Third Edition

RISK MANAGEMENT

Knowledge, Forecasting, Prevention, Protection, Planning, Preparedness

20 - 27 July 2025

Managed Aquifer Recharge: a solution to adapt to water scarcity in the context of climate change

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Orvieto
25 July 2025

ADAPTATION

How to anticipate the adverse effects of climate change and acting to prevent or to minimise damages?

How to move from generalised adaptation strategies to local and regional plans and actions?

- Mitigation is the option… but…

Conventional vs. non-conventional water resources

Deep aquifer exploitation?

Dams?

Non-conventional water resources

Water banking/ reuse of **treated** wastewater/desalinisation

Managed Aquifer Recharge

Val di Cornia
Osservatorio UNESCO per l'Ecoidrologia
GLOBAL ECOHYDROLOGY NETWORK
unesco ecohydrology programme

Intentional recharge of an aquifer

A process to intentionally increase the volume ordinarily stored underground soil surface

Techniques mimicking/enhancing natural processes

(or, Bower (2002): *the main objective of artificial recharge techniques are to increase the available groundwater resources and to improve groundwater quality*)

This recharge is intentional (managed) in order to assure an adequate protection of human health and the environment.

This management makes this recharge different from non intentional recharge (i.e. excess irrigation), which may pose threath to the above.

MSCA Marie Skłodowska-Curie

NEXUS-NESS

ISTITUTO DI PRODUZIONI VEGETALI Sant'Anna Scuola Universitaria Superiore Pisa

REWAT sustainable water management in the lower Cornia Valley Life

Managed Aquifer Recharge

Not a novelty!

Highly developed from 1950.

(In Italy: Mario Canavari's Manuale di Geologia Tecnica, 1927)

Geoengineering schemes

Potential use and objectives:

- Increase groundwater availability;
- Compensate diminishing recharge due to human activities;
- Replenishment against overdrafting;
- Control of subsidence phenomena;
- Combat seawater intrusion;
- Sustain groundwater-dependant ecosystems;
- Improving groundwater quality.

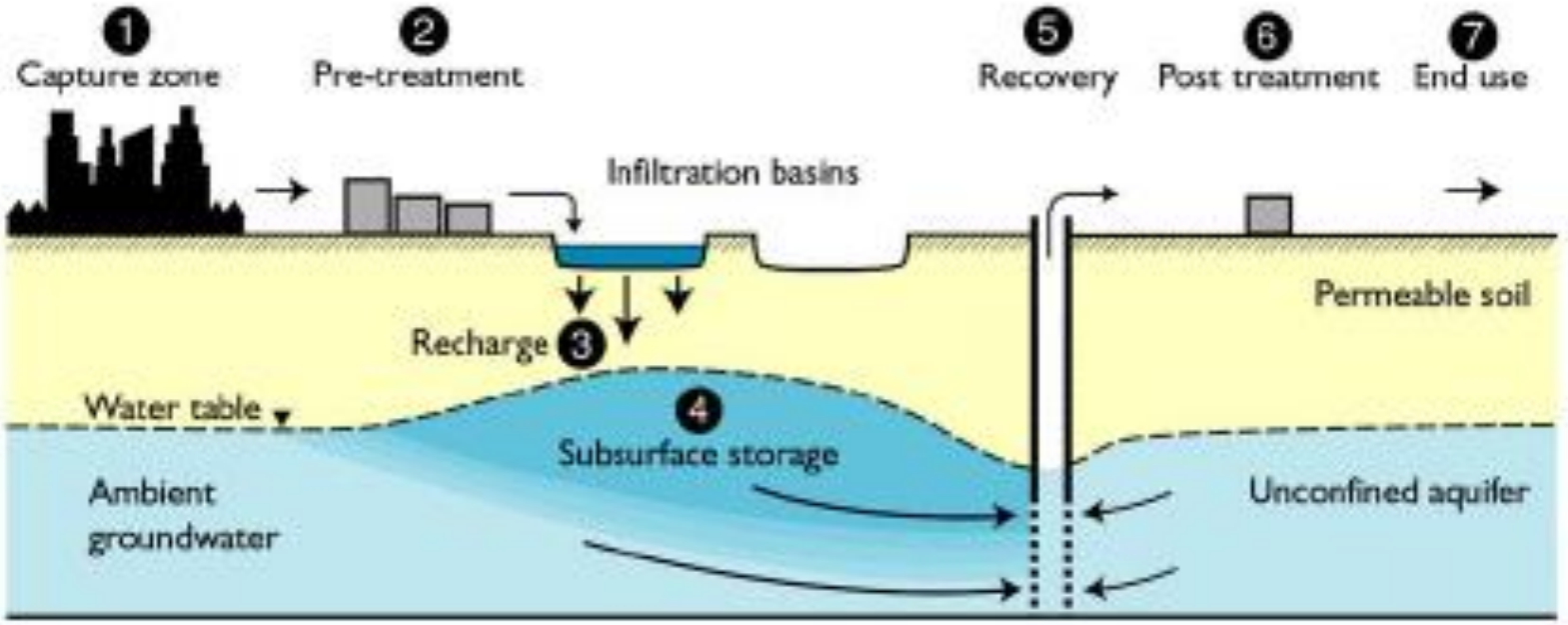
Video resource

Managed Aquifer Recharge
(CSIRO – Australia)

