


Figure 18 – Steady-State condition of model B, reached after 1 year of simulation. The white line indicates the water table imposed.

The results of steady-state simulations were set as initial condition for the recharge simulation developed in the next paragraph.

4.5.3 Simulation of aquifer recharge

Several simulations have been carried out to evaluate several aquifer recharge configurations. Moreover, a sensitivity analysis has been performed to investigate the influence of the most uncertain parameters on the simulation results.

For each model, the simulations explore different set-up as reported in table 1:

In Model A was set different Sea water levels on East side. We consider 3 sea-level scenarios that analyse the increase of seawater level affected by climate change as reported in WP3 (ASTERIS project). We analyse two water level recharge in retro dune area from 0.15 to 0.30 m. Two different time-varying recharge, continues and seasonal, have been considered;

Model B investigates two different water level recharge on ditches from 0.15 to 0.30 m. Two different configurations of recharge, continuous and seasonal, have been tested.

4.5.4 Sensitivity Analysis and definition of the final parameter

A sensitivity analysis is performed to investigate the effects of 1) Soil, hydraulic parameter, and 2) the dispersivity coefficient on the solute concentration around the recharge area. All of the performed simulations for each model are summarized in Tables 1 and 2.

ID	*K_x /K_z* (m/day)	*α_L/ α_T* (m)	*Recharge level* (m)	*Sea level* (m asl)
S1.1	40.0/13.0	0.1/0.01	0.60	0.0
S1.2	40.0/13.0	1.0/0.1	0.60	0.0
S1.3	40.0/13.0	0.1/0.01	0.30	0.0
S1.4	4.0/1.3	0.1/0.01	0.30	0.0
S1.5	40.0/13.0	0.1/0.01	0.60	0.70
S1.6	4.0/1.3	0.1/0.01	0.60	0.0
S1.7	40.0/13.0	0.1/0.01	0.30	0.70
S1.8	40.0/13.0	0.1/0.01	0.15	0.0
S1.9	40.0/13.0	0.1/0.01	0.15	0.70

Table 1 – Summary of the set of simulations performed for Model A. The table provides the vertical and horizontal hydraulic conductivity, longitudinal and transversal dispersivity parameters, pond water level recharge and sea level. The final simulations reported in this work are highlighted in blue color.

ID	*K_x /K_z* Top sand layer (m/day)	*K_x /K_z* sand layer (m/day)	*α_L/ α_T* (m)	*α_L/ α_T* (m)	*Recharge level* (m)
S2.1	10.0/3.3	40.0/13.0	0.1/0.01	0.1/0.01	0.60
S2.2	10.0/3.3	40.0/13.0	1.0/0.1	1.0/0.1	0.60
S2.2	10.0/3.3	40.0/13.0	0.1/0.01	0.1/0.01	0.30
S2.3	10.0/3.3	4.0/1.3	0.1/0.01	0.1/0.01	0.30
S2.4	1.0/0.33	40.0/13.0	0.1/0.01	0.1/0.01	0.60

S2.5	1.0/0.33	4.0/1.3	0.1/0.01	0.1/0.01	0.60
S2.6	10.0/3.3	40.0/13.0	0.1/0.01	0.1/0.01	0.15

Table 2 – Summary of the set of simulations performed for Model B. The table provides the vertical and horizontal hydraulic conductivity, longitudinal and transversal dispersivity parameters, pond water level recharge and sea level. The final simulations reported in this work are highlighted I blue color.

Transport behaviour of non-reactive solutes in groundwater is generally governed by two principal processes: advection and dispersion, which describe the role of hydrodynamics in governing transport and dilution of soluble substances. Advection refers to the mean movement of the solute in the flowing groundwater, while dispersion describes the solute spreading about the mean motion caused by local fluctuations in velocity.

Hydrodynamic dispersity (α_L, α_T) is an empirical factor that quantifies how much contaminants stray away from the path of the groundwater which is carrying it (dispersion process). Some of the contaminants will be "behind" or "ahead" of the mean groundwater, giving rise to a longitudinal dispersity (α_L), and some will be "to the sides of" the pure advective groundwater flow, leading to a transverse dispersity (α_T). Dispersion in groundwater arises because each water "particle", passing beyond a soil particle, must choose where to go, whether left or right or up or down, so that the water "particles" (and their solute) are gradually spread in all directions around the mean path. This is the "microscopic" mechanism, on the scale of soil particles. More important, on long distances, can be the macroscopic inhomogeneities of the aquifer, which can have regions of larger or smaller permeability, so that some water can find a preferential path in one direction, some other in a different direction, and the contaminant can be spread in a completely irregular way, like in a (three-dimensional) delta of a river.

Dispersity is actually a factor that represents our “lack of information” about the system we are simulating. There are many small details about the aquifer which are being averaged when using a macroscopic approach (e.g., tiny beds of gravel and clay in sand aquifers) that can be usually summarized into an apparent dispersity. Because of this, α is often claimed to be dependent on the length scale of the problem — the dispersity found for transport through 1 m^3 of aquifer is different from that for transport through 1 cm^3 of the same aquifer material (Gelhar et al., 1992). Moreover, dispersity also accounts for the numerical dispersity introduced into the solution by the numerical approach and the space discretization used to resolve the partial differential equations.

The results of the sensitivity analysis shown that the longitudinal dispersity and hydraulic conductivity are the sensitive aquifer parameters to evaluate seawater intrusion in the study area. The test conducted by imposing lower hydraulic conductivities, compared to what was determined in the literature, showed similar behaviour in groundwater distribution but a lower infiltration capacity and flow due to the hydraulic gradient of the sea. Hydrodynamic dispersity (α_L) values were chosen by considering the dimensions of the geometric mesh elements and evaluating the effects on the groundwater salinity distribution. This ratio is usually employed in numerical models when dispersity values cannot be determined with certainty through a specific investigation.

4.5.5 Simulation results

The main objective of this set of simulations is the definition of an effective filtration plan (dunes or ditches) to recharge the shallow aquifer in the Ravenna test site.
We identify the final parameter set and the final simulation to perform in the previous paragraph.

ID	*K_x /K_z (m/day)*	*α_L/ α_T (m)*	*Recharge level (m)*	*Sea level (m asl)*	*Time varying recharge*
S1.3	40.0/13.0	0.1/0.01	0.30	0.0	YES
S1.7	40.0/13.0	0.1/0.01	0.30	0.70	YES
S1.8	40.0/13.0	0.1/0.01	0.15	0.0	YES
S1.9	40.0/13.0	0.1/0.01	0.15	0.70	YES

Table 3 – Summary of the final set of simulations performed for Model A. The table provides the vertical and horizontal hydraulic conductivity, longitudinal and transversal dispersity parameters, pond water level recharge and sea level and if time-varying recharge is performed.

ID	K_x/K_z Top sand layer (m/day)	K_x/K_z sand layer (m/day)	α_L/α_T (m)	α_L/α_T (m)	Recharge level (m)	Time varying recharge
S2.2	10.0/3.3	40.0/13.0	0.1/0.01	0.1/0.01	0.30	NO
S2.2b	10.0/3.3	40.0/13.0	0.1/0.01	0.1/0.01	0.30	YES
S2.6	10.0/3.3	40.0/13.0	0.1/0.01	0.1/0.01	0.15	NO
S2.6b	10.0/3.3	40.0/13.0	0.1/0.01	0.1/0.01	0.15	YES

Table 4 – Summary of the final set of simulations performed for Model A. The table provides the vertical and horizontal hydraulic conductivity, longitudinal and transversal dispersity parameters, pond water level recharge and sea level and if time-varying recharge is performed.

