D.5.1.2. Report on Best practices

Document Control Sheet

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Author (s)	Renzo Brunori, Davide Frulla (Comune di Fano) Nicola Quaranta, Elena Cogo (Geo Engineering – External Assistance)
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1. Introduction

This report is identified on the basis of the results of the studies of WP3 “Modelling present and future salt ingression in Adriatic coastal” and of WP4 “Identifying needs and barriers in coastal aquifer management”.

Best practices could be implemented in order to response to the priority issues identified in the report D.5.1.1 – Priority issues.

The analysis was based on case studies outputs and on further situations in similar conditions, also out of the study area, all around the world. Have also been identified examples, useful for the evaluation and admissibility of new requests for water concession acts in coastal aquifers zones subjected to salt intrusion risk.

2. Best practices for lowering fresh water and salt water interface

2.1. Physical barriers

Physical barriers are constructed parallel to the coast and consist of a low-permeable material (such as steel or concrete) that acts to block the intrusion of saltwater into the aquifer.

The construction of subsurface physical barriers is one of various methods used to control seawater intrusion in coastal aquifers. The results of many studies and experiments show that the MPB induced a visible lifting of the dense saline flux upward towards the outlet by the light freshwater.

Actually 3 types of physical barriers are most commonly used:

- Cut-off walls extend from the top of the aquifer to a predefined depth.
- Coastal Land Reclamation that involves the artificial extension of the coastline towards the sea. In this technique, new land is introduced by artificial filling of the appropriate type of soil at the desired geometry and slope.

- Subsurface dams: are imbedded in the impervious bottom layer of the aquifer only obstructing the lower part and allowing the natural discharge of freshwater to the ocean above.
- Mixed system of (Mixed Physical Barriers) thar combines an impermeable cutoff wall and a semi-permeable subsurface dam.

Geochemical barriers have also been experimentally tested, with dedicated field-tests, in order to verify their efficiency in response to chemical reactions.

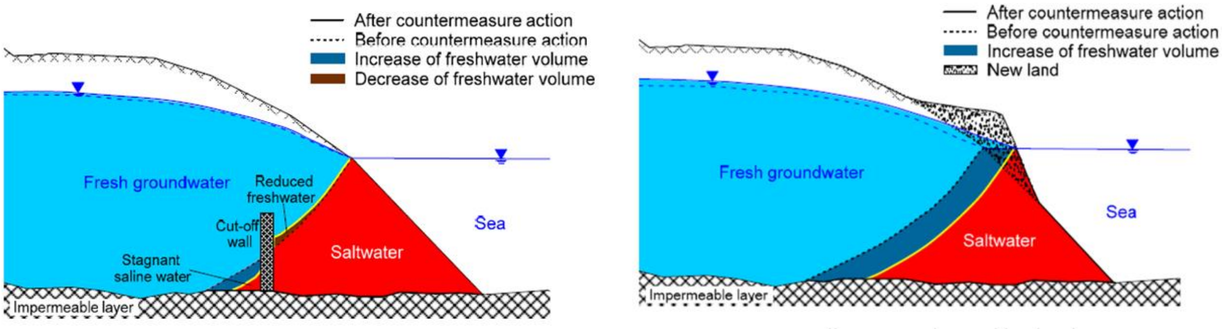

Figure 1: Schematization of cut-off wall (to the left) and land reclamation to the right (*Management of Seawater Intrusion in Coastal Aquifers: A Review* - Mohammed S. Hussain et al. – 2019)

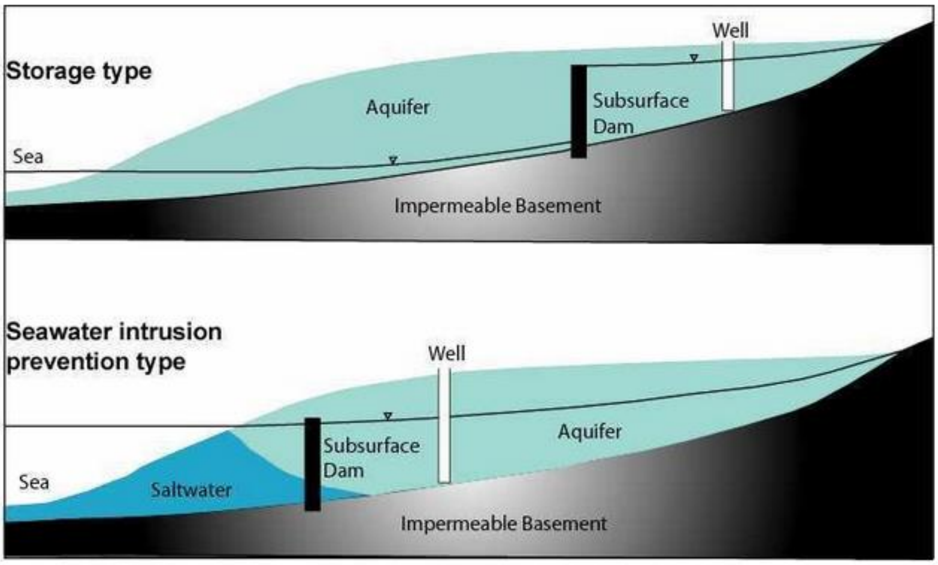

Figure 2: Schematization of sub surface dam (*Management of Seawater Intrusion in Coastal Aquifers: A Review* - Mohammed S. Hussain et al. – 2019)

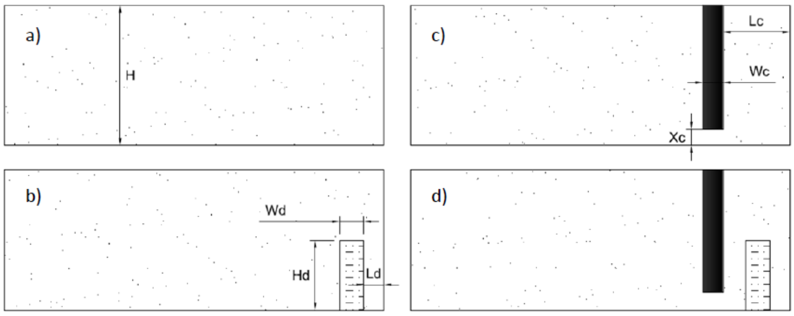

Figure 3 Investigated cases: a) baseline case; b) subsurface dam case; c) cutoff wall case; d) MPB case. The freshwater flows from left to right.

Figure 3: Example of experimental application of dam, cut-off wall and MPB (*A new physical barrier system for seawater intrusion control* - Antoifi Abdoulhalik, Gerard Hamill - Article in Journal of Hydrology - April 2017)

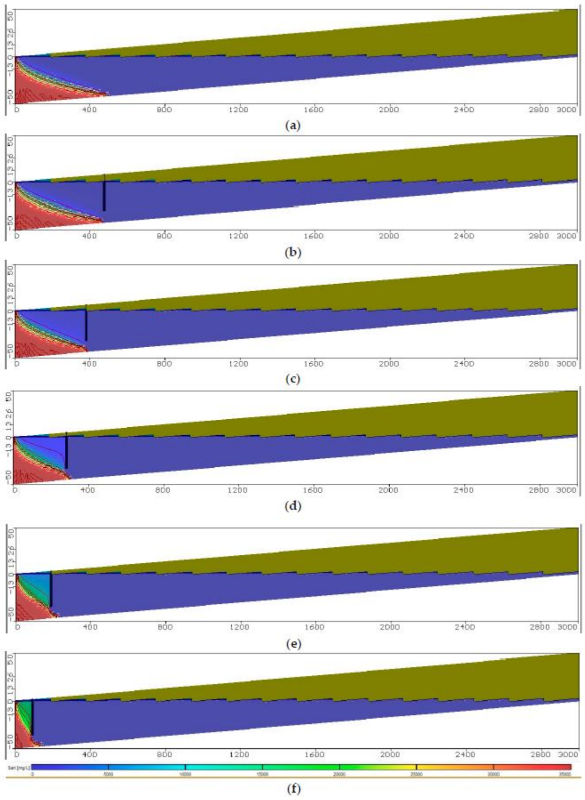

Figure 12. Saltwater distribution (in mg/L) in the Akrotiri aquifer for **(a)** the steady state and embedded barrier wall with $d_b/d = 0.7$ and **(b)** $X_b/L_o = 1.0$, **(c)** $X_b/L_o = 0.8$, **(d)** $X_b/L_o = 0.6$, **(e)** $X_b/L_o = 0.4$ and **(f)** $X_b/L_o = 0.2$.

Figure 4: Effects of the hydraulic barrier on the saline wedge based on its location (*Underground Barrier Wall Evaluation for Controlling Saltwater Intrusion in Sloping Unconfined Coastal Aquifers* - Asaad M. Armanuos et al. – 2020)

2.2. Hydraulic barriers (artificial recharge)

Hydraulic barriers can be divided into positive, negative and mixed barriers.

