# Water technology as a tool box for self-sufficient regional water supply

**Work package leader: Prof.dr. P.J. (Pieter) Stuyfzand**

## Content



## 1 Description work package

### 1.1 Problem definition, aim and central research questions

Climate change projections for the Netherlands reveal the risk of periodic shortage of fresh water supply in the future (Loaiciga et al., 1996). During periods of summer drought various parts of the Dutch coastal zone will heavily depend on surface water supply from the major rivers. However, due to the effects of climate change, brackish and polluted intake water from the Rhine/Meuse basin may be more common due to periods of low discharges from rivers and salinity pressures from rising sea levels (Middelkoop et al. 2001; Zwolsman & Van Bokhoven 2007; Van Vliet & Zwolsman 2007; Kwadijk et al, 2007; Oude Essink, 2007). In addition, structural changes in water management are forecast, with profound implications for fresh water availability in especially the Zuidwestelijke Netherlands, in connection with the EU obligation to raise the ecological sustainability of the Deltaworks region. In order to ensure economic sustainability (especially regarding horticulture) and growth in both hotspots 'Haaglanden'and 'Zuidwestelijke Delta', it is crucial to have a sufficient, continuous supply of high quality fresh water, especially in summer. The resulting water stress can be significantly alleviated by storing high quality water when abundant, and by looking at alternative water resources like brackish groundwater and various waste waters, which require treatment prior to use.

WP-4 therefore aims at the following: (1) testing the performance of 2 storage techniques in a brackish groundwater environment, in terms of water quality, storage capacity and recovery efficiency (project 4.1), and (2) making alternative regional water resources, like waste water and brackish groundwater, suitable for use in the greenhouse sector and industry and for flushing the surface water network (project 4.2, link with project 2.1).

The storage techniques are composed of: (a). LSR-ASR, an unprecedented new technology composed of a Leaky Storage Reservoir combined with phreatic Aquifer Storage and Recovery (ASR), with recovery by directly pumping from the reservoir (hotspot Zuidwestelijke Delta); and (b). ASR, a relatively proven technology of aquifer storage and recovery via wells that are used for both injection and recovery (Pyne, 2005; hotspot Haaglanden). Although various small-scale ASR systems are already operational in the region, no monitoring has been carried out to date while lots of problems have been reported due to well clogging, aquifer pollution, the admixing of brackish groundwater and undesired water quality changes due to interaction with very reactive aquifers (PZH 2008).

The alternative regional water resources consist of eutrophic brackish surface water or groundwater, rain water, polluted drainage water and polluted communal wastewater. In a.o. the hotspot Haaglanden some of these resources are being used already, with or without ASR , reverse osmosis (RO) and brine disposal. The situation is running out of hand, because either the treatment and storage systems do not function properly (yielding insufficient water of desirable quality), or the aquifer storage systems and surface water network become polluted; the aquifer by injecting polluted water types, and the surface water by disposal of membrane concentrate or concentrated drain water from the greenhouses (LIT).

The main research questions in project 8 will focus on the following:

1. What are the hydrological and chemical effects of LSR-ASR systems during the filling, storage and recovery stage, how can their hydrological effects be mitigated, and how can salinization, eutrophication and iron flocculation during abstraction from the reservoir be prevented?
2. How can a LSR-ASR system be optimized in order to also form a buffer against extreme annual anomalies in either supply or demand?
3. How can ASR systems be improved so as to maintain or enhance favorable soil-water interactions (like denitrification and biodegradation of pollutants) while minimizing the negative interactions with the local environment (such as arsenic mobilization)?
4. How can ASR fresh water lenses be monitored and prevented from drifting away due to lateral groundwater flow or buoyancy?
5. How can the suspended solids content of turbid surface or rain water during short peak flows be reduced rapidly and at low cost so that this water can be infiltrated directly without clogging the ASR well or aquifer?
6. How can ASR systems be combined with brackish water reverse osmosis to store and recover desalinized water? (See companion project nr. 9)

The leading research questions in project 9 are:

1. What is the availability and quality of the alternative water resources, and which purification techniques can be applied to make them fit for agricultural or industrial use?
2. Are innovative desalination techniques (like Memstill technology and forward osmosis) feasible along with more common desalination techniques (reverse osmosis and evaporation)?
3. Can membrane distillation-crystallization technology be applied to change membrane concentrate into solid waste (no liquid discharge), and can this be demonstrated on a laboratory scale (2 L/h)?
4. Can membrane concentrate (brine) be disposed of by deep well injection into a deeper, (more) saline aquifer without clogging the well or aquifer and without return flow to the wells pumping brackish groundwater?

