LIFE Project Number

<LIFE +10 ENV/IT/000394/WARBO>

FINAL Report

Covering the project activities from 01/01/2012 to 31/12/2014

Reporting Date

<31/03/2015>

LIFE+ PROJECT NAME or Acronym

<WATER RE-BORN - Artificial Recharge: Innovative Technologies for the Sustainable Management of Water Resources>

Annex 61

Name of Deliverable:

Modelli innovativi della dinamica degli acquiferi sottoposti a R.A e supporto all'aggiornamento delle Dierettive Europee sull'acqua e raggiungimento degli obiettivi della WFD

Code of associated action: 5,10,12

Modelli innovativi della dinamica degli acquiferi sottoposti a R.A e supporto all'aggiornamento delle Dierettive Europee sull'acqua e raggiungimento degli obiettivi della WFD

Tiago Carvalho (1) ; José Martins Carvalho (1); Rita Carvalho (1); Anna Gutz (1) Rui Agostinho (1); Andrea Comerlati (2) ; Pietro Teatini(2)

(1) TARH – Terra, Ambiente e Recursos Hídricos, Lda
(2) Dept. of Civil, Environmental and Architectural Engineering, University of Padova

1 Introduction

This document constitutes a tentative approach to address the conclusions taken within the WARBO project test sites (with special focus in the conceptual and numerical modelling results), and to use it as a support for a possible update on the European water law and regulations. Hence we give a set of suggestions for the implementation and regulation of Managed Aquifer Recharge (MAR), which may speed up the development of such activities and also guarantee that they are aligning with the main objectives of the European Policy.

2 MAR in the Water Framework Directive

The European Water Frame Work Directive (2000/60/CE), has a few references to the Managed Aquifer Recharge (previously generally designated as Artificial Recharge).

In Article 11 – Programme of measures - artificial recharge is indicated as a possible measure to achieve the environmental objectives (number 3 f)). It is stated however that the MAR activities shall be subject of an Authorization by the national/regional authorities. The water sources may be derived from any surface water or groundwater, provided that the use of the source does not compromise the achievement of the environmental objectives established for the source or the recharged augmented body of groundwater. It also calls for a periodic control of the activity, and a systematic upgrade of the control system.

In Annex II, Artificial Recharge sites is one of the pressures to which the groundwater body or bodies are liable to be subject (that shall be identified for the groundwater body characterization) alongside water extractions, punctual pollution and diffuse pollution.

In Annex VI, part B, MAR is identified as a supplementary measure on which Member States within each river basin district may choose to adopt as part of the programme of measures.

Furthermore, article 4 – Environmental Objectives - b), ii) states that:

Member States shall protect, enhance and restore all bodies of groundwater, ensure a balance between abstraction and recharge of groundwater, with the aim of achieving good groundwater status at the latest 15 years after the date of entry into force of this Directive, in accordance with the provisions laid down in Annex V, subject to the application of extensions determined in accordance with paragraph 4 and to the application of paragraphs 5, 6 and 7 without prejudice to paragraph 8 of this Article and subject to the application of Article 11(3)(j);

All these items were transposed to the national legislation through adequate mechanisms. In Italy, only very recently the legislator has promulgated a specific directive on the topic. In fact, only in 2013, the previous D.lgs. n. 152/2006 "Norme in Materia Ambientale" has been updated by the Law n. 97/2013, Article 24 ("Modifiche al decreto legislativo 3 aprile 2006, n. 152, per il corretto recepimento della direttiva 2000/60/CE che istituisce un quadro per l'azione comunitaria in materia di acque. Procedura di infrazione 2007/4680"). The Comma 1, point (e), states:

"all'articolo 104 - of the D.lgs. n. 152/2006 -, dopo il comma 4 e' inserito il seguente:

«4-bis. Fermo restando il divieto di cui al comma 1, l'autorita' competente, al fine del raggiungimento dell'obiettivo di qualita' dei corpi idrici sotterranei, puo' autorizzare il ravvenamento o l'accrescimento artificiale dei corpi sotterranei, nel rispetto dei criteri stabiliti con decreto del Ministero dell'ambiente e della tutela del territorio e del mare. L'acqua impiegata puo' essere di provenienza superficiale o sotterranea, a condizione che l'impiego della fonte non comprometta la realizzazione degli obiettivi ambientali fissati per la fonte o per il corpo idrico sotterraneo oggetto di ravvenamento o accrescimento. Tali misure sono riesaminate periodicamente e aggiornate quando occorre nell'ambito del Piano di tutela e del Piano di gestione»."