https://www.youtube.com/watch?v=9HyeGKYulwo

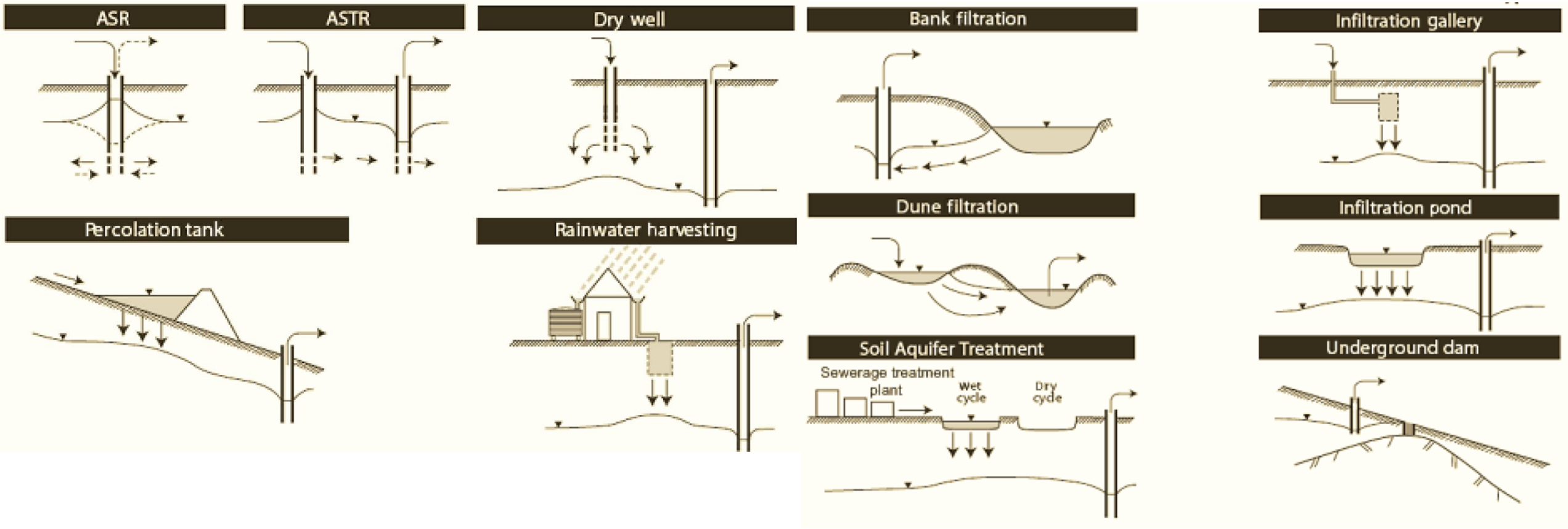
MAR components

1) Source
2) (if needed) pre-treatment
3) Recharge scheme
4) Aquifer
5) Pumping system
6) Post-treatment
7) Final users



Scientific resource
From: AUSTRALIAN GUIDELINES FOR WATER RECYCLING: MANAGING HEALTH AND ENVIRONMENTAL RISKS (PHASE 2)
Managed Aquifer Recharge
(Natural Resource Management Ministerial Council + Environment Protection and Heritage Council +National Health and Medical Research Council 2009)
https://www.waterquality.gov.au/sites/default/files/documents/water-recycling-guidelines-full-21.pdf

MAR types



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Managed Aquifer Recharge
(Natural Resource Management Ministerial Council + Environment Protection and Heritage Council +National Health and Medical Research Council 2009)

Amsterdan dune system (Netherlands)

85 ha con 40 bacini di infiltrazione e rete di canali di infiltrazione

Capacità di infiltrazione: **55 Mm^3/anno**

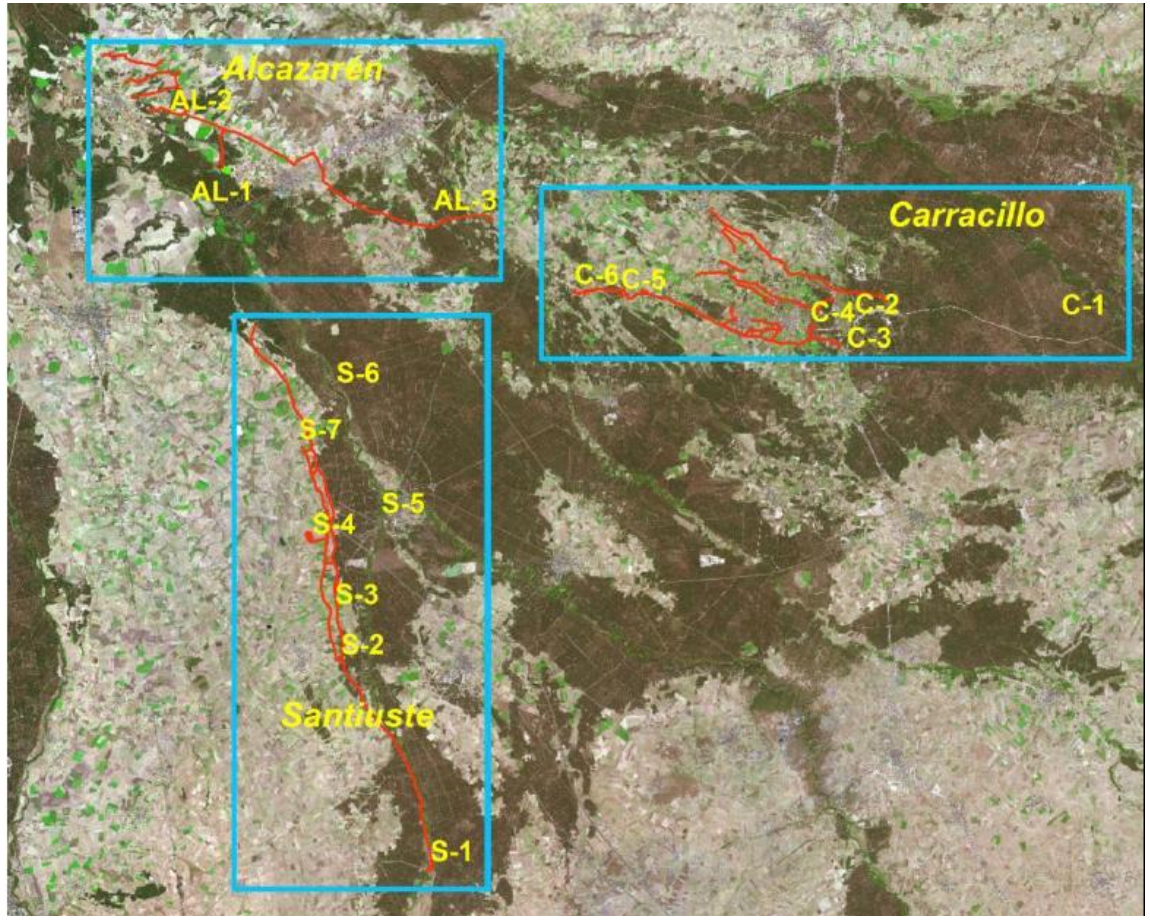
Obiettivi: **fornire risorsa potabile**, mantenere le aree umide, contrastare intrusione salina

MAR in Los Arenales (Spain)

Sistema di bacini/canali infiltrazione **12 Mm^3/anno max**

Derivazione dal Fiume Voltoya (8 km da area ricarica)

Obiettivo: mantenere irrigazione 850 Ha irrigui



Courtesy of TRAGSA, 2015

The Shafdan reclamation scheme (Israel)