The model A (retro dunes recharge model) results are presented through the following figures:

- Figure 18 shows the distribution of salt concentration on the model domain with sea level at **0.0 m asl** at four-time: 30, 90, 120 and 180 days (ID: S1.3). The **recharge level** on the pond is set at **0.30 m**. The recharge is constant during the first 3 months of simulation time and subsequently stopped for the next 3 months (total simulation time: 6 months).
- Figure 19 shows the distribution of salt concentration on the model domain with **sea level at 0.7 m asl** at four-time: 30, 90, 120 and 180 days (ID: S1.7). The **recharge level** on the pond is set at **0.30 m**. The recharge is constant during the first 3 months of simulation time and subsequently stopped for the next 3 months (total simulation time: 6 months)
- Figure 20 shows the distribution of salt concentration on the model domain with **sea level at 0.0 m asl** at four-time: 30, 90, 120 and 180 days (ID: S1.8). The **recharge level** on the pond is set at **0.15 m**. The recharge is constant during the first 3 months of simulation time and subsequently stopped for the next 3 months (total simulation time: 6 months)
- Figure 21 shows the distribution of salt concentration on the model domain with **sea level at 0.7 m asl** at four-time: 30, 90, 120 and 180 days (ID: S1.9). The **recharge level** on the pond is set at **0.15 m**. The recharge is constant during the first 3 months of simulation time and subsequently stopped for the next 3 months (total simulation time: 6 months)

Results show (Figure 18) a decrease of salinity level after only 30 days in the first 10 m of soil. At this level, it is present an interface between two layers of soil with different hydraulic property. The vertical hydraulic conductivity in the upper part is about 10 m/day and the only limit of infiltration is the availability of freshwater during the different seasons. The second soil layer is characterized by a lower hydraulic conductivity and the behavior is like an impermeable layer for freshwater. The horizontal hydraulic conductivity is very high, about 40 m/day, and the hydraulic gradient from the sea pushes the freshwater to the inland. After three months of recharge, the freshwater bubble dimension increase and migrate to the inland due to hydraulic gradient from the sea. The freshwater layer can persist in this area for the subsequent 3 months without any pond recharge.

In the second scenario (Figure 19) we set the water-table level at +70 cm asl. The increase of the hydraulic gradient pushes more saltwater in the inland and also increases the salinity in the upper part of the sand dunes where the capillary rise and salt diffusion can transport saltwater on the surface. The behaviour is quite similar to the previous simulation. The freshwater remains in the first 10 m of soil, characterized by a quite large hydraulic conductivity, and creates a freshwater hydraulic barrier for the saltwater intrusion.

Figure 20 and Figure 21 shown similar results with only 15 cm of water recharge in the pond area. This behaviour is due to the vertical hydraulic conductivity is very high and we can infiltrate a lot of water with a very less hydraulic head. The problem is how much volume of freshwater is available to recharge the pond area and the water availability during the different season.

Similarly, the model B (ditch recharge model) results are presented through the following figures:

- Figure 22 shows the distribution of salt concentration on the model domain at four different times: 90, 180, 270 and 360 days. The **recharge level** on the ditch is set at **0.15 m**. The recharge is constant during all the simulation time of 1 year;
- Figure 23 shows the distribution of salt concentration on the model domain at four different times: 90, 180, 270 and 360 days. The **recharge level** on the ditch is set at **0.15 m**. The seasonal recharge is set for 3 months and subsequently stopped for the next 3 months.
- Figure 24 shows the distribution of salt concentration on the model domain at four different times: 90, 180, 270 and 360 days. The **recharge level** on the ditch is set at **0.30 m**. The recharge is constant during all the simulation time of 1 year;

- Figure 25 shows the distribution of salt concentration on the model domain at four different times: 90, 180, 270 and 360 days. The **recharge level** on the ditch is set at **0.30 m**. The seasonal recharge is set for 3 months and subsequently stopped for the next 3 months.

The infiltration behaviour is quite similar to model A because the soil materials have the same properties except for the first thin layer of 3 m in the surface that is less permeable compared to the other sandy layers. The infiltration from the ditch pushes saltwater down and can create a freshwater layer until the less permeable layer is reached (Figure 22). The saltwater occlusion, show near the boundary, is due to the difficulty of freshwater to push down saltwater through the less permeable soil layer where the vertical infiltration velocity (i.e. freshwater flux) is too high to move the freshwater in this layer of material. High horizontal conductivity allows water to expand laterally and overlap freshwater infiltrated from other ditches creating a continuous "barrier" of freshwater in the first 10 m.

We report a similar behaviour for a seasonal recharge (Figure 23). In this case, the freshwater layer can also persist in the first meters of the soil layer even if the freshwater bubble cannot reach the impermeable layer. During the non-recharge season, the freshwater layer can persist for a long time because the hydraulic gradient of the aquifer (provided by the drainage system) is limited and there is no appreciable movement of saltwater from the coast or upwelling from deeper layers.

Finally, we test similar scenarios with 30 cm of water in the ditch (Figure 24 and Figure 25). The results are quite similar to the previous simulation because the soil is highly permeable in the first 10 m. The hydraulic head is not important to groundwater recharge with these kinds of soils because they permit to infiltrate lot of freshwater with a very lower hydraulic head.