- In <u>positive barriers</u> freshwater is injected through recharge wells into the aquifer to raise the water table thus impeding the inland motion of saltwater.
- <u>Negative barriers</u> involve the interception of the intruding saltwater by pumping near the coast.
- A <u>mixed hydraulic barrier</u> combines a positive barrier and a negative barrier injecting freshwater inland to repulse the saltwater wedge and extracting saltwater near the shore to slow its advancement. In mixed hydraulic barriers can be combined continuos abstraction of saltwater, desalinization (with reverse osmosis plant), use of treated waters for low-valuable purpose and artificial recharge (injection wells or recharge pond).
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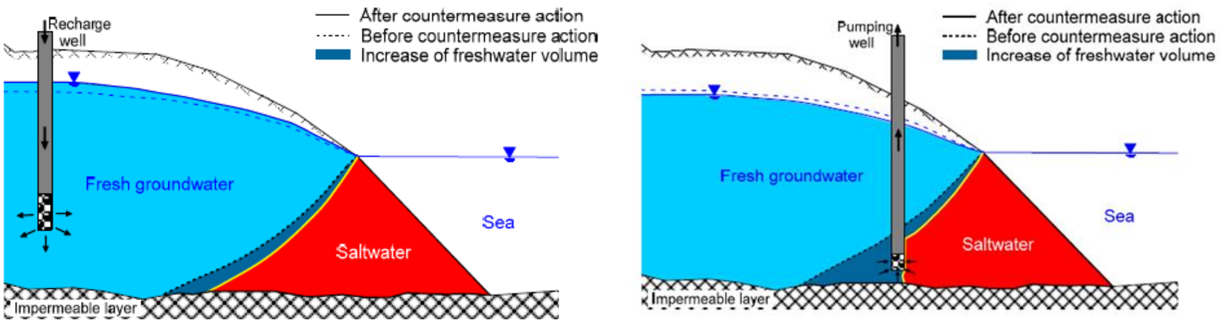


Figure 5: Example of hydraulic barrier: positive to the left and negative to the right, (*Management of Seawater Intrusion in Coastal Aquifers: A Review* - Mohammed S. Hussain et al. – 2019)

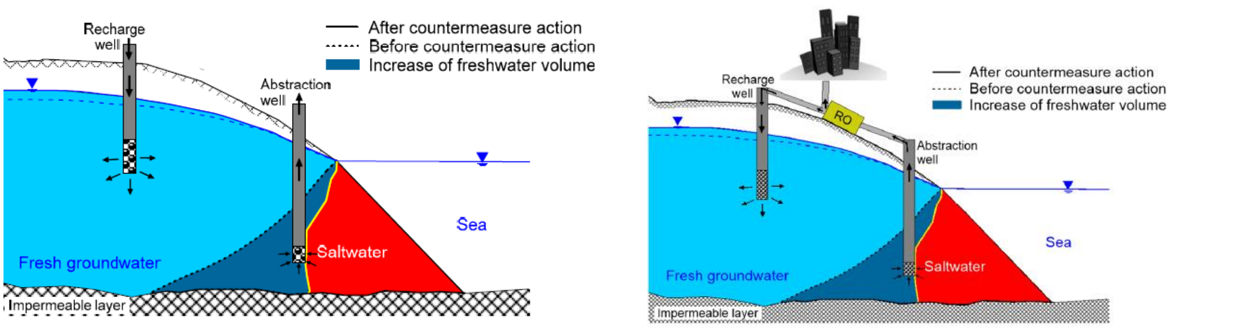


Figure 6: Example of mixed hydraulic barrier (*Management of Seawater Intrusion in Coastal Aquifers: A Review* - Mohammed S. Hussain et al. – 2019)

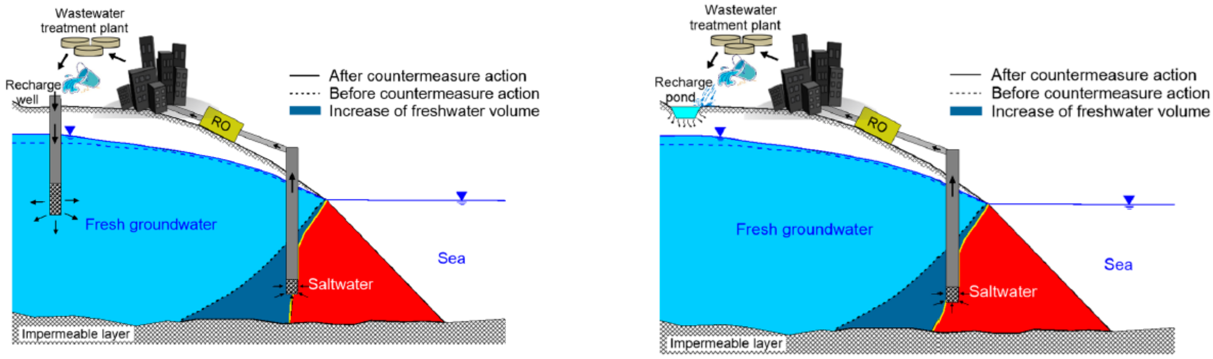


Figure 7: schematic sketches of mixed hydraulic barrier with Abstraction, Desalination, and Recharge by treated wastewater (*Management of Seawater Intrusion in Coastal Aquifers: A Review* - Mohammed S. Hussain et al. – 2019)

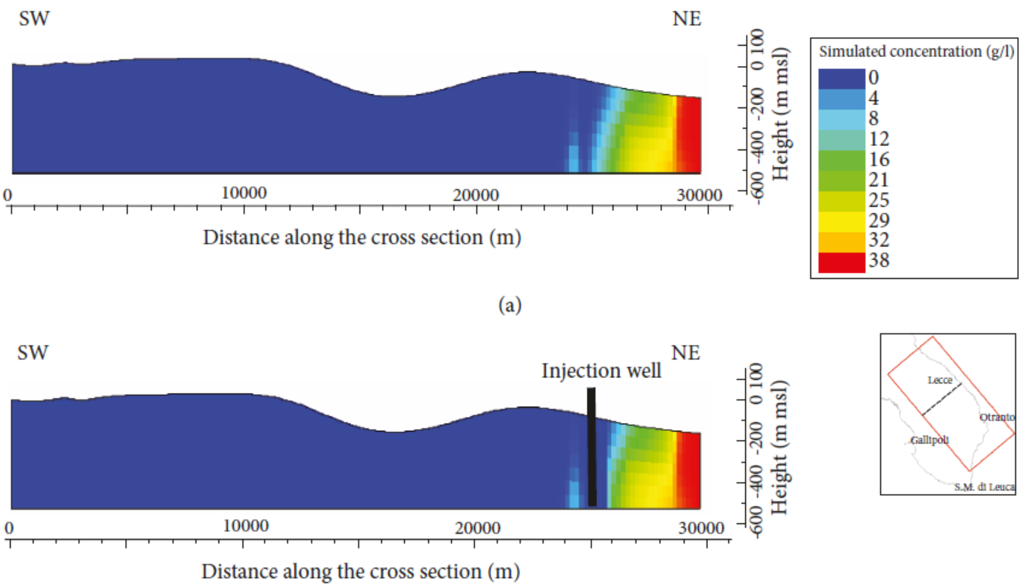


Figure 8: Natural condition and injection wells of treated waste-water (*A Modelling Approach for Assessing the Hydrogeological Equilibrium of the Karst, Coastal Aquifer of the Salento Peninsula (Southeastern Italy): Evaluating the Effects of a MAR Facility for Wastewater Reuse*" - Giovanna De Filippis et al. - 2019)

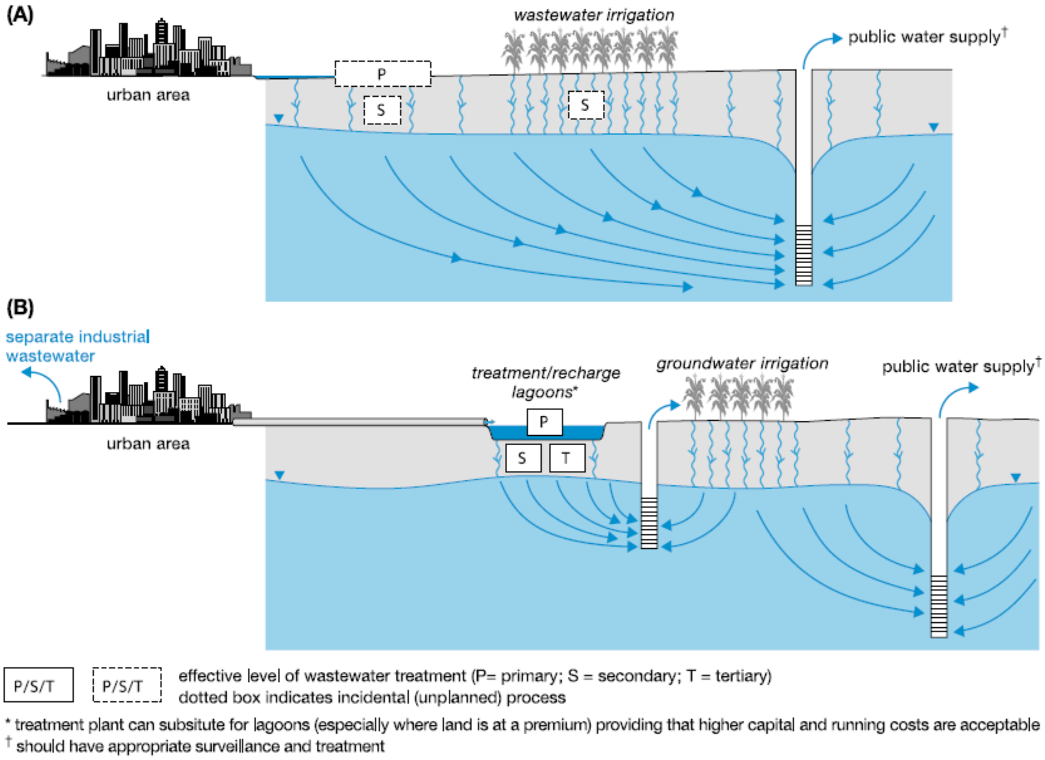


Figure 9: General scheme of wastewater generation, treatment, reuse and infiltration to aquifer (*Urban Wastewater as Groundwater Recharge - evaluating and managing the risks and benefits* - Stephen Foster at all, 2015)

3. Best practices for allow the retreat of the saline wedge in surface waters

In order to prevent the intrusion of the saline wedge through surface waters is applicable the construction of control sctucture that can effectively prevent the inflow of seawater into the basin, such as movable barrage or bridges with mobile weir.