## 1.2 Interdisciplinarity and coherence between the projects

Within WP-4:
The matching of demand and supply requires storage (project 8) of treated, alternative water resources (project 9).Vice versa, the storage of polluted water in a reservoir or aquifer (project 8) may assist in (further) purifying a treated, alternative water source (project 9).

With other WPs:
Water storage developments are closely related to the groundwater-surface water system studied in WP-2. In addition, the behaviour of ASR fresh water lenses is similar to those studied in WP-2 project 2.2, and as such, knowledge on these lenses will be exchanged.
The output of this study will be used in integral case project 13 (WP6), focusing on the self-sufficiency of fresh water in the region Haaglanden (being the major centre of the greenhouse sector in the Netherlands).

## 1.3 Stakeholders

- Provinces of South Holland and Zeeland.
- Water boards (Delfland, Brabantsche Delta, Hollandsche delta, Zeeuwse Eilanden)
- Municipalities.
- Industry and agriculture sector (ZLTO)
- Drinking water companies (Evides, Dunea, Oasen)

# 2 Project 4.1 Water storage for self-sufficient regional water supply

**Project leader: Prof. dr. P.J. Stuyfzand**

## 2.1 Problem definition, aim and central research questions

### Problem definition

In the Netherlands, climate change may lead to increased peak flows and flood risks during winter in addition to more pronounced low flows during summer [9]. Consequently, it is expected that in surface water systems the concentrations of total suspended solids and pathogens will increase in winter, and those of most other pollutants in summer [10,11]. As a result, many KvK hotspots in the Netherlands may experience reduced water availability and impaired water quality for domestic, agricultural, and industrial purposes during summer and peak demand times. Furthermore, in deltaic regions these problems can be further exacerbated by the threat of marine salinization of water resources during low flow periods [12,15]. In order to prevent regional water shortages, the storage of rainwater, surface water, treated sewage or de-mineralized water in aquifers and/or surface reservoirs constitutes an important adaptation measure. The objective is to store excess water of suitable quality during hydrological peaks for later use during periods of water shortage or peak demands. Innovative and efficient methods of storage will help alleviate regional water availability pressures and ensure delivery of sufficient, high quality water for agriculture, horticulture, industry and municipal drinking water.

Two hotspot areas have been identified where additional local and regional storage is in high demand: the “Zuidwestelijke Delta” and “Haaglanden”. Both regions are home to intensive horticulture and agriculture and are experiencing water shortages during times of peak demand and water quality problems in summer when water supplies are more saline. Two types of storage will be considered: LSR-ASR, a new technology composed of a Leaky Storage Reservoir combined with phreatic Aquifer Storage and Recovery via the reservoir (hotspot Zuidwestelijke Delta); and ASR, a relatively proven technology of aquifer storage and recovery via wells that are used for both injection and recovery (hotspot Haaglanden). Proper water storage is a complex procedure, particularly when native groundwater is brackish and infiltration water is eutrophic or demineralized. Expected difficulties with LSR-ASR include algal blooms, deposition of clogging muds, hydrological impacts on local surroundings, and negative quality changes due to interactions with the aquifer and muddy sediments. Utilizing ASR wells presents numerous hydrochemical challenges [7, 8]. Firstly, infiltration water must be of sufficiently high quality, or otherwise selective intake and/or pre-treatment will be necessary [5]. Furthermore, chemical reactions with the aquifer can lead to Fe, Mn, NH4 and As concentrations above drinking water standards [1]. The loss of infiltration water (or “bubble drift”) can also occur in aquifer systems that become increasingly saline or are used for other purposes [5]. Finally, aquifer deterioration can occur due to accumulation of pollutants, clay mobilization, or leaching [6].

### Aim

The goal is (1) to evaluate and optimize the performance of LSR-ASR and ASR in a brackish to saline groundwater environment, in terms of water quality, storage capacity and recovery efficiency; (2) to evaluate and minimize their adverse environmental effects; and (3) to evaluate the feasibility of their integration with brackish water reverse osmosis to store and recover desalinized water.