Taking into account that D.lgs. n. 152/2006 , Article 104, comma 1 reports: "È vietato lo scarico diretto nelle acque sotterranee e nel sottosuolo".

3 WARBO project conclusions

Within the WARBO project scope several hydrogeological conceptual models were developed and served as the backbone for the numerical modelling. Those were later calibrated with the monitoring results taken in the last year of the project. Thanks to those, the impacts of the WARBO MAR experimental approaches in a long term can be extrapolated, with an acceptable adequacy.

The main conclusions of the WARBO test sites were:

Abandoned excavations/pits/ponds can be easily transformed into MAR infrastructures: The test sites in Mereto and Copparo were under a state of abandonment in a long run (around 5 years) and still didn't require any particular preparation for the MAR activity.

A small, isolated MAR structure has a limited impact: The impacts of all three test sites are likely to be felt at local scale, and not further. For a more Municipal/Regional impact it is required an integrated water management, considering both surface and groundwater. Just in these situations it will be possible to get cumulative impacts in the groundwater with a direct benefit for water users. This also applies for the biodiversity improvement, as it may be possible to create ecological corridors;

Benefits aren't restricted to groundwater: The benefits of using such a structure for MAR activities aren't restricted to groundwater or to the aquifer (Pyne, 1995). The clearest example is the biodiversity improvement. In the case of Copparo, where a large area is available with a deficient water quality, this improvement for the wildlife was more evident. In ZIPR, the impacts of the MAR may also be felt in the surface water stream, as MAR would avoid a constant load with high temperature and some heavy metals.

MAR structures can be used as a contingency plan against pollution (Pyne, 1995; EWRI/ASCE, 2001)**:** MAR in the ZIPR test site may be more effective in managing the waste water load to the surface water stream than to the aquifer itself. This is due to the current shallow water levels in the aquifer and the fact that the phreatic aquifer isn't currently being under heavy utilization. However, the possibility of having a MAR facility can be of enormous benefit in case of an accidental groundwater contamination. Depending on the contaminant type, decision makers may take a decision to flush and dilute the contamination plume in the groundwater by using the MAR facility.

Aquifer characterization and conceptualization is extremely important (Pyne, 1995; EWRI/ASCE, 2001; Maliva & Missimer, 2010; Kresic & Mikszewski, 2013)**:** WARBO test sites targeted 2 phreatic aquifers (Mereto and ZIPR) and a confined aquifer (Copparo). All the investigations were taken in porous aquifers. However the geometry of the recharged aquifer in Copparo (Paleochannel) was extremely limited and hard to access. The MAR in Mereto and ZIPR, in aquifers with high hydraulic conductivity, is easy to conduct and high infiltration rates are observed. However the positive effects of recharge are easily "dispersed and diluted" in the aquifer, keeping its influence area relatively small. In the Copparo Paleochanels, even with lower permeability than Mereto or ZIPR, the effects of recharge have the potential be more concentrated, but just in the narrow geometry of the aquifer, limiting its users. The current water level has also an important role to play: shallow water levels (like in ZIPR and Copparo) impair the capacity to build up an adequate hydraulic gradient for the infiltration.

Not all aquifers are suitable for Aquifer Storage and Recovery (ASR) a sub domain of MAR: When the aquifer is unconfined and the water table is very shallow it is extremely hard to create a good gradient for infiltration and the rise in water level might affect the vegetation roots; Thin aquifers or composed of fine grained unconsolidated material are also rather poor for the infiltration; If the site is adjacent to a leaky fault or a semi-confining layer containing poor quality water, it might be risky to store water for future recovery. It may however be useful as a barrier against salt water; Aquifers that contains poor quality water and are highly heterogeneous or has a high lateral flow rate are also not good for ASR (CSIRO, 2011).

MAR licensing shall require a number of multiple investigations: The interconnection between the different subjects was fundamental for the setup and management of the test sites. Hydrogeological investigations are necessary for the aquifer characteristics assessment and monitoring; Geochemistry is extremely relevant in order to predict, monitor the chemical impact and prove the recharge efficiency; Geophysical investigation are necessary for the assessment of the aquifer geometry; Hydrogeological conceptual modeling, integrating the dynamics of the geological processes, is critical for the numerical modeling; Numerical modeling is extremely useful for predicting the groundwater and contaminant flow; Biology and Ecology may also have a role to play to identify the benefits on the ecosystem services;

Problems of non-managed recharge: The management of the MAR facilities is required for the quality control of the recharged water, quality control of the aquifer, and for maintenance of the hydraulic structures and biodepuration ponds. Without management, water filters and the pond bottom may clog, reducing drastically the water infiltration rates (Pyne, 1995; Maliva & Missimer, 2010). It may also create conditions for algae growth (like in Mereto) that might have to be removed, otherwise might be a pollution load for the aquifer during the dry period. The regular chemical control on the recharge water and observation points is also fundamental to stop the recharge, in case of danger.