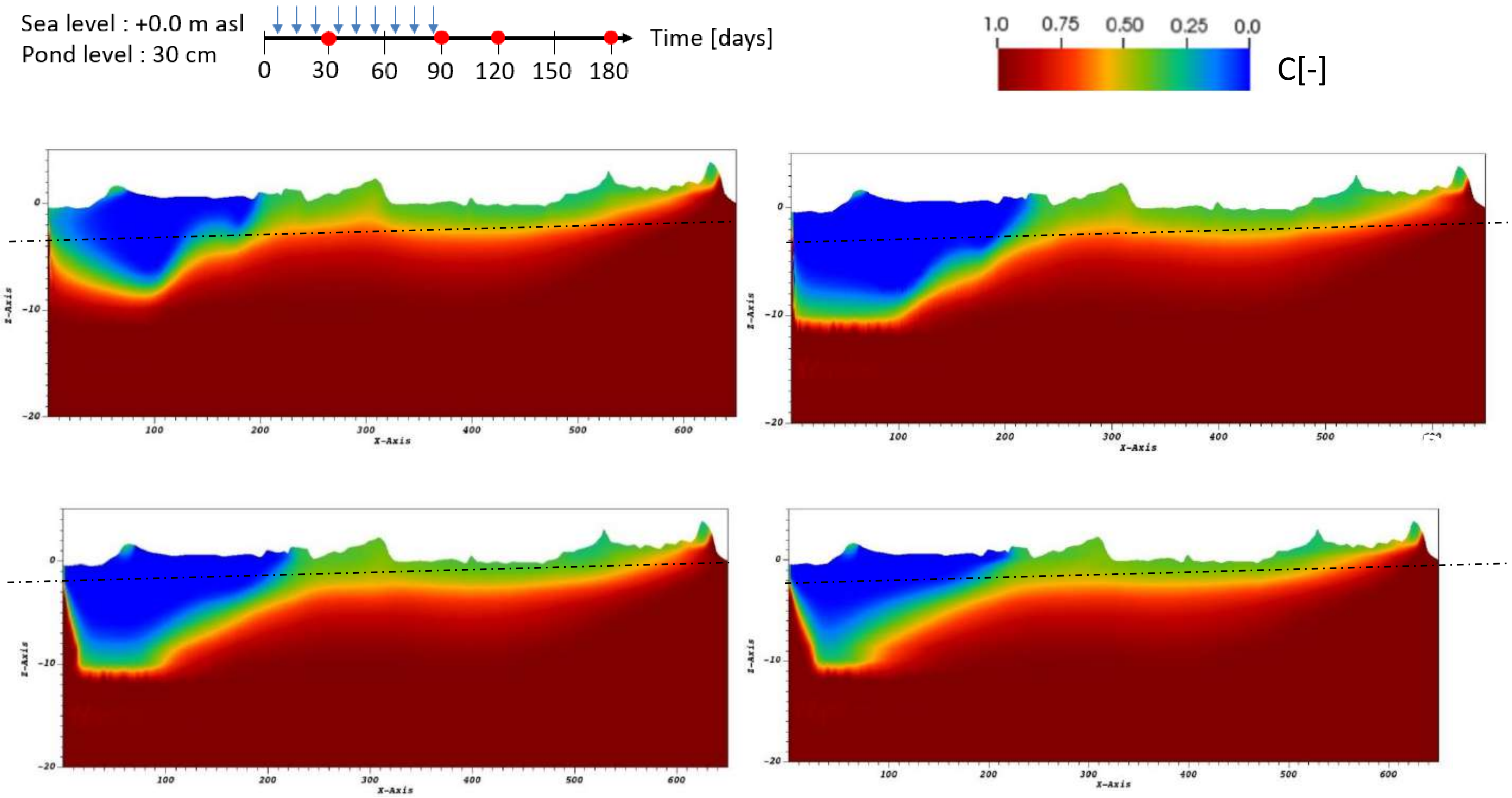


Figure 18 – Model A: solute concentration on a vertical section through the barycenter of the model after 1, 3, 4 and 6 months of aquifer recharge with h = 30 cm and sea level 0.0 m asl.

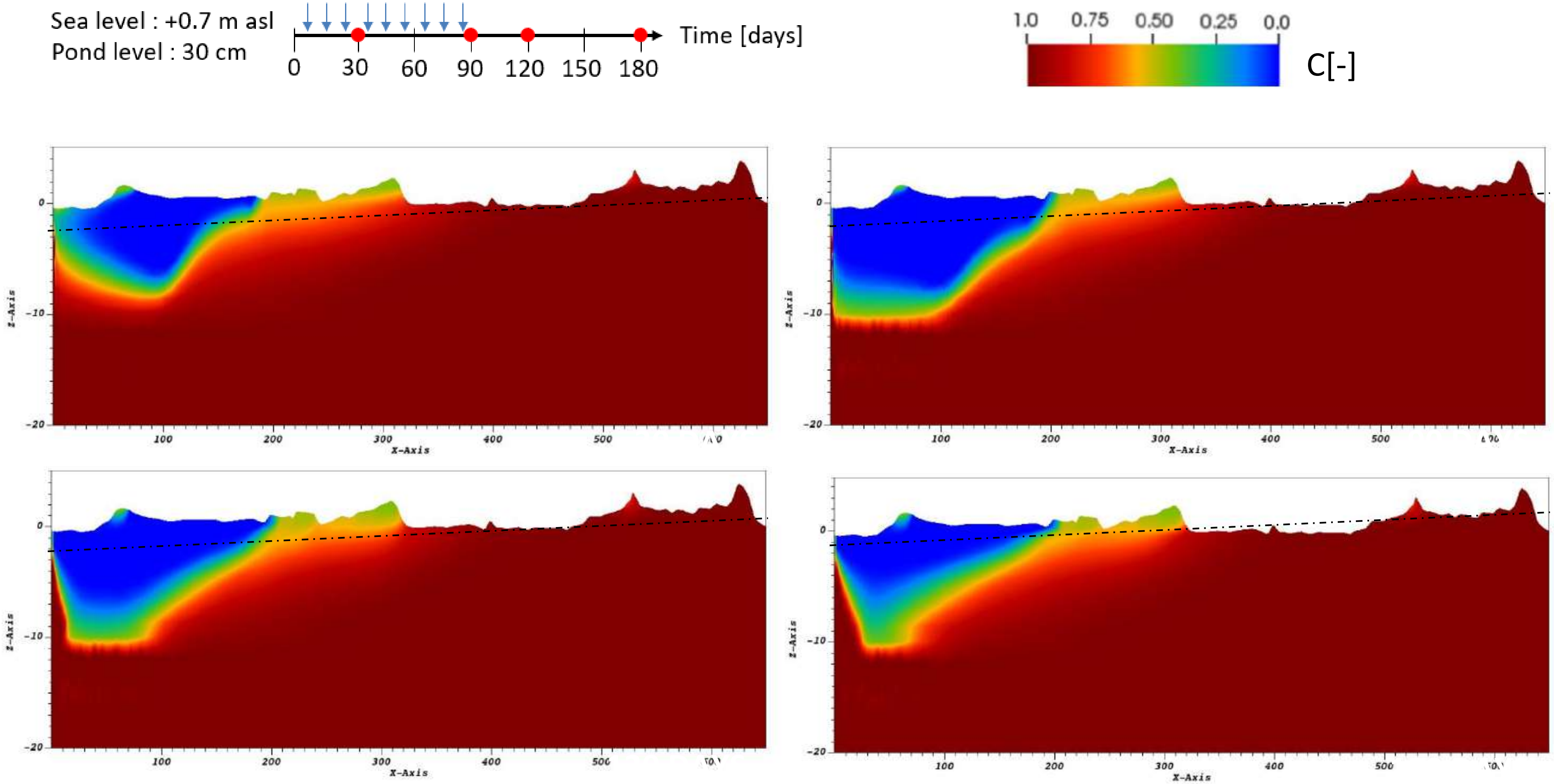


Figure 19 – Model A: solute concentration on a vertical section through the barycenter of the model after 1, 3, 4 and 6 months of aquifer recharge with h = 30 cm and sea level 0.7 m asl.