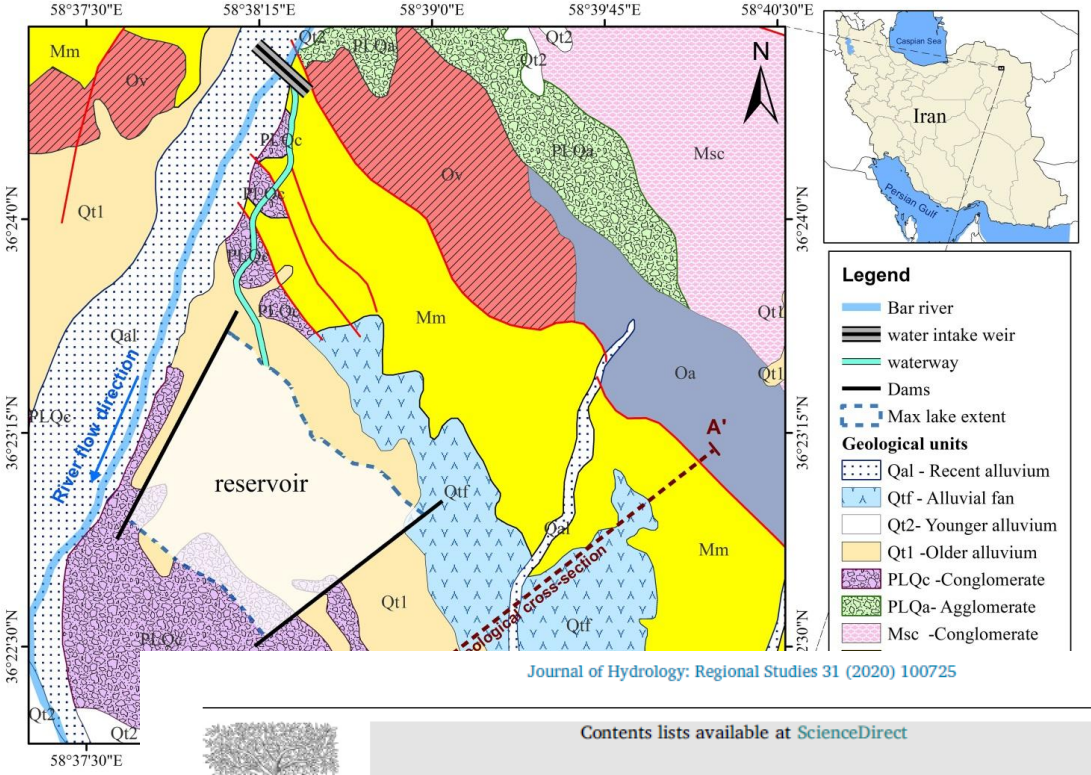
Tratta e infiltra i **reflui dell'area metropolitana di Tel Aviv** per mezzo di una serie di bacini di infiltrazione.

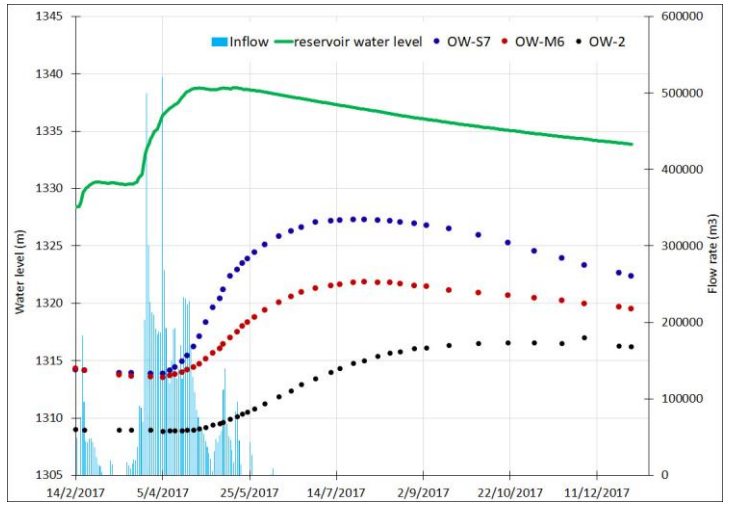
Capacità infiltrazione: 130 Mm^3/anno

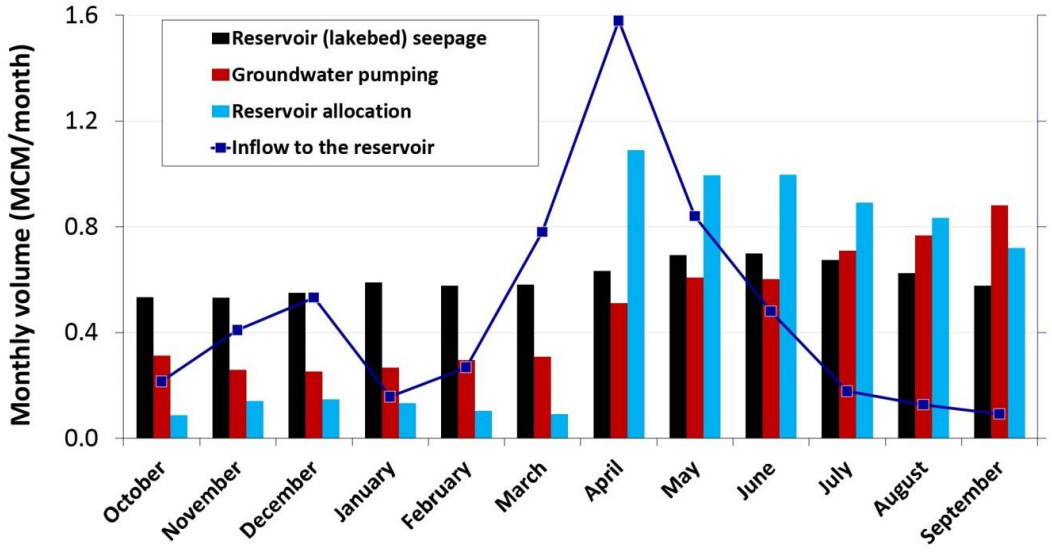
Il più grande schema a sfruttare il continuo suolo/acquifero

Scopi irrigui

Conjunctive use of surface and groundwater







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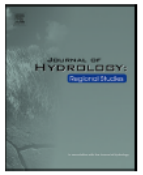


Deriving optimal operational policies for off-stream man-made reservoir considering conjunctive use of surface- and groundwater at the Bar dam reservoir (Iran)

Ata Joodavi[a,b], Azizallah Izady[b,c], Mohammad Taghi Karbasi Maroof[d], Maysam Majidi[a,e], Rudy Rossetto[f,*]

Ricarica Indotta di Subalveo F. Serchio

Sfrutta la connesione idraulica tra acquifero e Fiume Serchio attraverso 10 pozzi verticali ed una traversa in alveo.