The barrage acts as a sea dike that helps to decrease of the salinity of water upstream.

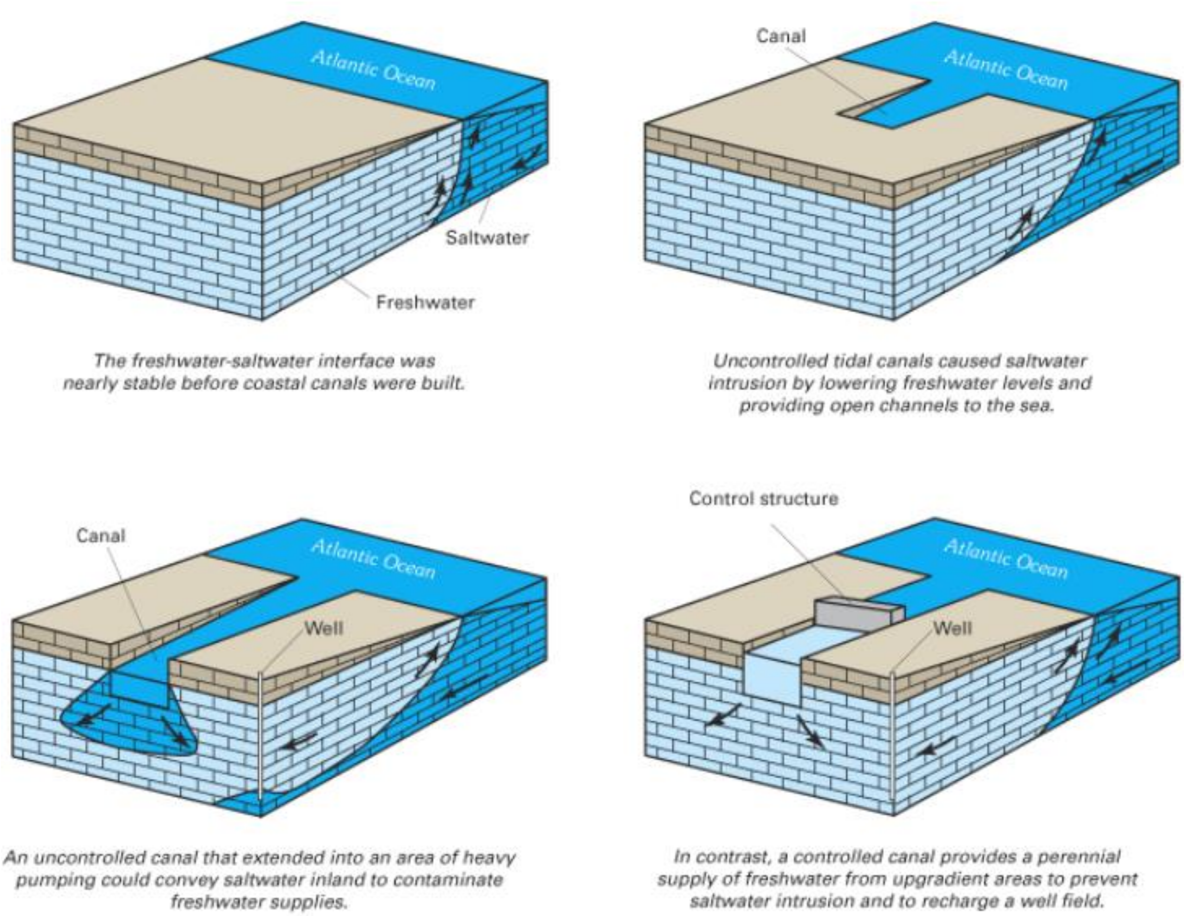


Figure 10: Scheme of control structures placed on the southeastern Florida canals to prevent inland migration of seawater, as well as to provide flood protection and artificial recharge to the aquifer (*Ground Water in Freshwater-Saltwater Environments of the Atlantic Coast* - Paul M. Barlow - 2003)

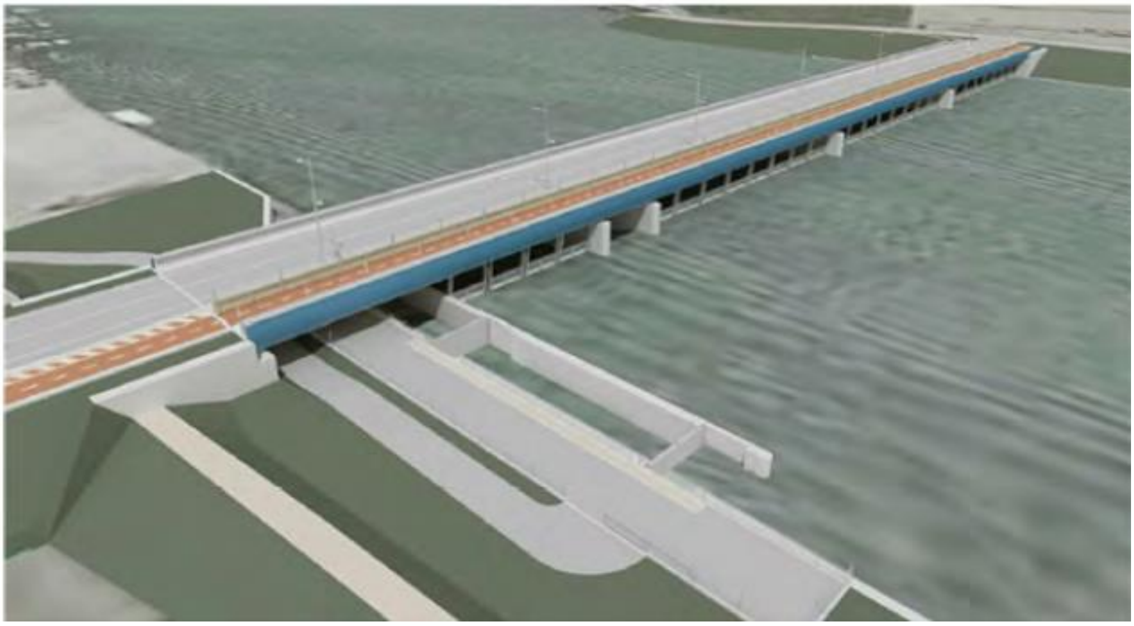


Figure 11: Saltwater barrage in Brenta river (*Laboratory experiments on the saltwater intrusion process* - Erika Bertorelle PhD, Padua University – 2014)

