Investment 5: Kreekruginfiltratie, Braakman Zuid (NL)

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Executive Summary

Demo setup

This demo site consists of a pilot scale "Creek Ridge Infiltration" (CRI; *Kreekruginfiltratie* in Dutch) installation combined with a feasibility study for a full-scale replication. Creek Ridge Infiltration is a kind of Managed Aquifer Recharge in which water is infiltrated and abstracted in a shallow (phreatic) sand aquifer in otherwise clayey polders. These sandy soil bodies are tidal creek deposits that are located at a slightly higher topography than surrounding clayey polders due to compaction of these surrounding clayey deposits. Hence the name Creek Ridge.

The demo of FRESH4Cs at Braakman Zuid consisted of two parts: a pilot scale demonstration of the CRI technique, and a feasibility study for a large (full scale) CRI investment in the future.

In the pilot scale demo, about 10,000 m^3 freshwater was infiltrated by gravity over an area of 35,000 m^2 during the winter of 2021-2022. During summer 2022 about 5,000 m^3 was abstracted and used for irrigation. Quality aspects of infiltration water and subsurface water quality were monitored on a regular basis. No negative impact revealed on size of the freshwater lens nor on the direct surroundings of the demo area.

The demo results and parallel investigations of suitable land areas (by using advanced models and data sets) and possible freshwater supply systems provide a solid basis for planning a full-scale system to store 1,000,000 m^3 and withdraw 500,000 m^3 over an area of approximately 3 km^2. The quality of infiltration water requires special attention as not all limits for components (especially various pesticides) may not be met, and therefor may require a pretreatment when designing for a full-scale system.
Direct and indirect costs are estimated for the Braakman Zuid case and indicate a freshwater pricing of 0.35 Euro/m^3.

Non-technical aspects

The collaboration in Braakman Zuid is fairly unique, involving chemical industrial company Dow Benelux and local farmers, who both are lacking freshwater availability during drought periods. The demo is further supported by HZ University of Applied Sciences on aspects of water technology and business development. Evides Water company and the regional waterboard Scheldestromen are observer partners in the project.
Getting a permit for the demo was not very straightforward since the regulatory framework around subsurface storage technologies is relatively new and not all boundaries seem fixed yet.
For the full-scale implementation several collaboration models will be evaluated, covering both financial, juridical, and operational aspects. The 'winning' model should address the required investment, the fixed and variable costs for both farmers and Dow, ownership and responsibilities, resiliency towards varying needs across seasons, and be attractive for participants and possible new tenants.

Lessons learned

Communication with (potential) partners (farmers) and stakeholders at an early stage is key. We organized several workshops, but more individual approaches may have been worthwhile.

The permitting process is cumbersome, since technologies for temporary subsurface storage of freshwater are new and appropriate legislation is still in development – it is suggested to set up a workshop specifically devoted to permitting aspects in relation to water storage in the underground.

Assessment of costs for full-scale implementation is difficult since many factors relate to local circumstances, like distances to the freshwater source and end-users and differences in elevation across the area, freshwater quality, local permit requirements, and availability of reliable models for the area.

The potential source water chosen to be infiltrated is extremely important; if it is not of the correct quality standards, extra treatment steps may be required leading to extra investment costs.

Introduction

The region of Zeeuws-Vlaanderen in the southwest of the Netherlands is scarce in freshwater sources. Industry and agriculture are dependent on remote supply from either the Biesbosch area (natural wetland area and prime source for potable water production) and Flemish polder run-off. Both sectors suffer from shortages in freshwater supply during drought seasons and explore opportunities for alternative sources. A promising source might be the excess of freshwater available during winter period (due to precipitation) provided that significant volumes can be captured and stored for later use. Beyond installing aboveground basins, options to use the underground are of particular interest as these involve no substantial land use with little visible impact on landscape.

In the province of Zeeland various initiatives were taken over the past years to explore different methods for temporary underground storage of freshwater (FRESHEM, GoFresh, de Waterhouderij, and others). The Creek Ridge Infiltration (CRI) demo in FRESH4Cs is initiated by Dow, a US based chemical company with one of its major manufacturing facilities located in Terneuzen, with the objective to secure water sources during summer periods by collaborating with local farmers and other stakeholders (like the Waterboard Scheldestromen, water company Evides, NGO's, and research institutes).