Capacità: 15 Mm^3/anno

Fornisce risorsa idropotabile a Pisa, Lucca, Livorno.

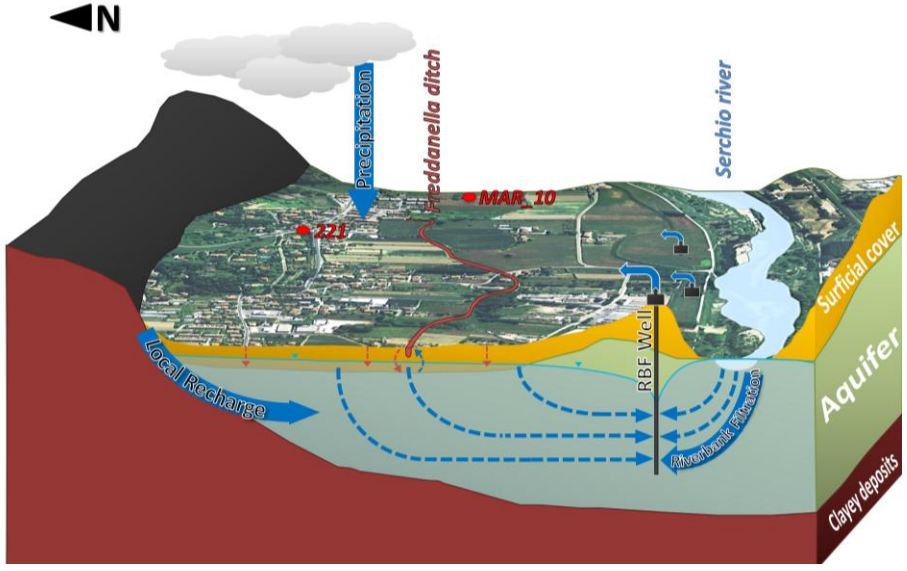


Table 1.
Investment cost and asset value (modified after Balzarini and Furlanis, 2016)[11].

Facility	Unit	Quantity	Unitary Cost €/Unit	Investment €	Asset €
Piezometers	Sum	1	20,000	20,000	20,000
Wireless Sensor Network	Sum	1	50,000	50,000	-
River Weir	m	140	20,682	2,895,480	2,895,480
ø300 mm Well	No.	5	150,000	750,000	415,000
ø500 mm Well	No.	7	250,000	1,750,000	1,155,000
DSS Development and Testing	Sum	1	250,000	250,000	-
Total				**5,715,480**	**4,465,480**

ARTIFICIAL AQUIFER RECHARGE IN ITALY

Vicenza:
7 dry wells
4 FIA's
Infiltration Pond
Infiltration Trench
Infiltration Channel
Infiltration Field

Padova:
FIA
IRBF

Treviso:
Infiltration Pond

Pordenone:
SAT

Udine:
Dry well
Infiltration Pond

Milano:
2 Infiltration Ponds

Ferrara:
Infiltration Pond

Rimini:
2 ASR's
2 Infiltration Ponds
IRBF

Ravenna:
Infiltration Pond

Prato:
IRBF

Pesaro Urbino:
ASR

Lucca:
IRBF

Livorno:
River scarification

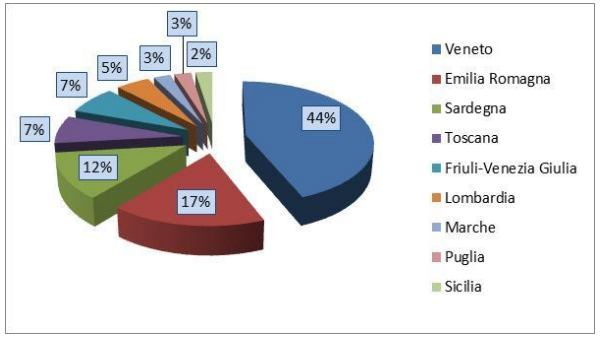
Bari:
ASTR

Carbonia – Iglesias:
ASR

Cagliari:
2 ASR's
Infiltration Trench
Infiltration Pond

Siracusa:
ASR

UNMONITORED



Credits: Silvia Di Bartolo – Alessio Barbagli

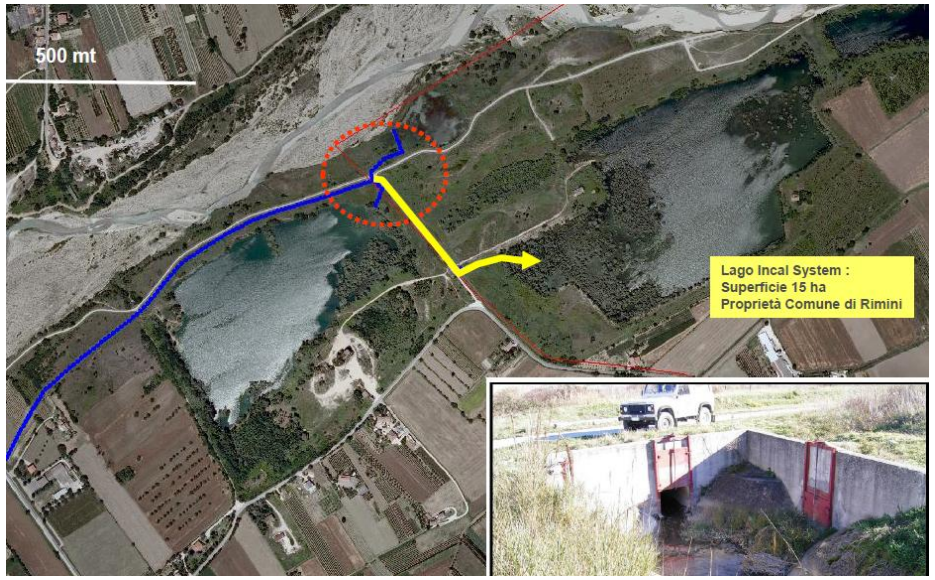
MAR in Italy

Some projects on aquifer recharge were co-financed by the European Commission mainly through the LIFE program.

- **TRUST** (*Tool for regional - scale assessment of groundwater storage improvement in adaptation to climate change*, LIFE07 ENV/IT/000475; Marsala 2014);

- **AQUOR** (*Implementation of a water saving and artificial recharging participated strategy for the quantitative groundwater layer rebalance of the upper Vicenza's plain* - LIFE 2010 ENV/IT/380; Mezzalira et al. 2014);

- **WARBO** (*Water re-born - artificial recharge: innovative technologies for the sustainable management of water resources*, LIFE10 ENV/IT/000394; 2014).