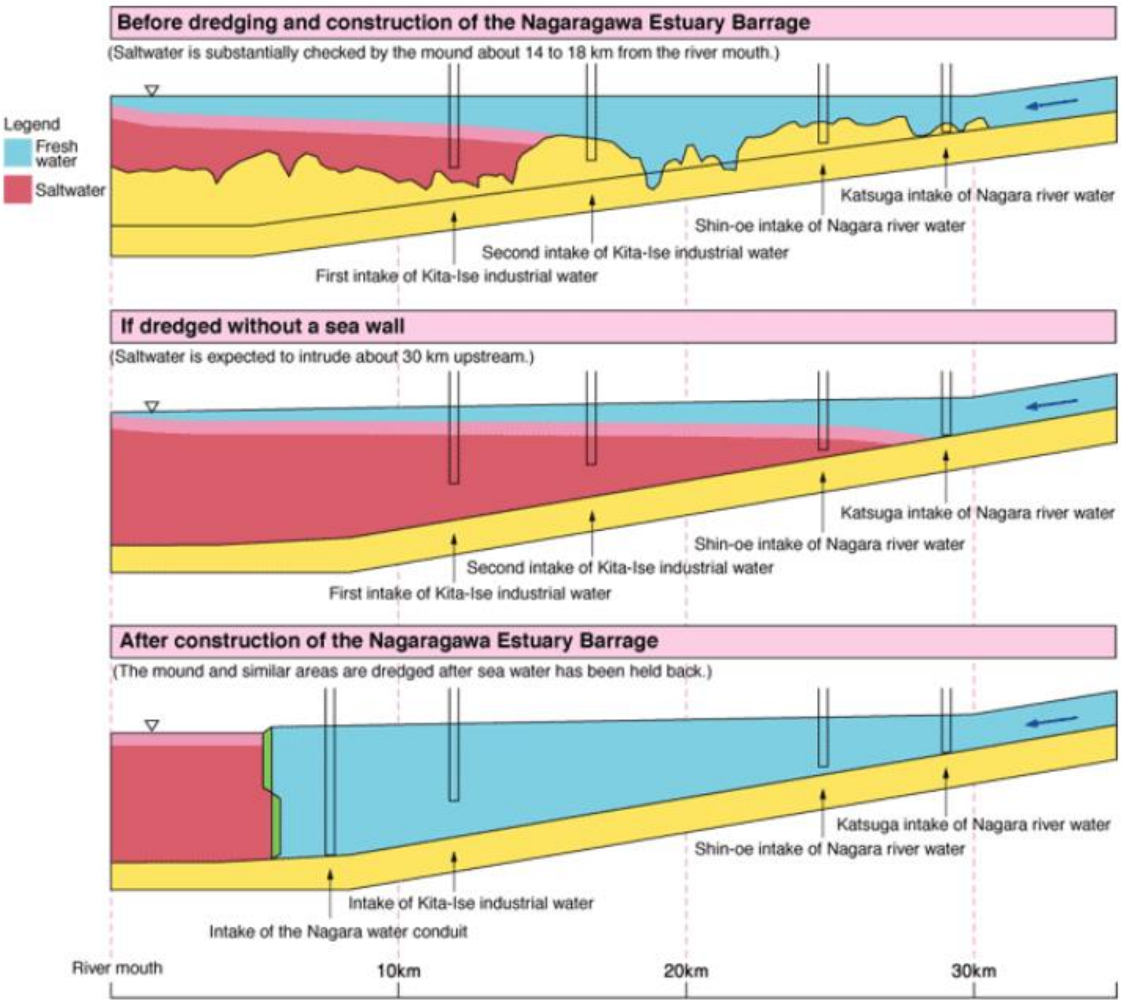


Figure 12: Example of decrease of salinity of water upstream of the barrage after dredging of the Nagara River and Prevention of Saltwater Intrusion - 1995/1997 (https://www.water.go.jp/chubu/nagara/27_english/04/03/index.htm)

4. Best practices for setback of the coast line

The erosion of coast line could be distinguished in:

1. Acute erosion linked to storm damages
2. Chronic erosion linked to shoreline recession

The best practices to be implemented in the first case are:

- Protection against wave attack
- Increase sediment storage
- Fixing the coastline
- Protect hinterland

The chronic erosion could be solved by:

- Supply sand to the dunes
- Improve protective role of natural structure

In both cases, a series of mitigation measures are feasible, using hard or soft solutions.

HARD SOLUTIONS	SOFT SOLUTIONS
Offshore breakwaters	Costal dune protection and restoration
Groynes	
Seawall/revetements	Cliff stabilization
Dikes	

4.1. Hard solutions

<u>Offshore breakwater</u> systems provide shoreline protection by intercepting incoming waves and creating stable pocket beaches between the fixed stone structures, or "headlands".

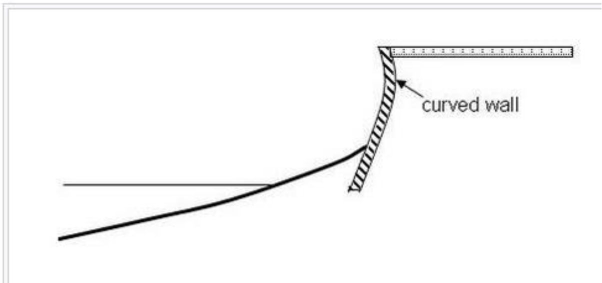
Figure 13: Artificial reef offshore breakwater at Sea Palling on the Norfolk Coast

Figure 14: Artificial reef offshore breakwater at Fano in 2002 and in 2020

Groynes are narrow, shore-perpendicular hard structures designed to interrupt longshore sediment transport by trapping a portion of the sediment that would otherwise be transported alongshore. By doing so, groynes help to build and stabilize the beach environment. Groynes are generally solid, durable structures and are considered a hard-engineering protection measure. Groynes are normally built on exposed and moderately exposed sedimentary coastlines to address erosion hazards. They can be constructed from a wide variety of materials including rock armour, concrete, dolos, tetrapods, steel piling and hardwood timber.

Figure 15: Rock groynes in Nederlands

<u>Seawalls</u> are vertical walls built to delineate the border between sea and land, in an area where the upland contains infrastructure that requires protection from storm surge and wave overtopping during an extreme storm event.



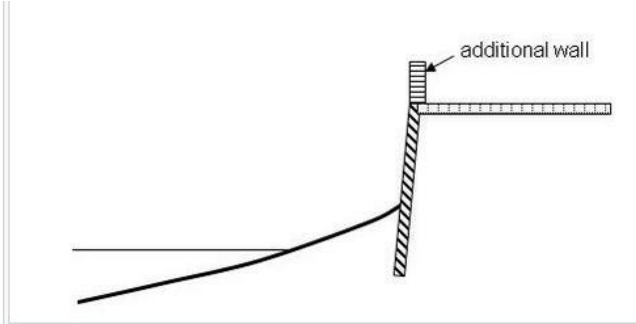


Figure 16: Seawall in Miami beach (USA)

Sea dikes are onshore structures with the principal function of protecting low-lying areas against flooding. Sea dikes are usually built as a mound of fine materials like sand and clay with a gentle seaward slope in order to reduce the wave runup and the erodible effect of the waves.

The surface of the dike is armored with grass, asphalt, stones, or concrete slabs (USACE, 2005).

Figure 17: Example of a dyke in German island of Pellworm

4.2. Soft solutions

An important approach is the implementation of measures to protect and restore the dune systems, based on naturalistic engineering techniques, in particular a combination of:

- construction of naturalistic engineering works (windbreak barriers, walkways for access management, …) to protect ad allow natural rebuliding,
- renaturalization of the dune bars,
- planting of pioneer species, which stabilize the dune and retain the sand,
- artificial dune rebuilding with for imported sand

Figure 18: San Rossore dune with wooden pedestrian walkway and revegetation with plioneer plants (Boccalaro, 2008)

Figure 19: Naturalistic engineering interventions in Circeo National Park with windbreak barriers (Onori. 2008)

Figure 20: Planting in Cala Mesquida dunes (Maiorca. 2010)

5. Best practices for improve knowledge of aquifer salinization

Implementing a monitoring system is essential to reach a basic level of knowledge to make choices and orientations in the context of an adaptation plan.
In particular an integrated monitoring devices of coastal water resources, headed by coordinated control bodies, with continuous instruments in order to:

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

They must be able to perform a real-time monitoring and operational planning in case of exceeding of threshold values of salt intrusion in coastal areas.
Monitoring systems must be able to integrate measures of:

- aquifer phreatimetry / pressure,
- electrical conductivity,
- hydro-chemical and physical characteristics of water (isotopes, age, temperature),
- tidal measurements,
- rainfall,
- geophysical measurements.

The implementation of measurement transepts with cluster points of piezometric level and electrical conductivity measure is useful in order to:

- Check the mineralization of the aquifer at increasing depths, recognize the origin of the saline water with isotope and age analysis;

- Monitoring the evolution of the interface area following the introduction of "Best Practices" (to verify the increase or reduction of the salinization of aquifers).

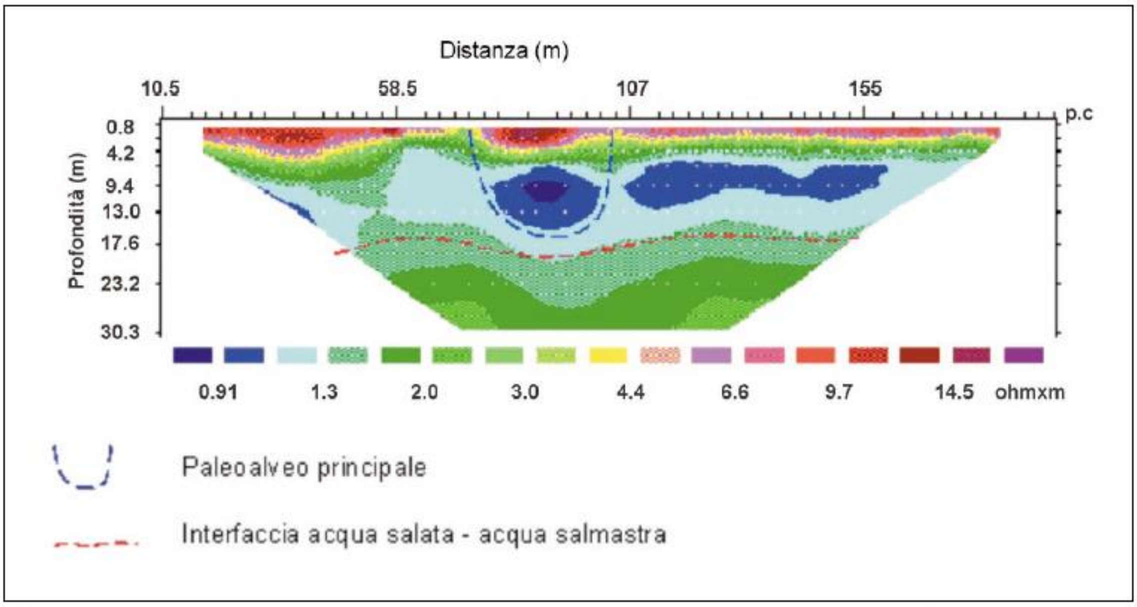


Figura 2.27 – Interpretazione del modello derivante dalla inversione dei dati per la Sezione Gorzone 2, rielaborata con classi di resistività più dettagliate rispetto a quella riportata in Tavola 9.