The principle of CRI is to let an existing freshwater bubble grow over time by means of a balance between infiltration and abstraction. A preliminary feasibility study was executed by Deltares (contracted by Dow) to screen the viability of CRI in the Braakman South area given the fact that potential sources for freshwater supply during wintertime are relatively close by. The results of this study gave sufficient confidence in both the technology and regional applicability to set up a demo as described in this document.

Technical aspects of the demo

Demo setup

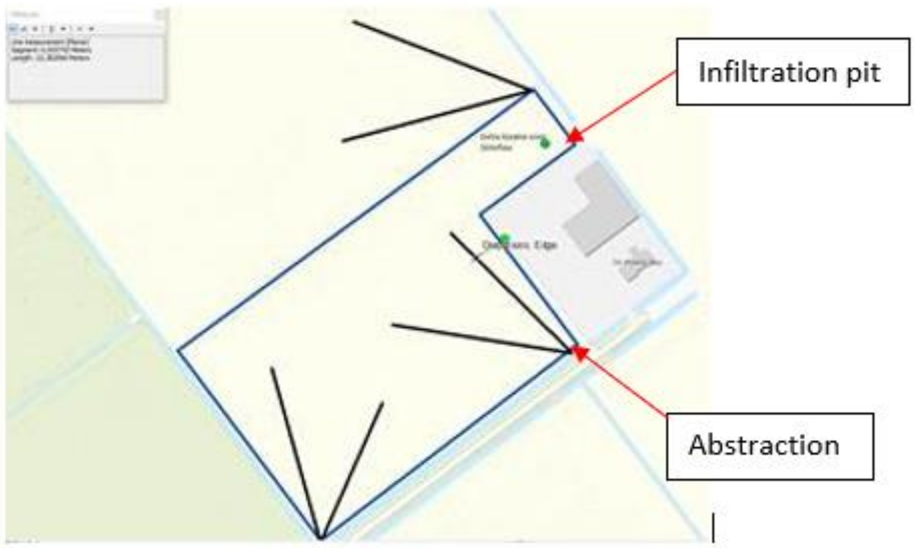
Selecting suitable locations

The abovementioned study resulted in an area map assessing the suitability of locations for CRI based on soil properties and saline/fresh groundwater appearance. Two interactive sessions and a round of semi-structured interviews with local farmers were conducted to ponder the interest of individual farmers to participate in a field demo. From six agricultural areas two were selected to conduct more detailed monitoring of groundwater levels and saline/fresh groundwater interfaces. These data and the access to freshwater supply in the winter season then favored one area for the demo.

Proof of concept pilot setup

The selected area was located nearby the freshwater basins of Evides water company with direct availability of freshwater to the premises of the farmer of choice. Also, some infrastructure at the farmers land was already available (deep drain strings (at -6m) for abstraction). For natural infiltration a drainage system at -0.5m still had to be installed though. The total area of the demo was 3.5 hectares (35,000 m^2). Deltares' estimation was that per hectare about 3,000 m^3 freshwater can be infiltrated and 1,500 m^3 abstracted (as per the regulators license) annually to create and maintain a sustainable freshwater bubble. Infiltration is done using gravity only, whereas abstraction requires dedicated pumping. Therefore, about 10,000 m^3 could be infiltrated in the demo area to withdraw 5,000 m^3 annually for irrigation and industry use. The demo location was instrumented to control the daily infiltration rate and measure volumes of infiltrated and abstracted water respectively. All data were accessible at an on-line platform for both the farmer and project participants.