RECENT YEARS/3

Moving from an agriculture only impacting the water resources to the provision of agroecosystem services

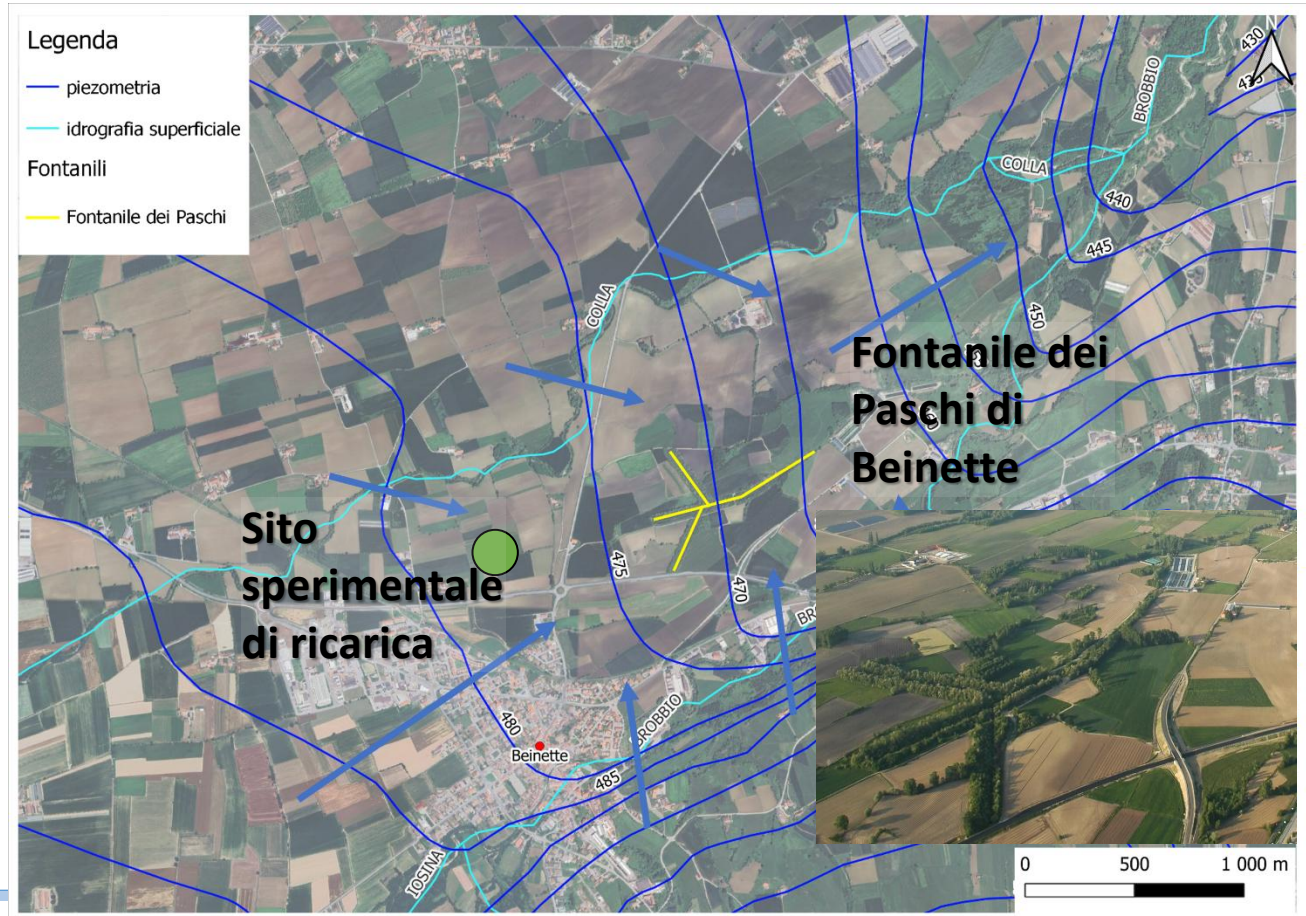
Forested Areas

Infiltration

(Veneto, Italy)