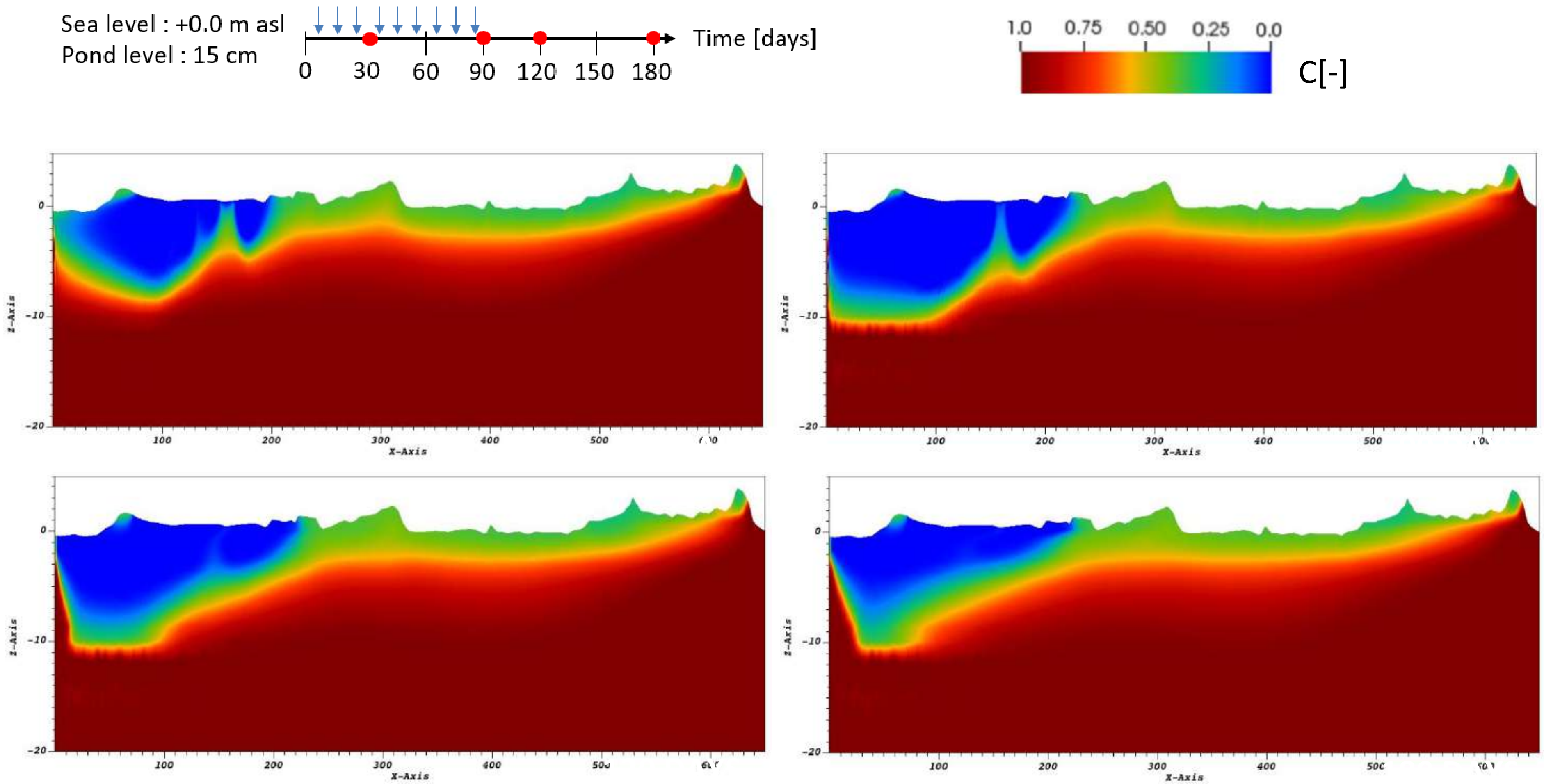


Figure 20 – Model A: solute concentration on a vertical section through the barycenter of the model after 1, 3, 4 and 6 months of aquifer recharge with h = 15 cm and sea level 0.0 m asl.

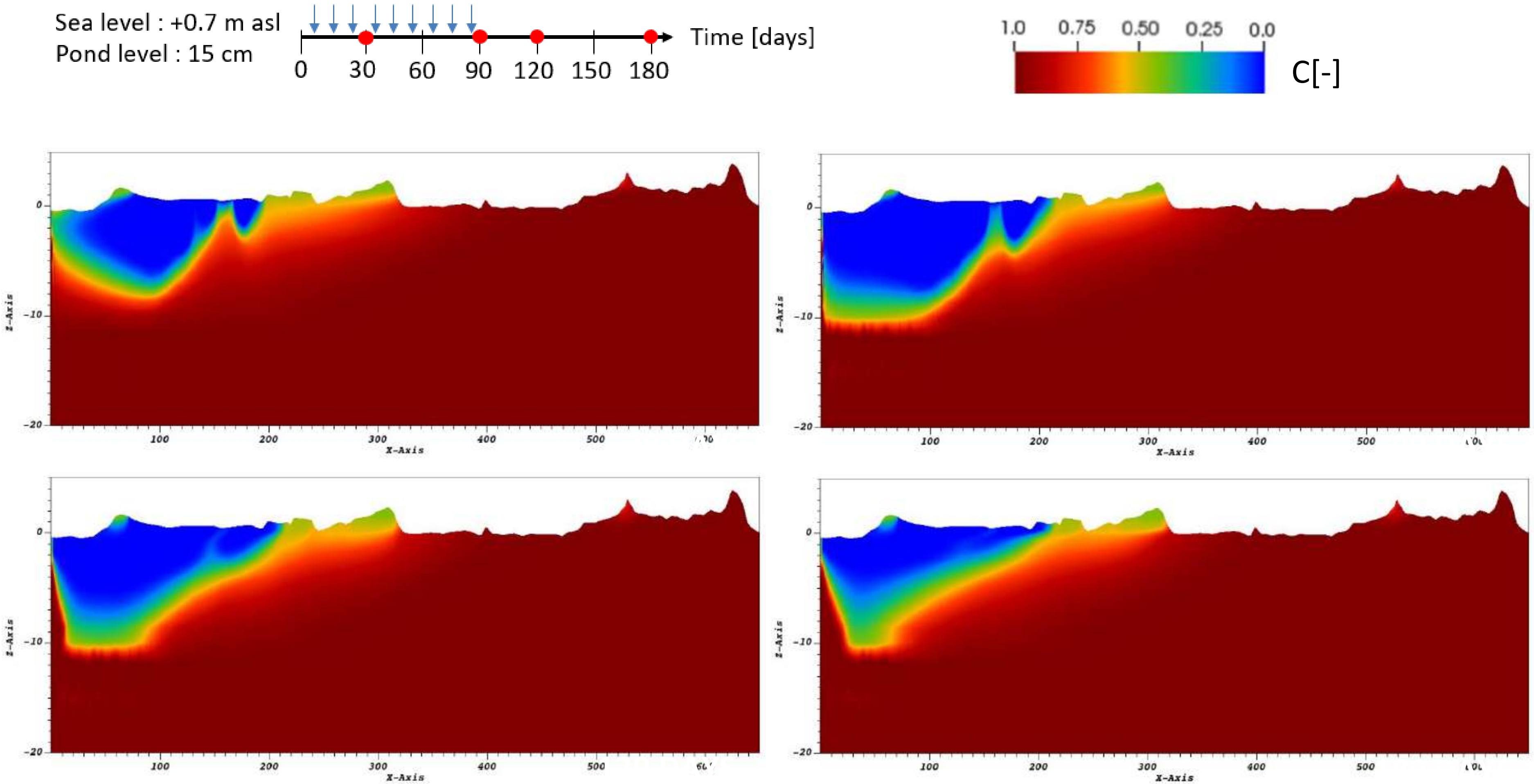


Figure 21 – Model A: solute concentration on a vertical section through the barycenter of the model after 1, 3, 4 and 6 months of aquifer recharge with h = 15 cm and sea level 0.0 m asl.