**Research questions**

The following main research questions will be analyzed in the context of the hydrogeological and hydrogeochemical setting of hotspots Zuidwestelijke Delta and Haaglanden:

1. What are the hydrological and chemical effects of LSR-ASR systems during the filling, storage and recovery stage, how can their hydrological effects be mitigated, and how can salinization, eutrophication and iron flocculation during abstraction from the reservoir be prevented?
2. How can a LSR-ASR system be optimized in order to also form a buffer against extreme annual anomalies in either supply or demand?
3. How can ASR systems be improved so as to maintain or enhance favorable soil-water interactions (like denitrification and biodegradation of pollutants) while minimizing the negative interactions with the local environment (such as arsenic mobilization)?
4. How can ASR fresh water lenses be monitored and prevented from drifting away due to lateral groundwater flow or buoyancy?
5. How can the suspended solids content of turbid surface or rain water during short peak flows be reduced rapidly and at low cost so that this water can be infiltrated directly without risks of clogging?
6. How can ASR systems be combined with brackish water reverse osmosis to store and recover desalinized water? (See companion project nr. 9)

## 2.2 Approach and methodology

Disclaimer: The methodology described below only gives an outline of the research possibilities. The final research project will depend on the project's budget, which is not defined yet as the amount of co-financing generated by the different stakeholders is still unclear.

The research will be comprised of 2 pilot studies in the Netherlands, in a brackish-saline groundwater environment:

1. A LSR-ASR system in a Holocene, sandy creek infill in Zeeland (hotspot Zuidwestelijke Delta); and
2. A selection of 1-3 ASR wells in the Westland greenhouse district in the province of South Holland (hotspot Haaglanden). The research methodology for both studies will involve an extensive field site characterization, intensive monitoring of hydrological and hydrochemical parameters, laboratory column studies, and modeling simulations to quantify the processes involved, to evaluate and analyze various climate and hydrogeochemical scenarios. This will result in an in-depth understanding of the mechanisms involved in both systems.

The field site characterization will map the sedimentary hydrogeological units and their geochemical composition using drilling, core penetration, and geophysical and laboratory techniques. Characterization and mapping of native groundwater quality will be accomplished by utilizing standard observation wells, mini-screened wells, pumping wells and by analyzing pore fluids from aquitard cores.

Intensive monitoring of hydrological and hydrochemical parameters will proceed using a variety of techniques. Water quantity, pressure, temperature, and specific electrical conductivity will be monitored for 1-2 years using CTD Divers. Vertical temperature logs in the surface reservoir and observation wells will be taken and water quality parameters (environmental tracers, major constituents, trace elements and selected organic micropollutants) will be routinely measured. This monitoring program will be reinforced by column studies in the laboratory, to elucidate the kinetics of the water-sediment interactions in relation to water temperature, pH and/or redox conditions.

Finally, using knowledge from the monitoring program and column studies, modeling of the system will be conducted and scenario studies carried out on results. The modeling will be performed utilizing a reactive transport code such as PHREEQC-2 or PHT3D and, where feasible, an analytical approach will also be undertaken.

## 2.3 Scientific deliverables and results

The proposed project will provide the comprehensive knowledge necessary to answer the research questions outlined, with intensive field measurements forming the basis of this knowledge. As it is a new concept, data from LSR-ASR systems have not yet been reported. Although various small-scale ASR systems are already operational in the region, no monitoring has been carried out and lots of problems have been reported [2] due to well clogging, aquifer pollution, the admixing of brackish groundwater and undesired water quality changes due to interaction with very reactive aquifers.

This research offers excellent opportunities to quantify the kinetics of (bio)chemical reactions and the complex surface/groundwater interactions necessary for proper evaluation. Research will address the need to obtain degradation constants for oxidants and specific micropollutants in real systems with combined seasonal and annual fluctuations in temperature, clogging and redox zonation [4,13,14], as opposed to utilizing biased data from rapid and overly specific laboratory testing [8]. Furthermore, as multi-tracing methods will be applied to characterize and follow infiltration water, the effectiveness of individual tracers in specific environments can be analyzed. The unconsolidated and fine-grained nature of the sediments involved will allow for a detailed and intricate monitoring set-up, providing a high quality data set. Finally, a reactive transport model will be delivered for each system, which can be utilized to predict water quality and quantity issues for similar systems under various scenarios.