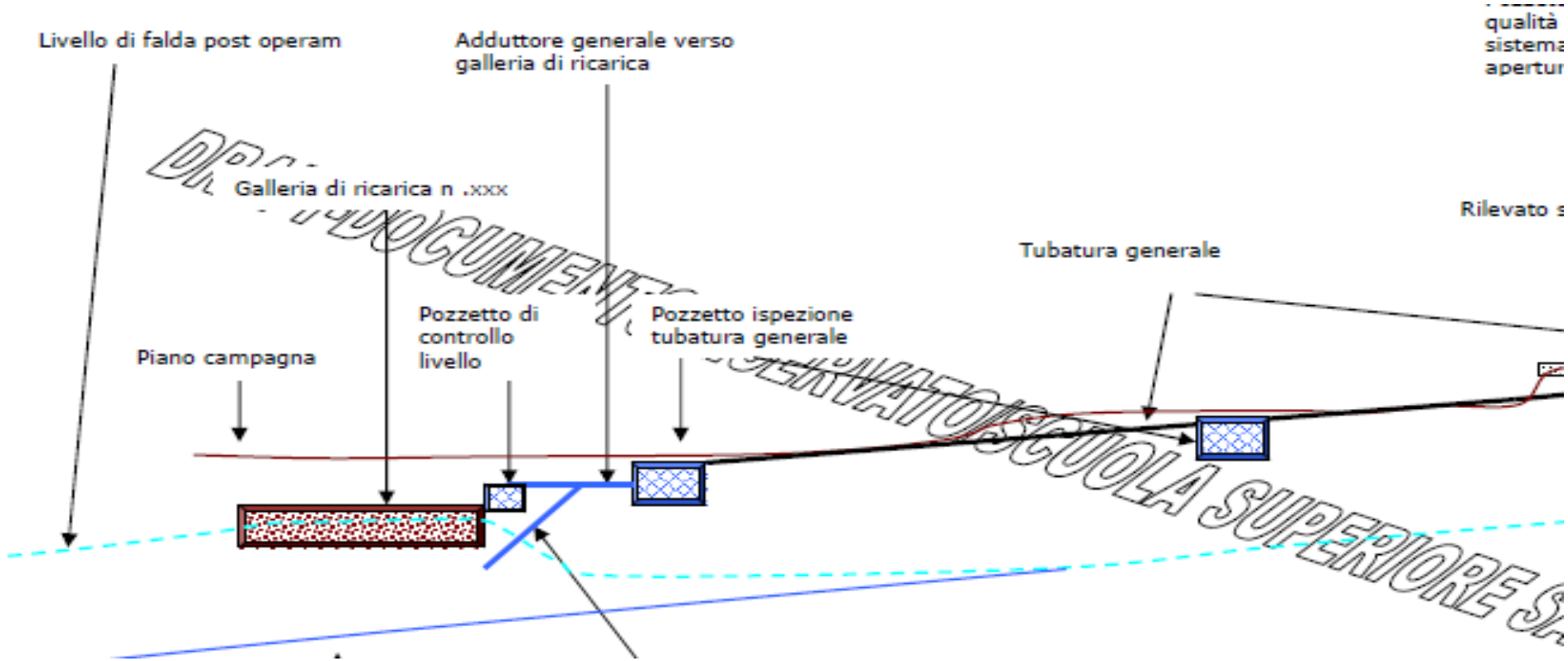
Il progetto SeTe Alcotra

- Progetto di cooperazione transfrontaliera nel quale è coinvolta la Provincia di Cuneo (partner, responsabile ing. Paolo Algarotti) e il Politecnico di Torino (supporto scientifico, responsabile prof. Alessandro Casasso)
- Durata 36 mesi (ottobre 23 – ottobre 26)
- Studio di fattibilità dell'infiltrazione controllata in falda in tre siti della pianura cuneese, caratterizzati dalla presenza di fontanili (Beinette, Morozzo – Tetti Pesio, Centallo)
- Siti sperimentali di ricarica con acqua dei canali irrigui, fuori dalla stagione irrigua



Rilievi topografici per la realizzazione delle trincee sperimentali di infiltrazione

DM 100/2016



Regolamento recante criteri per il rilascio dell'autorizzazione al ravvenamento o all'accrescimento artificiale dei corpi idrici sotterranei al fine del raggiungimento dell'obiettivo di qualità, ai sensi dell'art. 104, comma 4-bis, del decreto legislativo 3 aprile 2006, n. 152 e successive modificazioni

Regional authorities «may» define groundwater bodies suitable to recharge.

Key points of DM 100/2016

Recharge may be DIRECT (recharge wells are feasible) or through the unsaturated zone

For recharge:
Surface water
Groundwater (no mention of treated wastewater reuse)

Recharge only on groundwater bodies not achieving GOOD chemical status (WFD sensu)

Decreto Siccità (L.68/2023, 13/06/2023)
al Commissario sono attribuiti i seguenti compiti:

ricognizione dei corpi idrici sotterranei potenzialmente idonei a ricevere interventi per il ravvenamento o l'accrescimento artificiale della falda a garanzia della tutela delle risorse idriche, degli ecosistemi terrestri dipendenti e della salute umana, …

Key points of DM 100/2016
Annex 1

Annex 1 lists criteria to be respected for granting authorization to set up a MAR scheme.

The authorization is granted upon presentation of:

- a preliminary project (large area hydrological and hydrogeological characterization of the groundwater body and MAR type, source of water)
- an executive project (detailed area characterisation, type of MAR scheme, hydraulic and hydrochemical and socio-economic assessments).

The following must then be provided before full operation starts:

- **management plan**
- **monitoring plan**
- **emergency plan**

Key points of DM 100/2016: Annex 1

- A dedicated monitoring system is required:

  - full year discrete monthly monitoring for hydrodynamics and hydrochemistry

    during the design phase (TIME TO MAR CONSTRUCTION)

  - *operational monitoring*, to evaluate:

    i. effectiveness of the scheme, and

    ii. detect potential deterioration

  - *high frequency* or continuous *first alert monitoring*

    - at the upstream recharge point,

    - to halt the recharge flow in case of source contamination events

The LIFE REWAT MAR plant in Suvereto (IT)

Two-stage infiltration basin

Expected results

- Increase aquifer storage from 0.3 to 1.2 Mm^3/y (depending on meteo-climatic conditions)
- Environmental purposes

- Cost of about 350k €
- From preliminary design to operation: 24 months

The MAR scheme/1

The MAR scheme/2

The MAR scheme/4

The MAR scheme/5

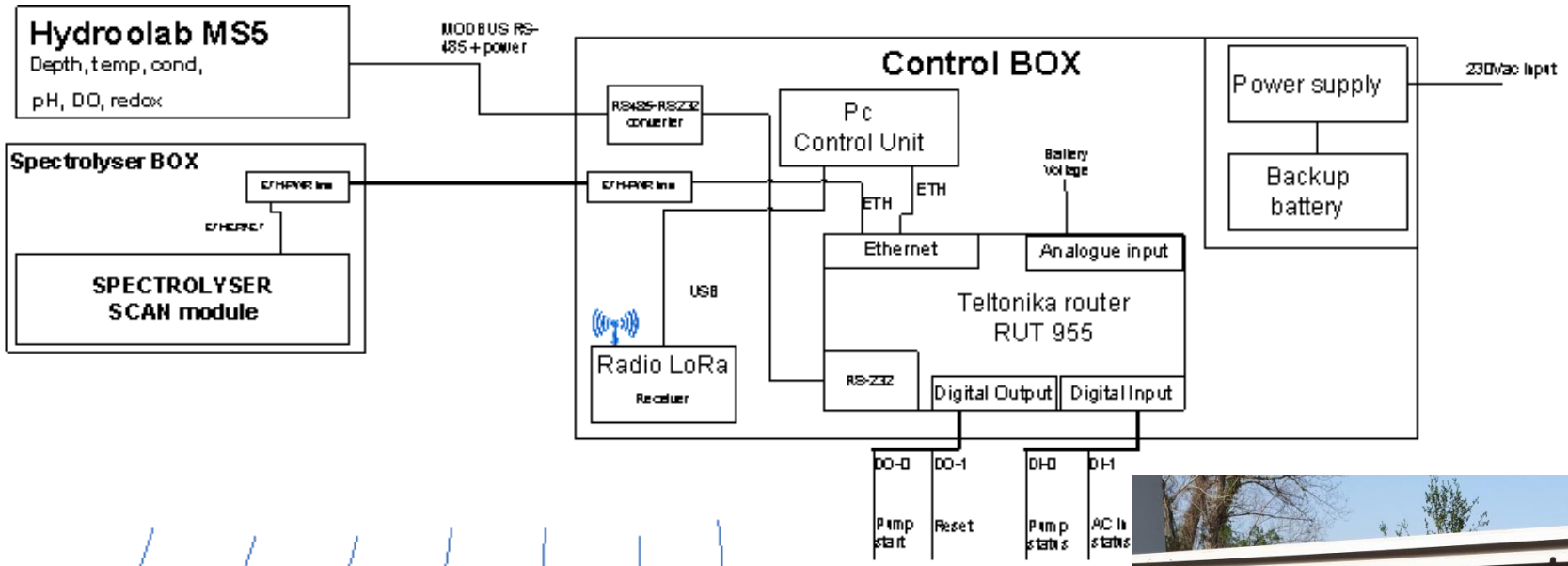
REWAT sustainable water management in the lower Cornia Valley