For the pilot scale demo (see location scheme of the demo with infiltration and abstraction below) the drains (0.5m depth) were used for infiltration and the existing deepdrains (6m depth) for extraction. Infiltration was done by connecting the drains to the supply line coming from the Evides basin (elevation of the basin is about 12m, so gravity was sufficient for infiltration in the drainage system). Infiltration rate was controlled by setting a daily maximum (in m^3/day) – the supply was continuous until the daily max was reached and the valve shut off automatically. The default setting for the maximum infiltration was 130 m^3/day. A picture of the infiltration location with control system is added below.
For extraction a centrifugal pump was used (Pedrollo type JCRm 1A, 0.55 kW, rate 5-60 l/min, head 48m). Abstraction was intermittent during summer periods when the farmer used the stored for irrigation.
Both infiltration and abstraction were monitored with continuous water meters (Siemens MAG5100W).

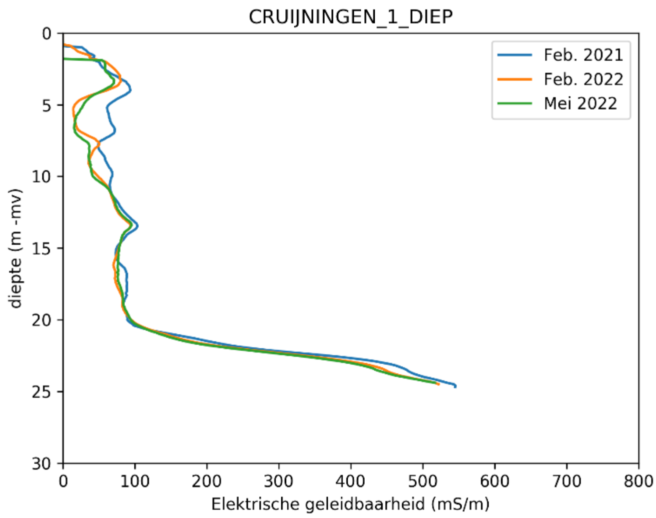


Monitoring

In the demo area two boreholes (-25m depth) were installed, each of them equipped with on-line groundwater monitoring (divers) and the possibility for sampling. To monitor the freshwater bubble development (size) regular SlimFlex measurements were conducted generating a conductivity profile over the depth of the borehole. Sampling prior to the demo execution and during the process of infiltration and withdrawal is required to monitor the composition of the infiltrated water and the subsurface freshwater bubble. A list of required analytical data with associated thresholds is provided by the regional waterboard Scheldestromen to obtain a permit for the demo. A picture of two boreholes at the demo location is given below. In total 8 boreholes were installed at various land areas, three of them at the demo plot.

Technical performance

Only a single cycle of infiltration and abstraction has been executed at the demo location. Therefore, the monitoring results are preliminary – it is expected that seasonal conditions, which vary considerably from year to year, will impact the actual performance of the system.
A graphical representation of the conductivity profile at one of the boreholes at the demo is given below. The three data curves reflect the situation at the borehole installation (Feb'21), the start of infiltration (Feb'22) and upon completion of the infiltration (May'22). Although 10,000 m^3 of freshwater was injected significant growth of the freshwater bubble could not be confirmed with these data – several factors, like soil saturation and horizontal extension will influence these results and may explain the phenomena observed. More detailed analysis therefor is needed to draw more solid conclusions.



Lessons learned

- The Infiltration and abstraction operations worked well, despite some issues which had to do with the local circumstances (at times there were restrictions in the supply line of the infiltration water, which impacted the ability to infiltrate on gravity)
- The software worked well and enabled a continuous tracking of the pilot.
- Based on a single season of measurement the saline border didn't move (no vertical growth of the freshwater lens in the underground), so question is where did the water go? Was the pilot not large enough for the very large creek ridge or was water pushed to the sides, etc – next cycles and additional monitoring should bring more clarity.

Non-technical aspects of the demo

Regulatory framework

In the Netherlands the so-called "Infiltratiebesluit" determines the rules and procedures that have to be obeyed with respect to infiltration and abstraction of subsurface groundwater. For different sizes (volumes of water) and type of operation maximum limits for infiltration/abstraction per year are defined whether a permit is required and which other rules have to be followed. Also, the quality of water being infiltrated is addressed, comprising a list of components that must be analyzed on both the infiltration water and the subsurface water, and the frequency this has to occur.
For the Braakman Zuid demo this meant that a permit has to be granted by the Waterboard Scheldestromen for both infiltration and abstraction – the submission had to comprise:

- the overall plan, the set-up, and technical details of the demo
- a "vormvrije" MER report (an assessment made by a certified independent party on the environmental impact of the demo)

The analytical requirements are described above.