Figure 21: Example of geophysical measures (*The ISES project for process analysis of saline intrusion and subsidence in the southern territories of the provinces of Padua and Venice* - Laura Carbognin and Luigi Tosi CNR - 2003)

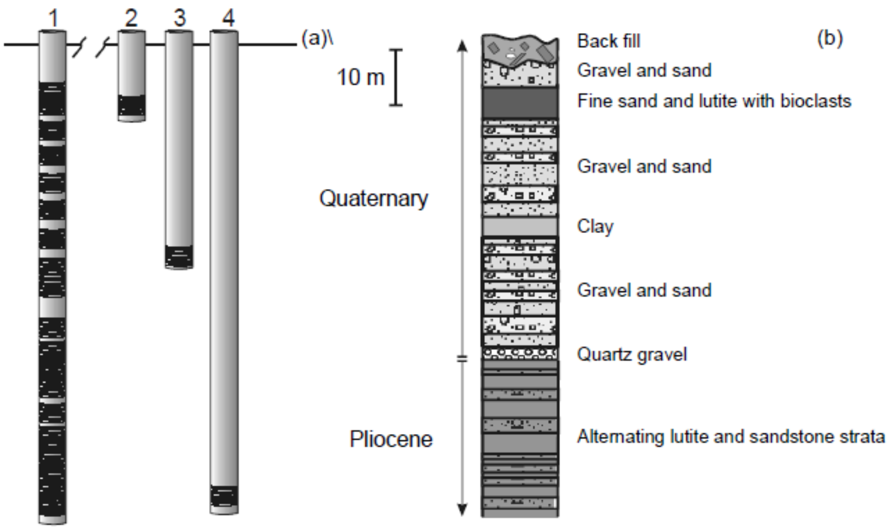


Figure 22: Piezometric cluster in order to check the mineralization of the aquifer at increasing depths (modified from Pulido-Bosch et al, 2002)

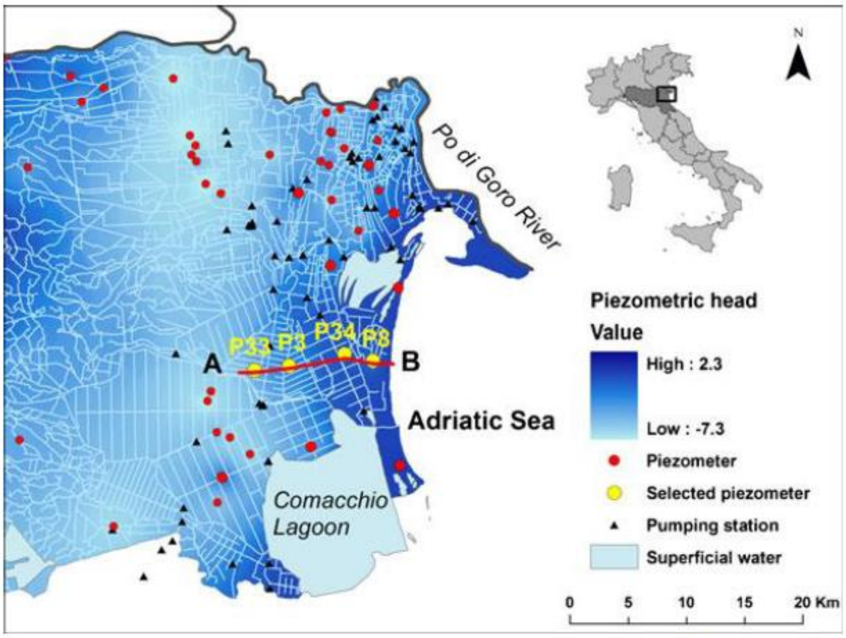


Fig. 1: Location of the study area with the piezometric contour map, canals network and borehole locations; in yellow the selected piezometers along a flow line (AB).

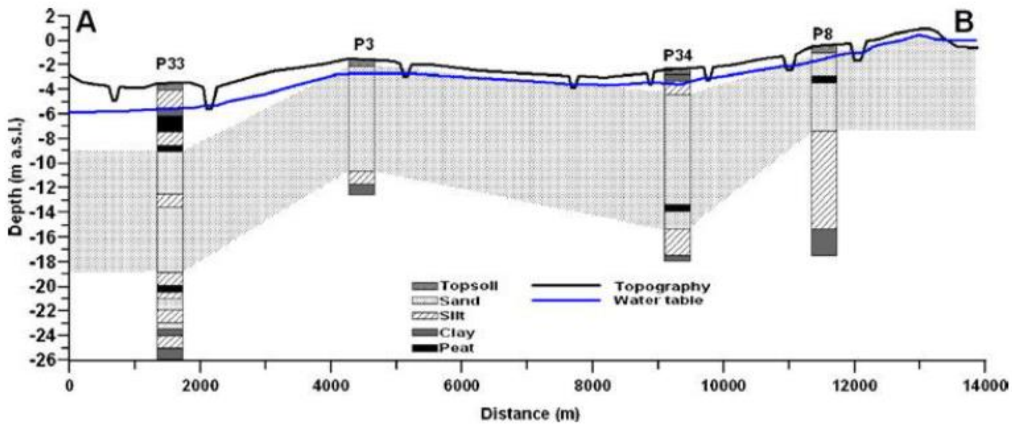


Fig. 2: Transect AB (refer to Fig. 1 for the location). Topography (DEM data), water table (monitoring data of November 2010), sandy aquifer thickness (dotted region) and stratigraphy (core logs data) are shown.

Figure 23: Example of a transept measure (*The Importance of Data Acquisition Techniques in Saltwater Intrusion Monitoring* - Mastrocicco et al – 2012)

6. Best practices for lack of planning in the following areas

The gap in planning the use of groundwater resource in coastal zone must be managed separately according to the following environment

1. Urban environment
2. Rural and agricultural environment

6.1. URBAN ENVIRONMENT

6.1.1. Re-orienteering groundwater pumping

The first step to stop groundwater overexploitation is the planning of methods, places and times of pumping, such as those listed below.

- Limitation in the use of deep wells (revision of concessions - water saving) according with IT National Environmental Law D.Lgs. 152/99, art.96 “limitations to abstractions”.
- Relocation of wells / pumping centers according with strategic planning: “PTA”, Water Management Plan III cycle 2021-2027, IT District Authorities.
- Preserve the use of fresh groundwater for valuable uses (IT-AATO), in particular human use.

6.1.2. Facilitate the storage of runoff and infiltration into the aquifer

Surface water should be managed for maximum benefit, integrating their management into the design of towns. Techniques of Sustainable drainage systems (SuDS) are various and allow reaching different multidisciplinary goals: flood protection, water quality improvement, urban restoration or biodiversity increase. In function of which goal wants to be maximized, it is possible to use simple trench filters, going through vegetated swales, up to bioretention systems, ponds, and wetlands.

In urban environment, can be hypothesized the following improvement actions:

- on-site collection, retention and reuse of the young water
- infiltration of rainwater (recharge of aquifers)

- stopping / reducing the waterproofing of urban areas
- controlled discharge into water bodies and treatment plants

Rooftop rainwater harvesting is the most common technique of rainwater harvesting (RWH), applicable at small-scale or in more sophisticated systems at large-scale. Rainwater harvesting can supplement water sources when they become scarce or are of low quality like brackish groundwater or polluted surface water in the rainy season.

The selection of the appropriate technique is based on the characteristics of the soil and of the urban context.