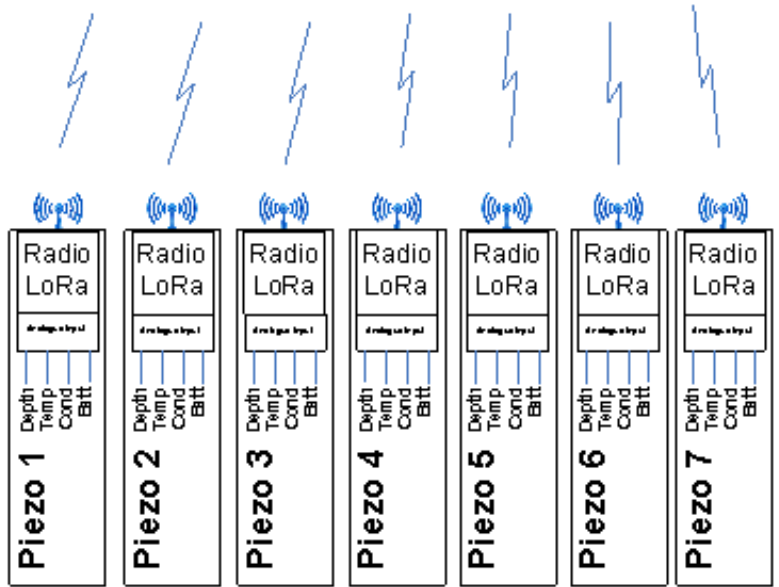
The MAR scheme/6

REWAT sustainable water management in the lower Cornia Valley

The MAR scheme/7

Automation and monitoring

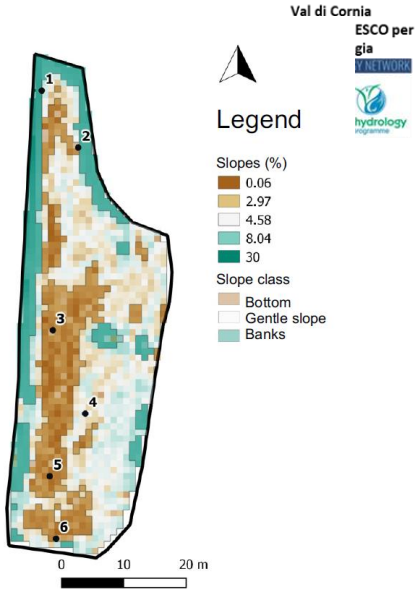




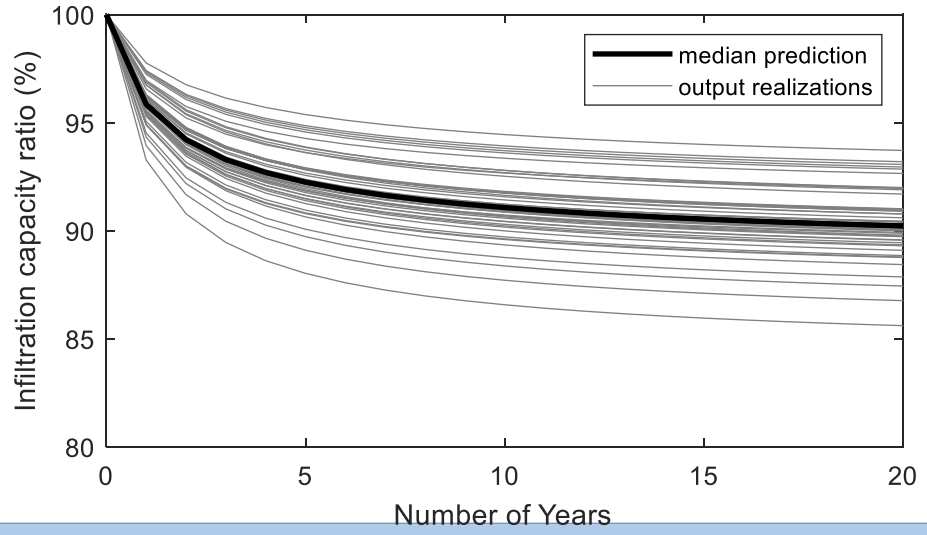
Clogging

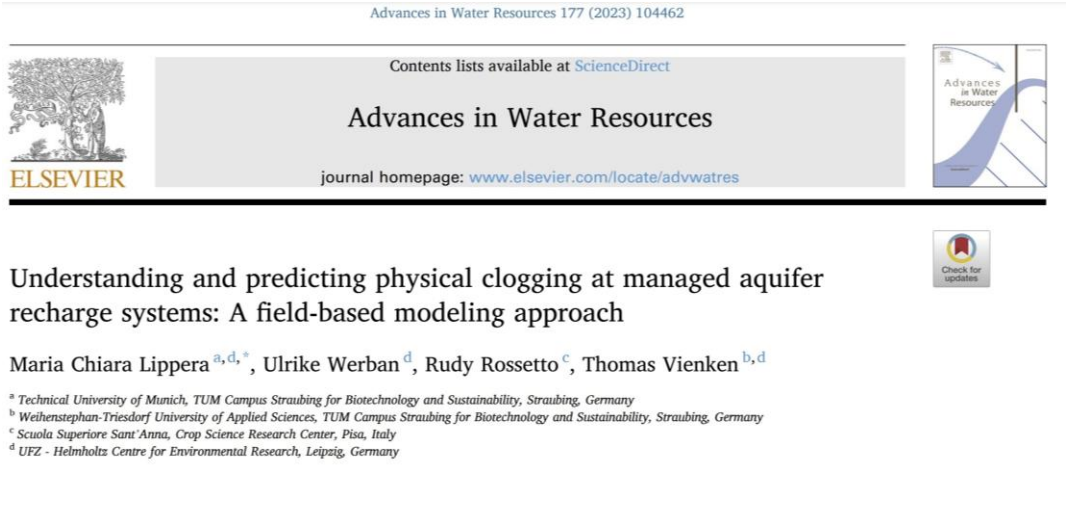
Infiltration basins may be clogged because of fine depositions and other processes