Distribution of costs and benefits: A future and sustainable use of a MAR operation depends on its financing, as there are (small) operational and maintenance costs. Therefore, a clear identification of the beneficiaries (which will likely be several persons/companies/industries) is necessary, as well as a degree of influence. Due to the migration of the groundwater, beneficiaries might be located away from the recharge site. Due to the groundwater movements, number and different nature of beneficiaries, a cooperative MAR operation may be advisable.

Even in water rich region, MAR can have a role: Although Fruilu-Venezia-Giulia is one of the regions of Europe with higher water resources (ARPA FVG,2011) , Mereto and ZIPR showed that MAR might have a role to play, mainly in the groundwater quality enhancement, stream flow control and pollution plume control (aquifer flushing).

4 Future for MAR regulations

There are few doubts that the future of the water supply and water integrated management will include MAR technologies at some point in the water cycle, together with other technologies, such as stormwater capture, desalinization, water treatment and water reclamation. This tendency will be especially evident in the regions with high scarcity index or Mediterranean climates. The need to adapt to Climate Changes is also driving the current interest in this kind of technologies (CSIRO, 2011).

However, Europe might still be a little behind in the MAR schemes development, if compared with USA, Israel or Australia. A European policy towards the regulation, dissemination and facilitation of the MAR might help in the development of more recharge sites, always under the integrated and holistic water management that is trying to be pursued in the EU.

With base on the WARBO project experience, as well as in the bibliographical investigations carried out, we suggest the following measures to be integrated in the water policy:

- Assessment of the ponds/excavations were the recharge might be carried on without any risk of water contamination;
- Assessment of the punctual alternative water sources;
- Creation of a SIG based cartography with the best areas for quantitative recharge (possibility to store large volumes) based on the aquifer permeability and water availability;
- Creation of a SIG based cartography with areas with high demand for MAR based on a fine monitoring network with information regarding the water level and quality; Creation of subsidized systems to create MAR structures to mitigate the effects;
- Creation of a SIG based cartography with the best areas to implement a cost-benefit MAR, crossing information of water scarcity, water extractions and economical activity
- Definition of recharge areas for confined aquifers. Numerical modelling studies over the benefits of MAR on those areas
- Definition of the documents required in order to license a MAR facility
    - Hydrogeological study, with aquifer characteristics and geometry
    - Flowdynamic and transport modelling to evaluate the expected fate of the recharged waters (to be updated appropriately based on the monitoring outcome)
    - Monthly chemical analysis of groundwater and recharge water
    - Recharge type, location and observation wells (which one shall be implemented outside the predicted influence area)
    - Pre-treatment type and protocol
    - Recharge plan and protocol
    - Monitoring protocol
    - Maintenance activities and clogging control
    - Project
- Creation of a special status for the aquifers areas/subunits where:
    - Groundwater budget is negative or near negative.
    - Groundwater quality doesn’t meet the required standards

    - Groundwater quality is worsening in the last years
- On these special status areas the creation of a liability mechanism is advisable, targeting the offsetting of impacts in the ground water system. For example, the construction of large impermeabilization areas shall be compensate through a contribution in a MAR system in the same area. The same might be applied to offset chemical load (such as nitrates), or as a compensation measure to apply during the Environmental Impact Assessment phase on the projects with impacts in the water cycle.
- Development of a financial system to reward the infiltrated m^3

Finally, we'd like to refer that, although MAR can be an effective technique to mitigate the fresh water scarcity and water environmental problems and to improve the hydrologic system resilience, its need to operate isn't desirable. Improvements in the water use efficiency, reduction of extraction and pollution load control can't be overlooked, even with the potential of the MAR to ease the impacts of an unsustainable water use.

The European Policy strategy shall therefore continue addresses all phases on the water sector. However, for a more effective MAR implementation, a shift is required in its policy approach: Small, isolated and private driven recharge structures have limited benefits in a relatively small area, and (at its scale) relatively high costs of construction, monitoring and maintenance. A common integrated regional strategy for the water resources protection and conservation is rather much more advisable, and the MAR priority sites and objectives should be listed in the watershed plans. This switch from a bottom-up to a top-down approach, under a central planning policy, might be fundamental for the development of the MAR, with great benefits in the water system resilience.

5 Bibliographic References

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