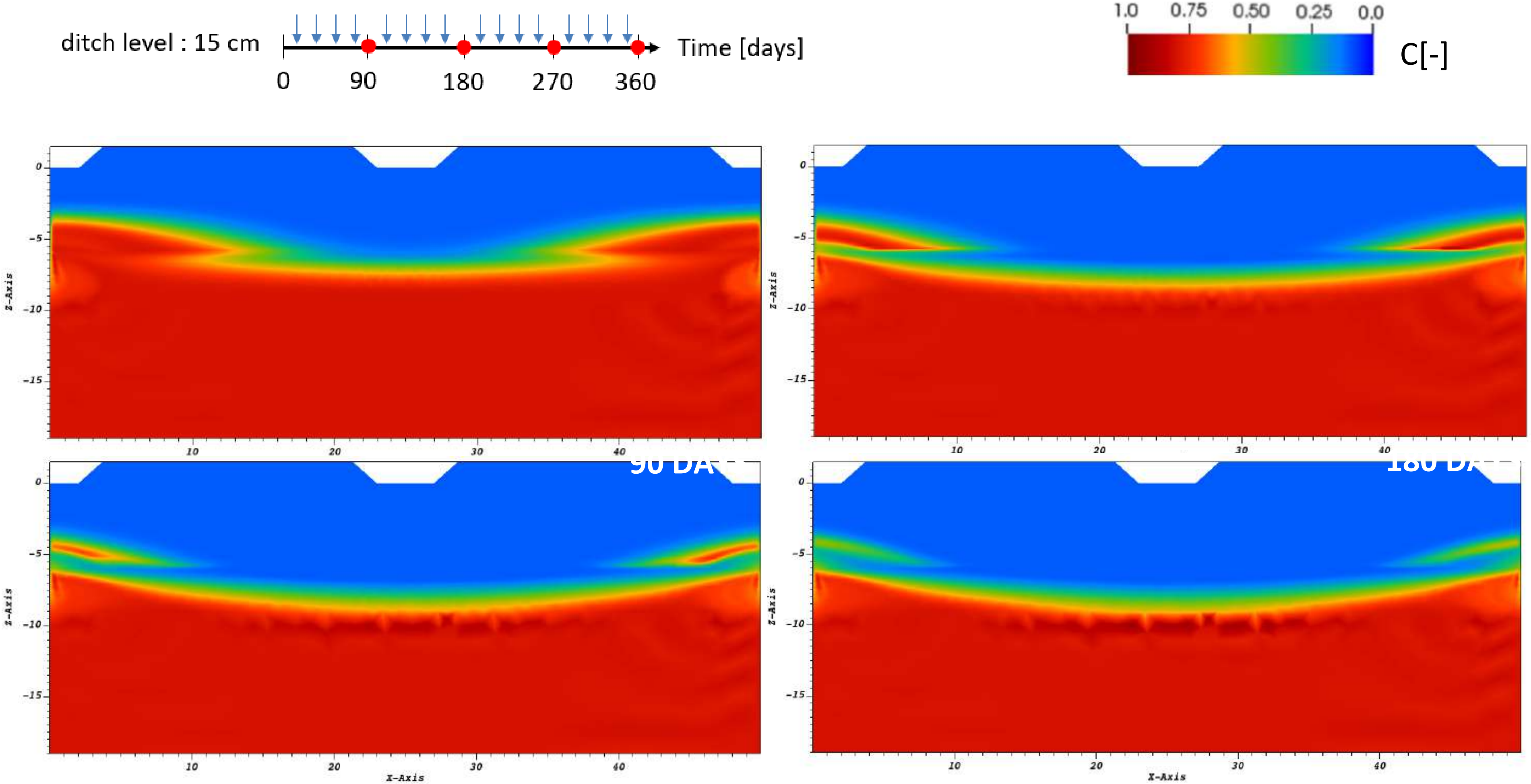


Figure 22 – Model B: solute concentration on a vertical section through the barycenter of the model after 3, 6, 9 and 12 months of aquifer recharge with h = 15 cm and constant recharge during the simulation time.