Yearly-mainteinance is needed (basin ploughing) and recommended



Simulating potential clogging turnaround to get an idea during the basin lifetime could be a good idea




Advances in Water Resources 177 (2023) 104462

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journal homepage: www.elsevier.com/locate/advwatres

ELSEVIER

Understanding and predicting physical clogging at managed aquifer recharge systems: A field-based modeling approach

Maria Chiara Lippera [a,d,*], Ulrike Werban [d], Rudy Rossetto [c], Thomas Vienken [b,d]

[a] Technical University of Munich, TUM Campus Straubing for Biotechnology and Sustainability, Straubing, Germany
[b] Weihenstephan-Triesdorf University of Applied Sciences, TUM Campus Straubing for Biotechnology and Sustainability, Straubing, Germany
[c] Scuola Superiore Sant'Anna, Crop Science Research Center, Pisa, Italy
[d] UFZ - Helmholtz Centre for Environmental Research, Leipzig, Germany

We grow up!

Thanks to a small additional fund from Protezione Civile (100k €) a new basin was designed, built and set in operation

Construction started in December 2022 – inaugurated March 2023

Now, infiltration capacity is up to 2 Mm^3/y

Issues to be dealt with

- poor or unefficient design (i.e. poor characterisation of hydrodynamic properties, etc.)
- poor quality of the water to be used (treatment trains to be designed and used)
- environmental impacts not duly evaluated (i.e. downstream of the MAR scheme)
- insufficient experience on real applications of the deisgners
- waterlogging (i.e. basement flooding in urban areas)
- socio- economical issues (problems with population not used to these new tech.)
- mainteinance not planned after the start of operations
- reduced functionality of the scheme (i.e. clogging with time)

MAR or not MAR?

- MAR is one of the tool for water management and planning
- when deciding for a solutions costs/benefits/waterworks values/efficiency should be thoroughly evaluated
- ------**viability studies should be done before deciding for**
  - **desalination/use of reclaimed water/MAR/dams …**

Or maybe all of the solutions!

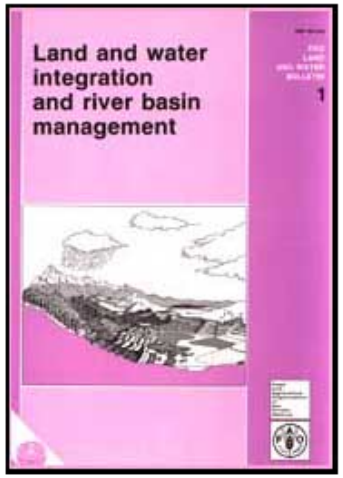
Advantages

- ✓ low investment costs
- ✓ (+ economic among techniques for water supply – about 1/1.5 €/m^3 construction costs vs 5/6 €/m^3 surface water reservoirs);
- ✓ no or minimal land loss;
- ✓ potential use of salinised/brakish aquifers (*salinised groundwater displacement*)
- ✓ **attention to energy issues**

NEXUS-NESS

https://prima-nexus-ness.org/

Conjunctive use of surface and groundwater



Land and water integration and river basin management

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Proceedings of an FAO informal workshop
Rome, Italy
31 January - 2 February 1993

Food and Agriculture Organization of the

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any opinion whatsoever on the part of the Food and Agriculture Organiza
the legal status of any country, territory, city or area or of its authorities, o
frontiers or boundaries.

M-50

ISBN 92-5-103655-1

"surface water storage,
because of the large investments involved,
is often preferred because it offers a ***much higher political visibility***

and because ***high construction costs*** *give an opportunity for private profit and corruption, opening the way for improper influence on decision making"* (FAO, 1995)

Comune di Suvereto

CONCLUSIONS

The implementation of managed aquifer recharge requires:

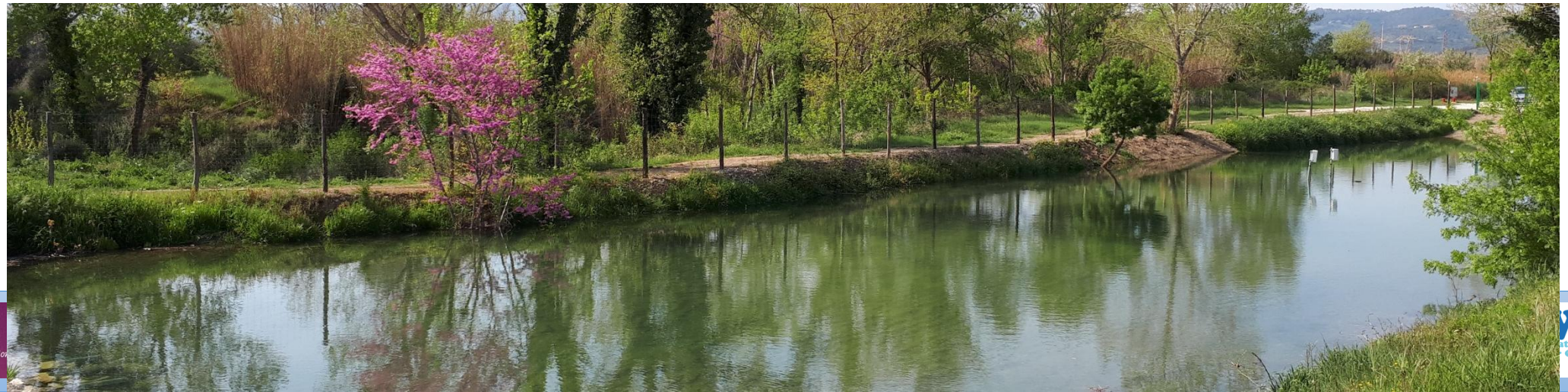
- careful planning and clear and sounding regulations;

- coordinated investments;

- monitoring of operations;

- creation of technical and managerial skills.

The environmental, energy, health and other consequences must be diligently considered while defining the potentials and limitations of these options.



CONCLUSIONS/2

MAR schemes can be a viable option to increase the supply of good quality groundwater and to restore unbalanced situations.

There is a growing interest on the use of this low-cost technique, which could move the water market also thanks to the potential interactions with agricultural policies.

The dissemination and promotion activities of MAR techniques and the results of scientific research, in the public and private sectors, are crucial for the exploitation of MAR techniques on a large global scale.