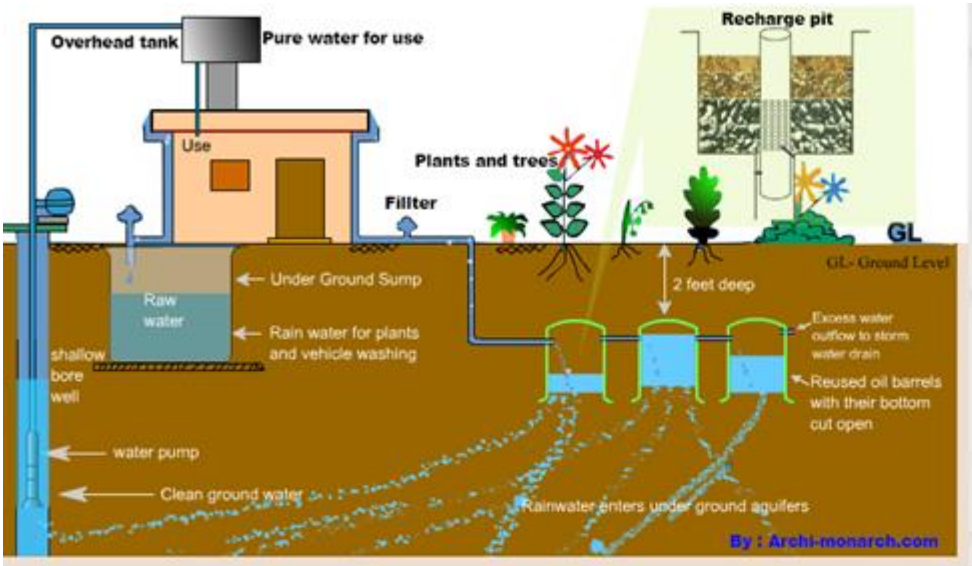


Figure 24: Example of on-site collection, retention and reuse of the young water infiltration of rainwater (recharge of aquifers) with rain water harvesting in urban area (*Norms of rain water harvesting in Haryana* – Archi Monarch - 2020)

Figure 25: Example of on-site collection, retention and reuse of the young water infiltration of rainwater with decentralised rainwater management in urban areas (*Technical Training Manual on Urban Circular Water Management for Municipalities* – Association for Rainwater Harvesting and Water Utilisation – INTERREG project – 2019)

Permeability				Selection procedure for rainwater management system	
Class	Permea-bility	k_f from	k_f to	Low area availability (1)	High area availability (2)
II	high	$1 \cdot 10^{-5}$	$5 \cdot 10^{-6}$	Swale infiltration	Swale infiltration 10 : 1
II	medium	$5 \cdot 10^{-6}$	$2 \cdot 10^{-6}$	Swale-trench infiltration without discharge	Swale infiltration 6: 1
III	moderate	$2 \cdot 10^{-6}$	$7 \cdot 10^{-7}$	Swale-trench infiltration with partly throttled discharge	Swale infiltration 4 : 1
IV	low	$7 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	Swale-trench infiltration with throttled discharge (3)	Swale infiltration 2 : 1

(1) Ratio of connected sealed area to infiltration area is 10:1
(2) Ratio of connected sealed area to infiltration area as indicated
(3) K_f value without limitation downwards

Figure 26: Selection of infiltration technologies under different soil and area conditions ((*Technical Training Manual on Urban Circular Water Management for Municipalities* – Association for Rainwater Harvesting and Water Utilisation – INTERREG project – 2019)

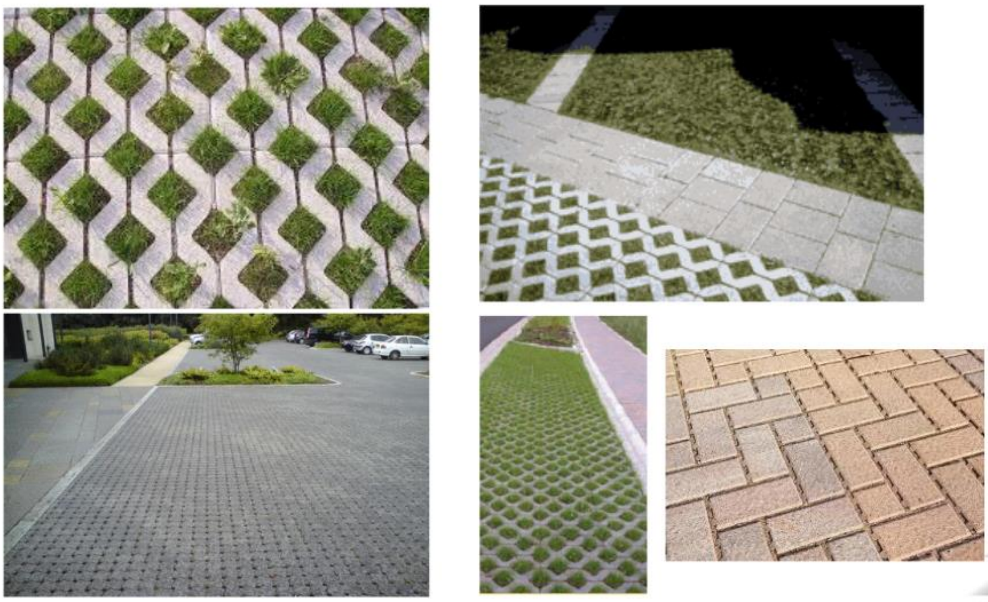
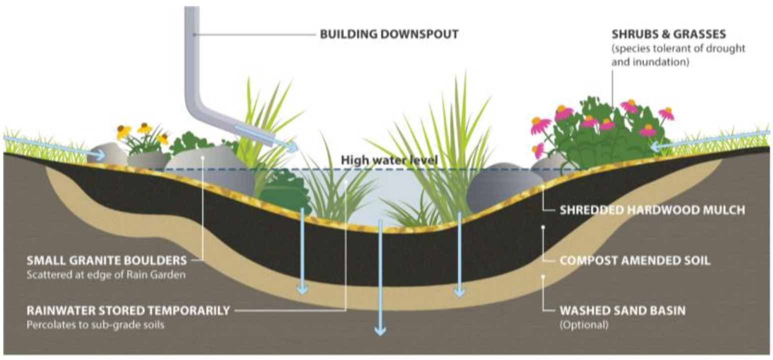


Figure 27: Example of reducing the waterproofing of urban areas and favor infiltration with permeable pavements (*Technical Training Manual on Urban Circular Water Management for Municipalities* – Association for Rainwater Harvesting and Water Utilisation – INTERREG project – 2019)



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

Figure 28: Example of system to collect runoffs from impervious surfaces such as roofs, walkways and parking lots and infiltrate it into the ground in urban areas (infiltration trenches and rain garden) (*Technical Training Manual on Urban Circular Water Management for Municipalities* – Association for Rainwater Harvesting and Water Utilisation – INTERREG project – 2019)

6.1.3. Manage of infrastructure

In order to plan an adaptation to the salt intrusion, is important a management and planning of underground structures and infrastructures, in particular:

- assessment of the degree of vulnerability of infrastructures (especially sewage networks) against the increase in salinity;
- assessment of the degree of vulnerability of existing structures (underground floors) to sea level rise;
- building regulations that prevent the construction of underground floors in the coastal area, of new structures and that provide methods (materials, laying depths) for adaptation and new construction of underground utilities.

6.2. AGRICULTURAL AND RURAL ENVIRONMENT

6.2.1. Re-orienteering groundwater pumping

It is necessary encourage alternative water supplies for non-human use, with joint use of surface and groundwater, but also relocate wells in the coastal area. It is also recommended reduce current irrigation needs by:

- Use of farming techniques and irrigation water distribution with innovative and technologic plants (micro-irrigation systems capable of providing only the water necessary to maintain the soil-cultivation system to be irrigated at maximum production potential).
- Management of irrigation networks with dedicated pipeline networks (upgrade/update Drainage & Irrigation Plans – IT Regional Level)
- Promotion of photovoltaic power supply pumping system

6.2.2. Facilitate the storage of runoff and infiltration into the aquifer

Also, in rural areas must be applied a rainwater management system that, in a reliable and automated way, allow to accumulate and then release fresh water to the subsoil ("rain harvesting and ponding" techniques) with:

- bank filtration
- dune filtration
- infiltration galleries
- infiltration ponds;