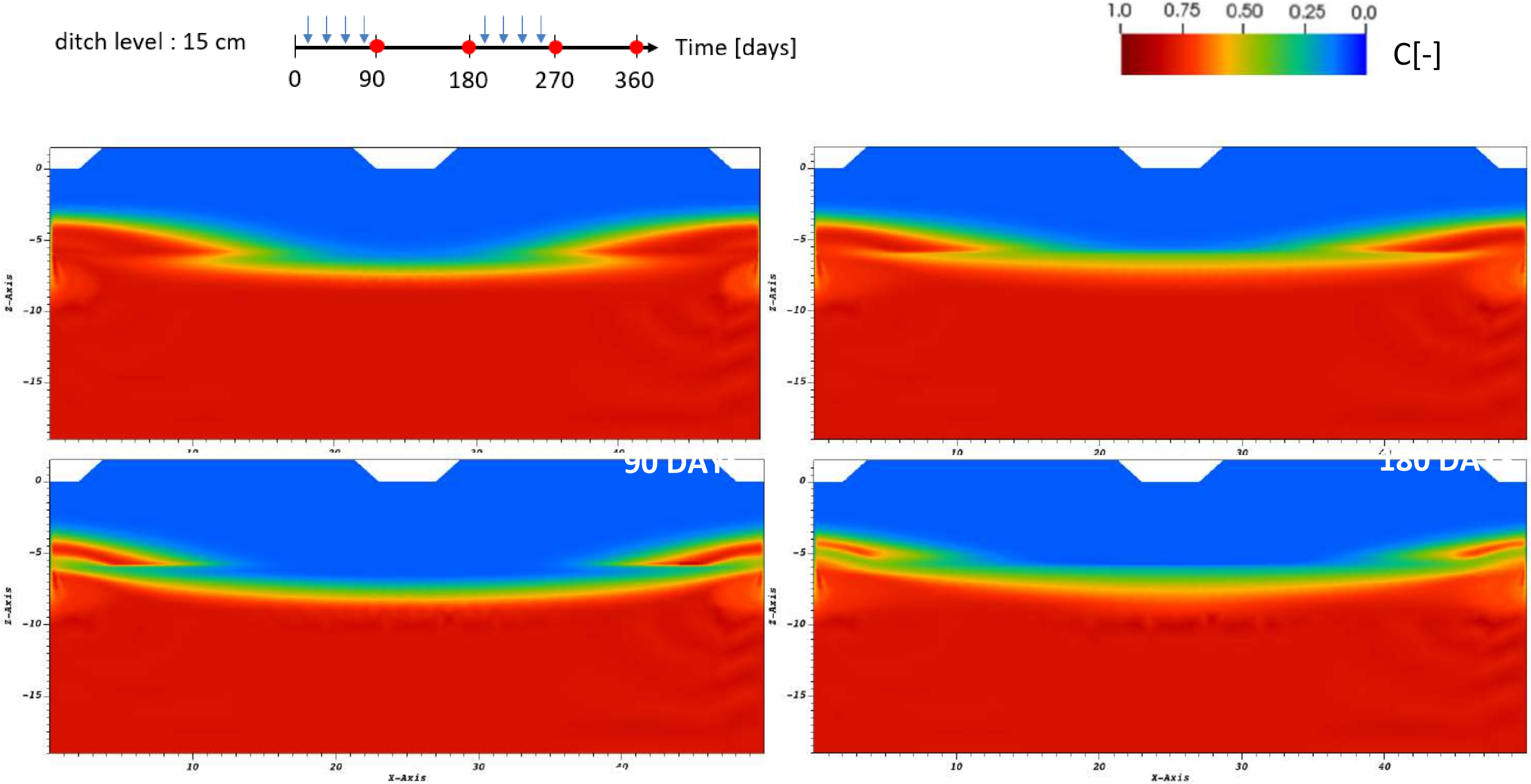


Figure 23 – Model B: solute concentration on a vertical section through the barycenter of the model after 3, 6, 9 and 12 months of aquifer recharge with h = 15 cm and seasonal recharge during the simulation time.

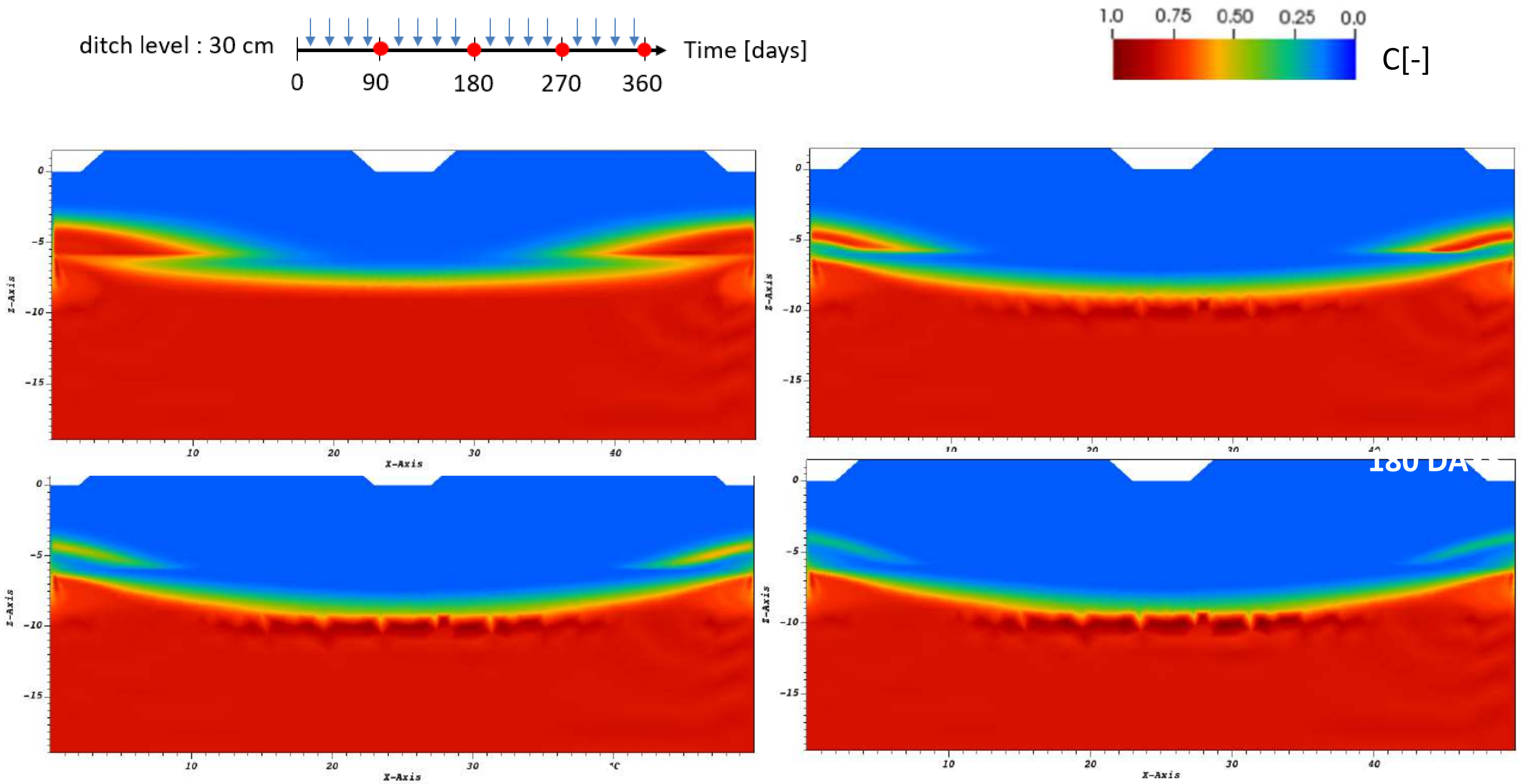


Figure 24 – Model B: solute concentration on a vertical section through the barycenter of the model after 3, 6, 9 and 12 months of aquifer recharge with h = 30 cm and constant recharge during the simulation time.