The research will be published in the form of a PhD thesis and four peer-reviewed articles in scientific journals. A management summary of the results, including all relevant implications for regional or local water supply, will be published in 2 progress and 1 final report.

### 2.4 Integration of general research questions with hotspot-specific questions

By investigating the challenges and potential of storing fresh water in LSR-ASR and ASR systems, the research assists in providing an additional source of secure and efficient water to the hotspots in question. Through understanding of the hydrological and chemical processes involved with both storage methods, the practicality and efficiency of both methods can be evaluated. Results from the research will optimize the systems so that the maximum amount of high quality water can be obtained.

### 2.5 Societal deliverables and results

An effective regional water supply is integral to the long-term environmental and economic sustainability of the involved hotspots “Zuidwestelijke Delta” and “Haaglanden”. Given current pressures on water resources in both areas and the threat of additional pressures from effects of climate change, this research will assist in making the hotspots more self-sufficient and resilient. This is important in ensuring a secure supply of water for horticulture, drinking water, and industrial and agricultural purposes. As the research is conducted in brackish-saline water environments, the results, tools and knowledge generated can be extrapolated to other areas of the Netherlands requiring additional methods of water storage as well as to coastal and deltaic regions worldwide.

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# 3 Project 4.2 Impact of flexible flood barrier systems

**Project leader: Ir . R.J.M. Creusen (TNO)**

## 3.1 Problem definition, aim and central research questions

**Problem definition**

The regional water system in the western part of the Netherlands depends on fresh water from the main rivers (Rhine/Meuse) in periods of drought. However, due to the effects of climate change, brackish/saline intake water from the Rhine-Meuse basin may be more common due to periods of low river discharges and salinity pressures from rising sea levels [11, 12]. In this low-lying region, the availability and quality of fresh water is of major importance particularly for the greenhouse and industrial sectors.

One adaptation strategy to ensure future availability of enough fresh water is to improve the regional self-sufficiency by optimizing the use of alternative water sources and making these sources suitable, through water technology, as fresh water sources for major users like agriculture, the greenhouse and industrial sectors. Alternative regional water resources can be eutrophic, brackish surface water or groundwater, and polluted waters like rain water, stormwater runoff, greenhouse drain water and treated sewage effluent. To optimally utilize these alternative resources, (innovative) water technologies are required for proper removal of suspended solids, dissolved salt and contaminants. Matching of demand and supply may also require storage (see project 8). Transport and distribution infrastructure is needed to bring collected and pretreated water to the storage location and transport the water from storage to end users. In case of agriculture, this may cause extra challenges, as salt sensitive crops can change position.

As an alternative, (small scale movable) units can be utilized, using water from local surface water as a source. Furthermore, desalination processes generate brine as a by-product and require environmentally accepted solutions for disposal [9,10]. This because the discharge of brine can contain high concentrations of nutrients, salt and/or pollutants.

**Aim**

Our aim is to select, develop and optimize various water technologies in order to contribute to a more self-sufficient regional water system for fresh water supply, particularly in low-lying regions in the Netherlands where salinization of surface water and groundwater is occurring or is projected to increase due to climate change. The water technology is to be developed for the above mentioned alternative regional water resources which in the current situation are not suitable for use as fresh water source for greenhouses and industry or use as regional surface water. Storage, transport and distribution concepts will be developed. Moreover, various techniques (solid salts, solutions) to solve the brine problem are studied.

**Research questions**

This research will address the following questions:

1. What are the major alternative water sources available for regional use and are they of suitable quality?
2. What is the best available technology to make alternative water sources suitable for use in the greenhouse sector, for industrial process water, agricultural use or flushing the regional surface water network? What are the pros and cons of these technologies, in terms of water quality, costs, energy consumption, environmental impact, regulations etc.?
3. If wastewater is used, can additional benefits, e.g. phosphorous reuse and energy production be combined with the required treatment systems?
4. Are innovative desalination techniques (like Memstill technology or Forward Osmosis) feasible as compared to more common desalination techniques (reverse osmosis and evaporation)?
5. Can membrane distillation-crystallization technology be applied to change membrane concentrate into solid waste (no liquid discharge), and can this be demonstrated on a laboratory scale (2 L/h)?
6. Can we dispose the brine in an environmentally acceptable manner (eg. by deep well injection into a deeper more saline aquifer, or by creating solid salt residues)?
7. What are effective distribution systems to feed storage systems and to provide fresh water to (moving) users?