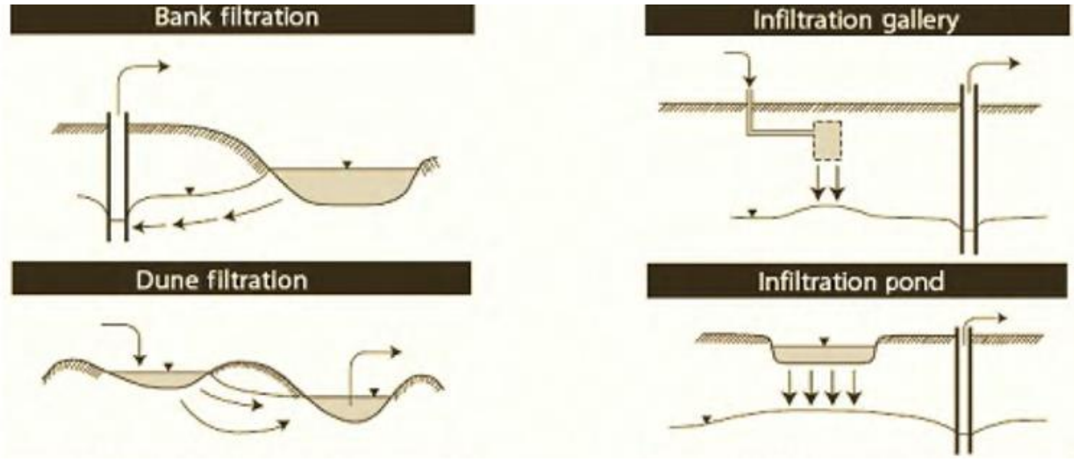


Figure 29: Type of filtration structures

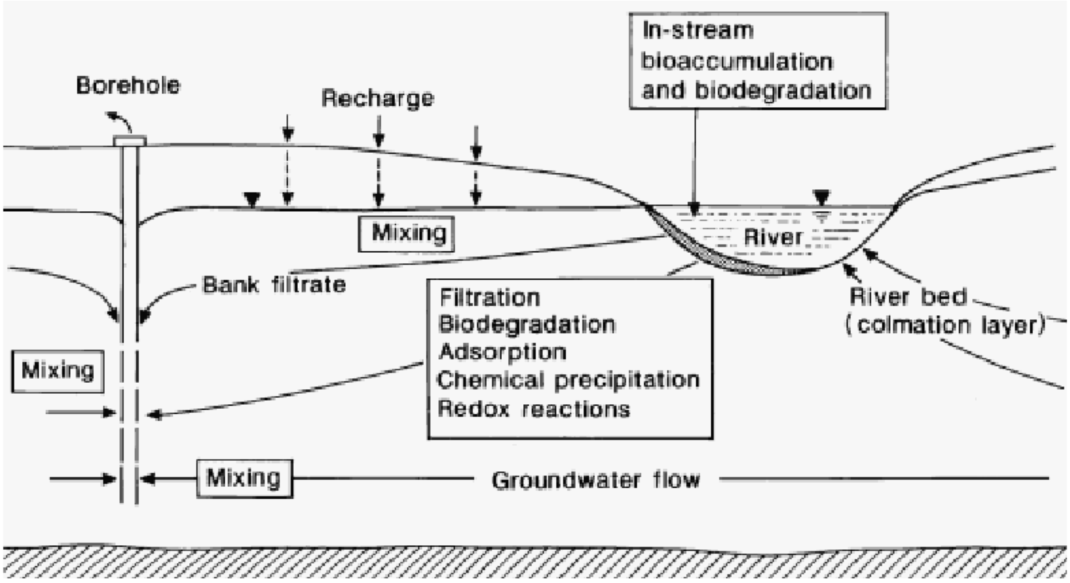


Figure 30: Schematic diagram of riverbank filtration (Feasibility of riverbank filtration for water supply in Nile valley, Egypt - Mohamed Shamrukh – 2006)

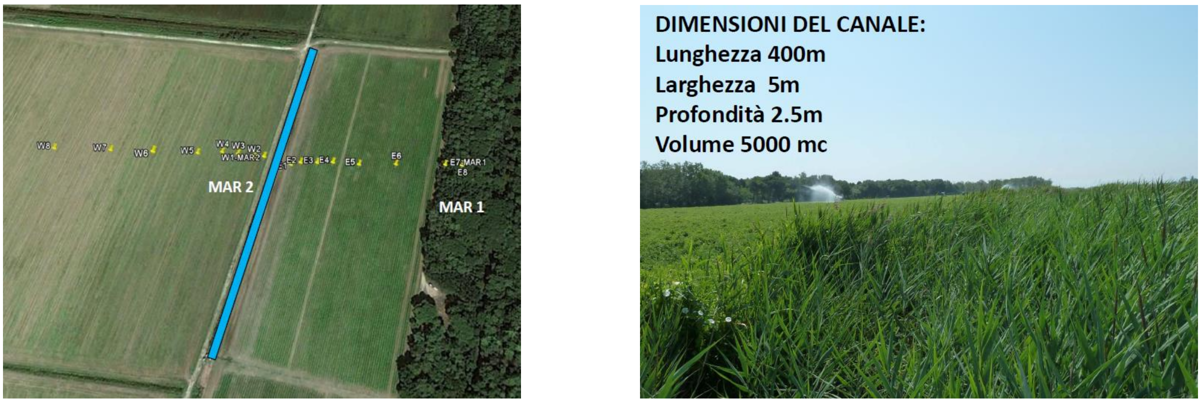


Figure 31: Example of recharge along a channel in agricultural area (Saline intrusion and irrigation in the surface coastal water in Ravenna: case study – Greggio – 2011)

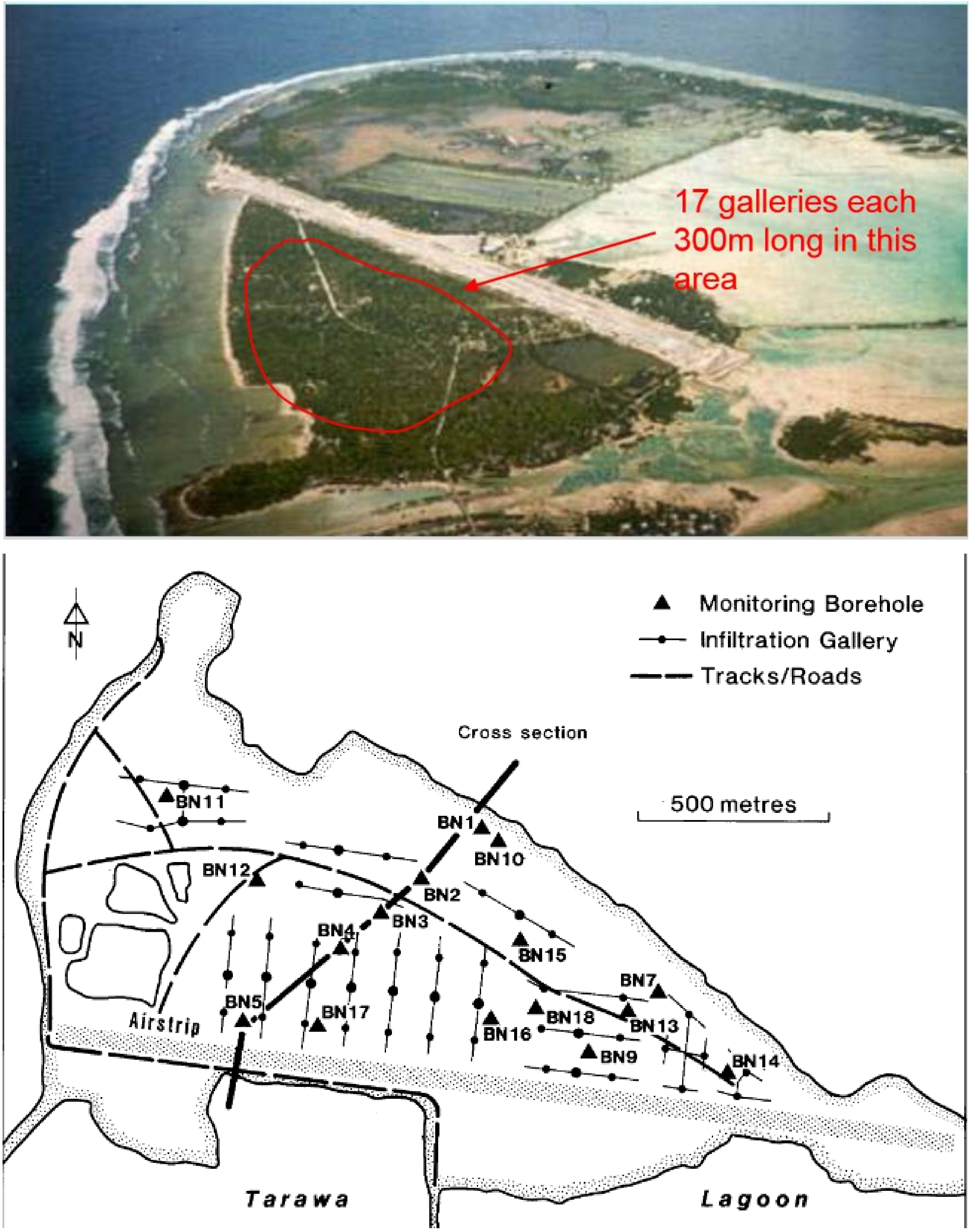


Figure 32: Example of infiltration galleries layout in Bonriki Tarawa atoll (Groundwater Training Course SOPAC - April 2005)

Figure 33: Example of retention ad filtration pond near Berlin

6.2.3. Land use planning

The application of measure to adapt salt intrusion is essential, some good practices that need to be regulated are cited below.