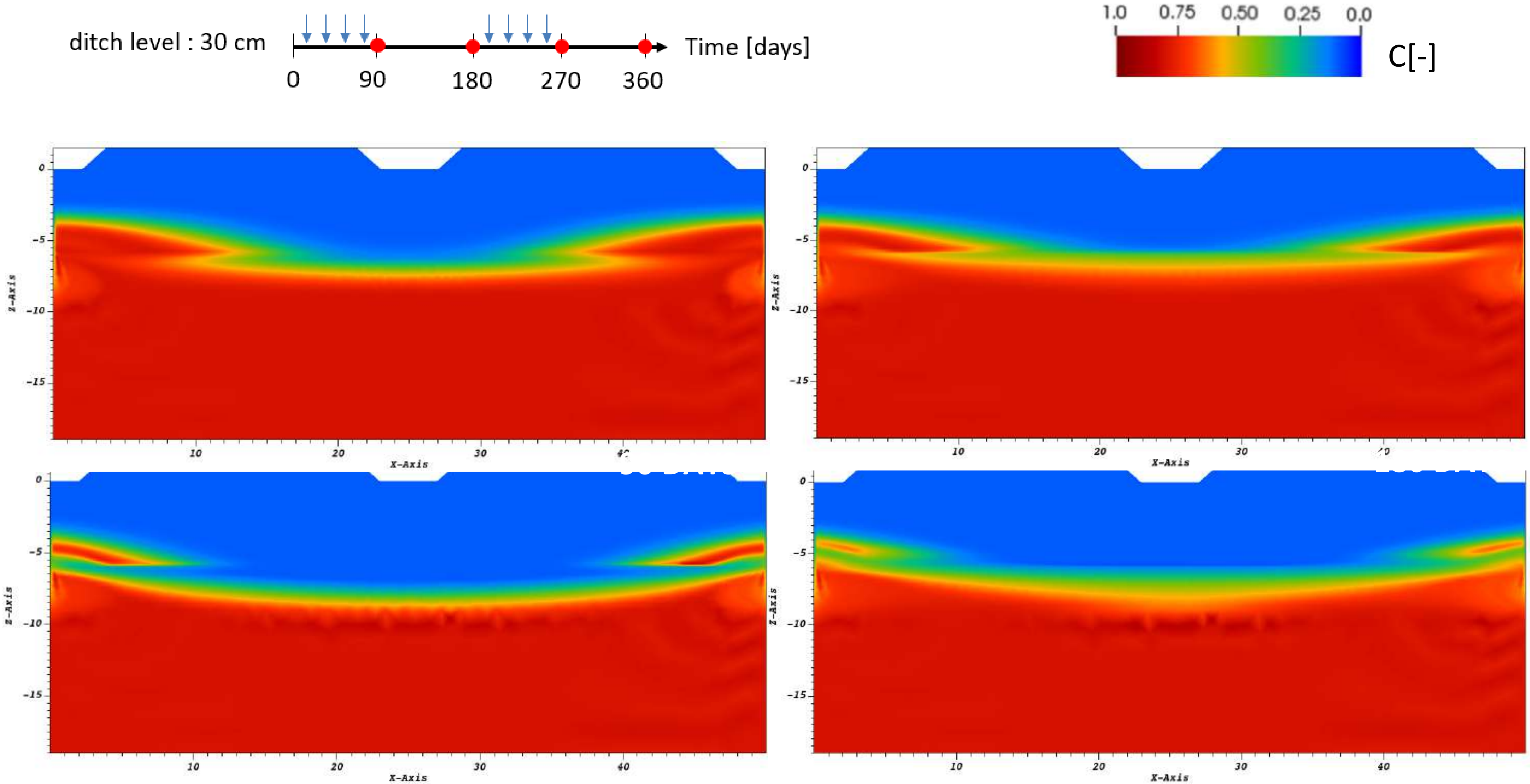


Figure 25 – Model B: solute concentration on a vertical section through the barycenter of the model after 3, 6, 9 and 12 months of aquifer recharge with h = 30 cm and seasonal recharge during the simulation time

4.6 Conclusion

In this work was implemented two simplified conceptual models of local interventions in the Ravenna coastal area. The purpose is to test the effectiveness of these local interventions in counteracting saltwater intrusion at our test site.

A state-of-the-art three-dimensional finite element model has been developed and used to predict the possible effects of artificially recharge the upper aquifer in the Ravenna area.

A set of scenarios of artificial aquifer recharge has been performed for every developed model. The freshwater provided by Lamone River has diverged in the two test sites ad used to create a natural infiltration system (pond/ditch).

Several scenarios have been performed to investigate the effect of the recharge in relation to:

- the freshwater level on pond/ditch ;
- the type of recharge to simulate constant or seasonal infiltration (time-varying recharge);
- the effect of sea-level rise due to climate change (projected to the year 2100)
- the uncertainty in the aquifer characterization represented by the dispersity parameters.

The model has allowed performing some evaluations about the effectiveness of the aquifer recharge to:

1. store freshwater;
2. use the aquifer recharge to contrast the aquifer salinization.
3. clean the surface soil for agricultural purposes;

The results have been presented in terms of vertical sections of salt concentration over the 6-months or 1-year periods spanned by the simulations. If the volume of water made available is sufficient, it is possible to produce significant effects on the targeted aquifer and improve the level of quality of the soils and waters therein. The recharge water accumulates at the top of the aquifer, generating a compact volume of freshwater that can potentially contrast the saltwater intrusion. Due to a natural subsurface flow regime characterized by average velocities, the freshwater volume moves eastward (inland) and the mixing zone between the brackish and the fresh waters can remain relatively narrow.

The analyses here presented must be considered as preliminary results, i.e. they constitute a sort of feasibility study that must be followed by a definitive and an executive project for the optimal planning and built-up of a real system to manage aquifer recharge.

4.7 Implementation of the adaptation plan

This chapter describes Ravenna's adaptation plan, which will be integrated with the adaptation measures proposed in the municipal strategic planning (PAESC and PUG).
The new Covenant of Mayors (the PAESC) reconfirms the key role recognized to the cities in the fight against climate change through the implementation of local policies that have as reference the climate and energy.

The Ravenna municipality its own PAESC structured on three specific documents:

1. Mitigation - Analysis of mitigation actions detected in the territory. Through the involvement of numerous local stakeholders, it testifies to the achievement of the target of 40% reduction in CO_2eq balance on the time horizon to 2030.
2. Adaptation - the second document is related to the strategy of adaptation to climate change. In this section are identified the main environmental risks and vulnerabilities of the territory in order to elaborate possible strategic choices aimed at increasing the resilience of the Municipality of Ravenna and its community against climate change already in place.
3. Adaptation Actions - the third and last document collects the Adaptation Actions and the territorial vision for a resilient, adaptive, and not fragile Ravenna.

Figure 26 reports a schematic plan of adaptation action in Ravenna municipality.

Figure 27 summarizes the interventions developed for the implementation of the adaptation plan.