## 3.2 Approach and methodology

*Disclaimer: The methodology described below only gives an outline of the research possibilities. The final research project will depend on the project's budget, which is not defined yet as the amount of co-financing generated by the different stakeholders is still unclear.*

First, in selected regions (hotspots Haaglanden and/or SW Delta) an inventory of the most appropriate alternative regional water sources will be made and analyzed. This will consist of a desk study on water quantity and quality, and localization of availability and demand points. This desk study will build upon local knowledge of the stakeholders.

Secondly, several water technology aspects are analysed in detail which make the water sources suitable for fresh water use. They include: desalination of brackish groundwater; use and treatment of the effluent from waste water treatment plants, including phosphorous recovery and energy production; re-use of wastewater; use and treatment of rainwater; methods for water transport and storage (in combination with project 8). The following specific steps are foreseen:

- ∇ Literature search into the technological opportunities (desk study and demonstration) to make the various sources of water suitable for agriculture, industry and regional surface water. Not only commercially available technologies will be addressed, but also innovative technologies like Memstill (membrane distillation) where waste heat can be used to make fresh water.
- ∇ Demonstration of Memstill technology [4,5,6], in which technology problems, like how to handle sustainable energy supply, fouling and scaling [7], are addressed.
- ∇ Feasibility study of the investigated technologies in terms of water quality, costs, energy consumption,environmental impact and regulations.

Thirdly, there is the question how to solve the brine problem that is inevitably associated with application of desalination techniques [9,10]. The following specific activities are foreseen, in order:

- ∇ An inventory will be made of the current projects on this theme in the province of South Holland, in terms of geographical distribution, water source, performance, technological issues, etc.
- ∇ The hydrological and hydrochemical impacts of brine injection into confined saline aquifers will be studied in a pilot study in the field in the hotspot Haaglanden.
- ∇ The following practical questions will be answered regarding the combined concentration-crystallization process to produce a solid end product which may be reused for industrial applications (the “no-waste” concept of TNO):
    - Can membrane distillation and crystallization be integrated in the same module?
    - How to prevent plugging of the module by crystallization on the membrane due to concentration polarization and/or temperature polarization?

### 3.3 Scientific deliverables and results

1. A decision instrument for selecting the best purification technology of a given set of raw water qualities, under conditions of quantity, availability (periodical, perennial), costs and environmental side effects.
2. Demonstration of innovative water treatment technology, in casu Memstill desalination, on a small pilot scale.

3. Demonstration of innovative brine treatment technology on laboratory scale (concentration and crystallization processes)
4. Field evidence of the hydrological and hydrochemical impacts of brine injection into a saline aquifer, with focus on injection well clogging and quality changes of the brine in the aquifer.

The research will result in 2-3 peer-reviewed scientific articles and a scientific report.

### 3.4 Integration of general research questions with hotspot-specific questions

The research theme of this project, using water technology to improve regional self-sufficient fresh water supply, is relevant to all the hotspots confronted with the impacts of salinization: Zuidwestelijke Delta, Haaglanden, Rotterdam, Schiphol (region) and Waddenzee. The Zuidwestelijke Delta and Haaglanden hotspots particularly have expressed their keen interest in research to enlarge the regional self sufficiency of water supply. Research on water technologies will provide innovative, new methods to help achieve this goal.

### 3.5 Societal deliverables and results

The research project will lead to innovative and practical knowledge and technological concepts which will contribute to more self sufficiency of fresh water supply on regional and local scale, thus constituting a robust adaptation measure to climate change. In a salinizing environment such as the Zuidwestelijke Netherlands, this knowledge is indispensable.
The results of the study will be used to advise both the regional and national authorities which have to make choices about adaptation strategies.

The provision of technology development for more regional self-sufficient water supply in saline environments is important for all deltaic and coastal regions. The knowledge and concepts generated in this research can be utilized to help develop alternative water supply in similar regions worldwide. In addition, newly-developed or optimized processes for treatment and disposal of desalination brine with minimal environmental effects are relevant for all countries that operate desalination plants (Middle Eastern countries, Spain, Australia). Addressing this environmental issue could open up new possibilities for the wider implementation of desalination plants globally.

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