- Apply reasonable shifts in agricultural practices.
- Select plants and crops which can be tolerant to various salt limits.
- Applying advanced cultivation techniques:
  - macro-sprinkling rrigation with new generation pivot (increasing of efficiency and reduction of needs),
  - macro-sprinkling irrigation
  - Sprinkler irrigation
  - Subirrigation
- Re-use of purified waste water as a support to irrigation

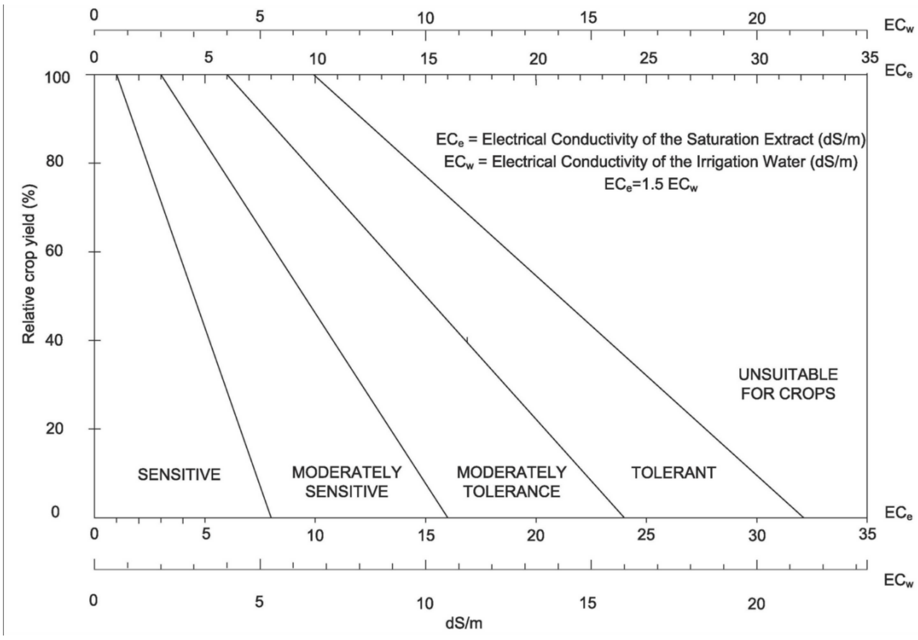


Figure 34: Division for classifying crop tolerance to salinity (Agricultural Drainage Water Management in Arid and Semi-Arid Areas Tanji et al.– 2002)

Figure 35: Example of advanced irrigation techniques

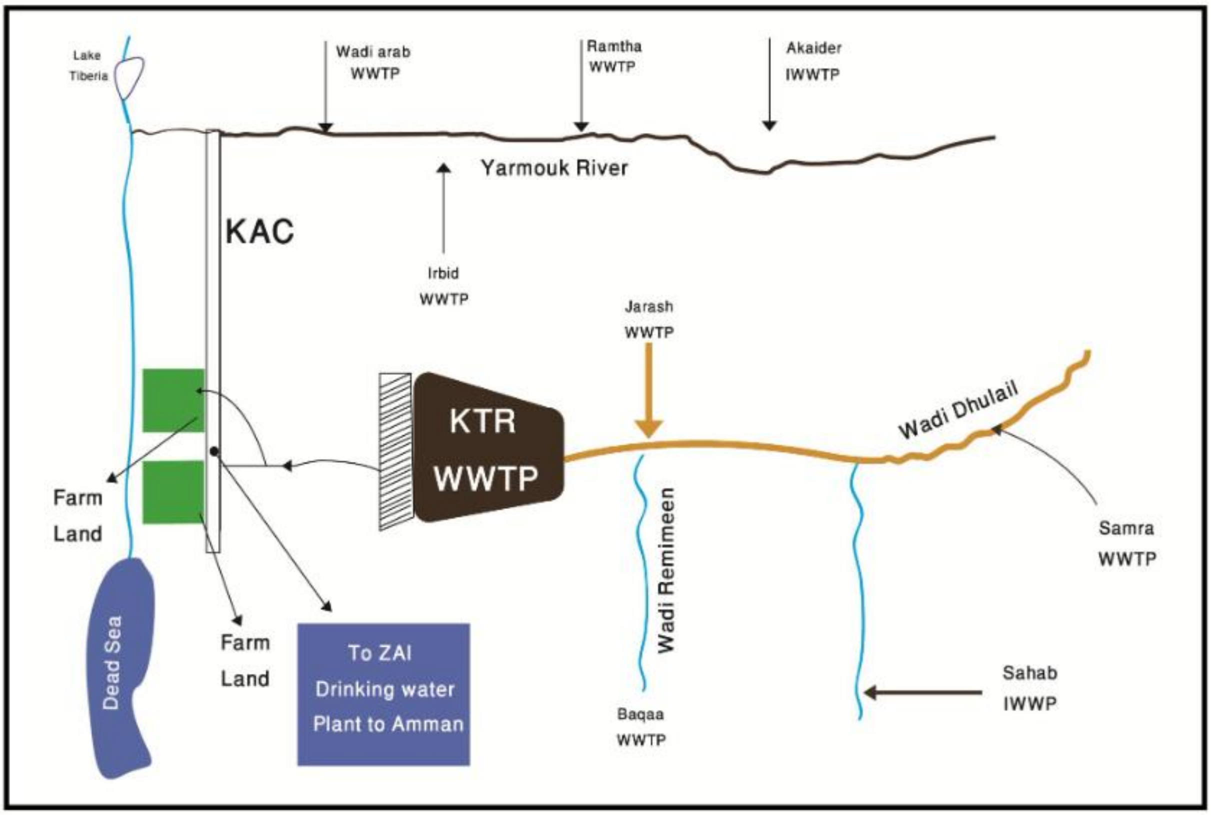


Figure 36: Example of euse of purified waste water as a support to irrigation trough river bank filtration (*Evaluation of Riverbank Filtration for Protection of Jordanian Surface and Ground Water Resources-* Ziad Al-Ghazaw)

7. Best practices for wet-zone coastal management (surface flow regulation)

Adaptation options for maintaining/restoring wetlands primarily focus on facilitating wetland migration through changes in legislation and regulations (e.g., rolling easements) and prohibitions on shoreline hardening.

Programs seeking to protect existing wetlands from development, pollution, and habitat changes that may be exacerbated by sea level rise could consider developing legislation or modifying land use rules (e.g., zoning) to facilitate wetland migration inland. Programs that are not constrained by existing institutions or policies could focus on prohibiting bulkheads and allowing marshes to migrate inland. Some examples of these types of policies are presented in U.S. EPA (2009). Synthesis of Adaptation Options for Coastal Areas. Washington, DC, U.S. Environmental Protection Agency, Climate Ready Estuaries Program. EPA 430-F-08-024, January 2009.

As an example, in Wetland Preservation in Houston- (Galveston, Texas) is proposed to:

- Allow coastal wetlands to migrate inland (e.g., through setbacks, density restrictions, land purchases)
- Incorporate wetland protection into infrastructure planning (e.g., transportation planning, sewer utilities)
- Preserve and restore the structural complexity and biodiversity of vegetation in tidal marshes, seagrass, meadows (and mangroves)
- Identify and protect ecologically significant (“critical”) areas such as nursery grounds, spawning grounds and areas of high species diversity

Figure 37: Example of management of wet zone (*Identification, Mitigation, and Adaptation to Salinization on Working Lands in the U.S. Southeast* - Gibson et al. - United States Department of Agriculture – 2021)

8. Suggestions for screening criteria for consents

In coastal zone, have been suggested criteria to support decisional process of water-manager in Public Administration, for a preliminary technical evaluation of new wells permission, with potential saltwater intrusion issues. The flow chart below shows suggests applications to determine (and avoid, if possible) the potential salt-water contamination effects.

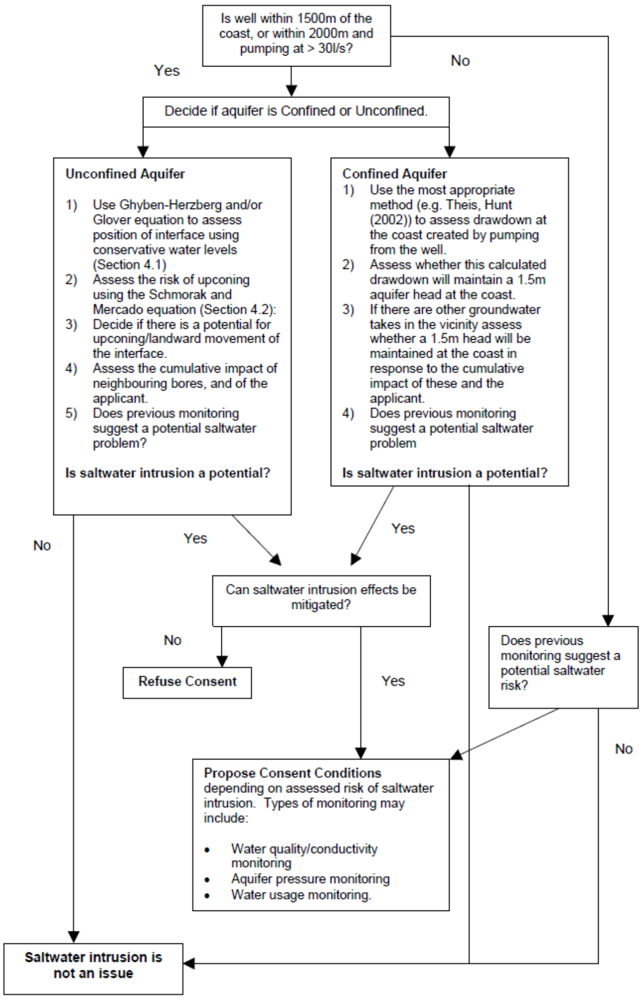


Figure 38: Example of Flow chart, showing decision process for handling groundwater take consents with potential saltwater intrusion issues (Coastal aquifer saltwater intrusion assessment guidelines - Environment Canterbury Unpublished Technical Report – 2003)