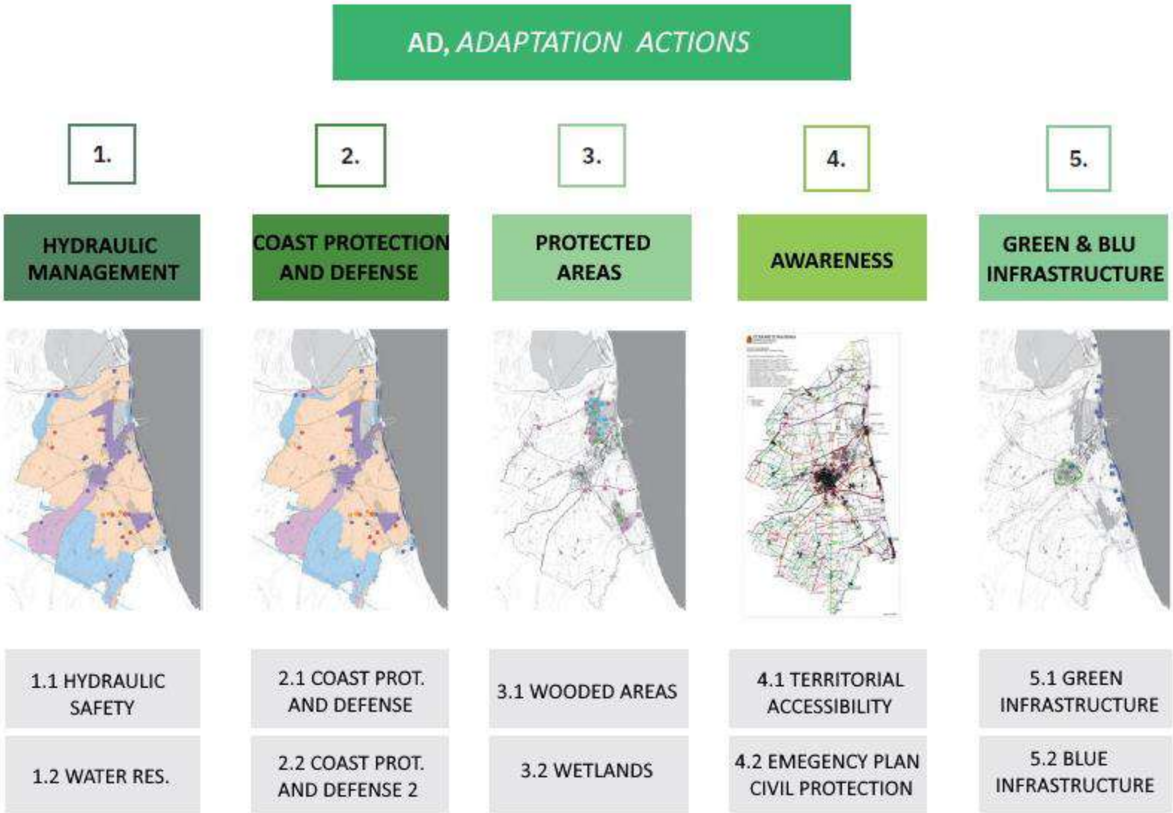


Figure 26 – Adaptation Actions in Ravenna Municipality

Hydraulic Management (AD 1): The hydraulic management represents all the coordinated set of actions aimed at the defense from the hydraulic risk as well as the distribution and saving of water resources, coastal protection and management of transitional waters, the management of transitional waters. Due to their valley nature, in these places adaptation actions have always been in place to defend and regulate water aimed at the defense and regulation of water.

Coast protection and defense (AD 2): The theme of protection and safeguard of the coast is a fundamental priority for the defense of the territory subject to phenomena of subsidence, erosion, marine ingression, as well as hydrogeological problems, criticality further amplified by the extent of the coastal strip of the municipal territory.

Adaptation Action				
SECTOR	COD.	TITLE	CONTENT	RISK
1. HYDRAULIC MANAGEMENT	AD. 1.1	HYDRAULIC SAFETY	WORK AND PROGRAMMING ON EMBANKMENTS AND CHANNELS, LAMINATION TANKS, FACILITIES	HYDRAULIC RISK, EXTREME WEATHER EVENTS, SUBSIDENCE
	AD. 1.2	WATER RESOURCE: DISTRIBUTION, WATER SAVING, AQUIFER RECHARGE	WORKS AND PROGRAMMING ON DISTRIBUTION WATER LINE AND IRRIGATION NETWORK	EXTREME WEATHER EVENTS, DROUGHT, SALT WEDGE
2. COAST PROTECTION AND DEFENSE	AD. 2.1	SAND REPLENISHING	BEACH NOURISHMENT AND REPOSITIONING OF SAND FROM THE CLEANING OF SANDY SHORES	COASTAL EROSION, SUBSIDENCE. MARINE INGRESSION, SALT WEDGE
	AD. 2.2	EMBANKMENTS AND SEA PROTECTIONS	STRENGTHENING OF EMBANKMENTS AND PROTECTION SEA BARRIERS	COASTAL EROSION, SUBSIDENCE, MARINE INGRESSION
3. PROTECED AREAS	AD. 3.1	WOODED AREAS	STUDIES AND INTERVENTIONS AIMED AT MAINTAINING AND IMPROVING ENVIRONMENTAL CONDITIONS IN WOODED AREAS AND NEIGHBOURING	COASTAL EROSION, SUBSIDENCE, FOREST FIRE, SALTWATER INSTRUSION
	AD. 3.2	WETLANDS	STUDIES AND INTERVENTIONS AIMED AT MAINTAINING AND IMPROVING THE ENVIRONMENTAL CONDITIONS OF WETLANDS	SUBSIDENCE , SALTWATER INSTRUSION, DROUGHT
4. PUBLIC AWARENESS	AD. 4.1	TERRITORIAL ACCESSIBILITY	TERRITORIAL ACCESSIBILITY IN AREAS OF NATURALISTIC VALUE AND PROJECTS TO IMPROVE THE USE OF THE TERRITORY	FOREST FIRES, HYDRAULIC RISK
	AD. 4.2	CIVIL PROTECTION	EMERGENCY PLANS AND PUBLIC AWARENESS	EXTREME WEATHER EVENTS, HEAT ISLAND, FOREST FIRES, HYDRAULIC RISK OF MARINE INGRESSION

5. GREEN AND BLUE INFRASTRCTURE	A D 5.1	GREEN INFRASTRUCTURE	INTERVENTIONS AND ACTIVITIES CARRIED OUT FOR THE QUALITY AND SAFETY OF URBAN GREEN, PERMEABILITY AND SOIL HEALTH	HEAT ISLAND, EXTREME WEATHER EVENTS, DROUGHTS
	A D 5.2	BLUE INFRASTRUCTURE	INTERVENTIONS AND ACTIVITIES CARRIED OUT TO REHABILITATE, CONSOLIDATE AND RECONFIGURE THE SYSTEM OF THE MAIN RIVERS, CHANNELS AND COASTLINE	HYDRAULIC RISK, COASTAL EROSION, EXTREME WEATHER EVENTS, FOREST FIRES, SALT WEDGE, SUBSIDENCE

Protected areas (AD 3) and Awareness (AD 4): The Ravenna territory is characterized by the presence of an extraordinary variety of landscapes and natural habitats derived from the interaction between the natural evolutionary processes of the territory and human activities. This combination factor has led to the creation of a unique environment, where together with extraordinary ecosystems, there is evidence of an important historical and cultural presence.
The most important elements, from the ecological point of view, are constituted by:

- brackish lagoons and transitional environments, such as the Pialassa Baiona, the Pialassa Piomboni, the Ortazzo complex, Ortazzino, Foce del Torrente Bevano;
- wet meadows, swamps and hygrophilous woods such as Punte Alberete, Valle Mandriole and the meadow of Bardello;
- mixed thermophilic, mesophilic and xerophilic forests such as the coastal pinewoods and the historical pinewoods of San Vitale and Classe, and the remaining coastal dunes.

Over time, these areas of great naturalistic-environmental importance have been increasingly isolated from the environmental conditions from which they originated. This situation, which does not concern only the Ravenna area, implies the need to constantly intervene with actions that allow the maintenance of these systems in the natural conditions they are intended to safeguard, preserve and protect.

Green and Blue infrastructure (AD 5): The green infrastructure is a multifunctional network that performs many functions:

- ecological because it connects natural and semi-natural elements (waterways canals vegetated areas and permeable areas);

- landscape and historical-cultural because it connects open spaces, historical and cultural heritage and green areas (squares, monuments, gardens, parks, etc.).
- of accessibility and public use because it connects recreational and working activities in safety through pedestrian and bicycle paths;
- of connection with the peri-urban spaces because it integrates the countryside and the urban environment.

The green areas are associated with the blue element (rivers, wetlands, waterways, and coastline) that work together to define a real infrastructure system that is articulated in a widespread and capillary way in the territory.

The permeability of soils is essential to ensure integrated management of risks and numerous ecosystem services provided by the hydro-geological system, point of contact of the blue infrastructure and green infrastructures.

In this perspective, a systemic and integrated approach of water and soil management brings benefits such as:

- aquifer recharge;
- reduction of the heat island phenomenon, improving the local microclimate;
- reduction of surface run-off (water stagnation during extreme weather events);
- improving the health of soils, ecological components and habitats that can support (obtaining useful surface for planting trees and vegetation in general)
- improvement of ecological endowments

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