Business setup

The demo was initiated by Dow and facilitated by the local farmer, who allowed the project taking advantage of the infrastructure present at the demo location. Dow provided the investment to install monitoring wells, pumping and metering equipment as well as a remote-control system. Evides (one of the observer partners in the project) supported using the connection to their freshwater basin as freshwater supply for infiltration. HZ had a dual role in the demo: 1) The research group of water technology performed sampling and analysis of the demo, while 2) The group KCOI (Knowledge Center for Business and Innovation) interacted with the local farmers on the socio-economic (non-technical) opportunities of the collaboration, especially focused on the business case and full-scale implementation. For full-scale implementation several models will be evaluated, covering both financial, juridical, and operational aspects. The 'winning' model should address the required investment, the fixed and variable costs for both farmers and Dow, ownership and responsibilities, resiliency towards varying needs across seasons, and be attractive for participants and possible new tenants.

Business case

Technical basis and direct costs

The business case Braakman Zuid is related to the potential of scaling up the demo to a size equipped to withdraw 500,000 m^3 from subsurface freshwater lenses annually. Using a 50% recovery of infiltrated water about 1,000,000 m^3 has to be infiltrated each year, which at an estimated load of 3,000 m^3 per hectare means that about 300 hectares (3 km^2) is required.
The required infrastructure costs need to cover:

- gravity infiltration drains (-0.5m), estimated at 2800 Euro/ha
- installation of deep drains for abstraction (-5-6m), estimated at 2000 Euro/ha, + pumps
- supply of freshwater during winter season to the premises involved (100 Euro/m) + pumps where needed
- distribution of abstracted water for irrigation and industry use

Then, also pre-treatment costs have to be considered (if needed to meet permit requirements), as well as instrumentation for metering and control, and project management costs including permit submission.

Financial basis

A preliminary calculation for Braakman Zuid based on the assumptions in the previous section indicates a pricing of about 0.35 Euro/m^3 for an assumed activity length of 20 years.
Different financial models can be applied to diversify costs among partners and over the duration of the activity. For example, the price per m^3 can be reduced by attracting external financing partner, invest more upfront, using different keys for distributing costs among partners, compensate land use to individual farmers, and acquiring subsidies. Also water prices can be diversified by using different price levels for standard off-take, fixed/variable rates, and higher charges for supplemental water. An indicative table below shows how these variables may impact the price per m^3.

Price per m^3	Distribution key (60-40)	Distribution key (50-50)	Distribution key (40-60)
Investment 0%	€ 0.57	€ 0.46	€ 0.38
Investment 20%	€ 0.46	€ 0.36	€ 0.30
Investment 40%	€ 0.34	€ 0.28	€ 0.23

Social aspects

The organizational structure that suits the collaboration between local farmers and the industrial partners has to be detailed in a concerted effort, which allows all parties to express their needs, demands, wishes, and limitations. The current business case is being reviewed by farmers to get a better view on their support. Collaboration models differ ranging from a cooperative agricultural construction to external financing. In earlier talks the farmers have indicated that they are open to collaboration with industrial and agricultural partners, and in some cases they already have agreements in place. The current price range estimate is acceptable for most farmers in the area. This could change depending on external factors like current weather, investment structure and definitive rights to water quantity. Main concerns of farmers are around contingency plans & legal liability, influence on own infrastructure and reliability of the solution. Drivers consist of higher earnings & crop yield and an increased reliability of their business.

Lessons learned

A few critical aspects were noticed during the preparation and execution of the demo:

- The regulatory framework is critical. Although contacts were established with the agencies (in particular the regional waterboard) in an early stage of the project, boundaries and requirements for an infiltration/abstraction demo remained unclear for a long period. The procedures are not straightforward and appear to be viable for various interpretations. Consequently the permitting process was very time-consuming and fairly inefficient.
- The quality aspects of the infiltrated freshwater are a potential showstopper for scale-up – the very strict limits for a number of components, especially all different crop protection agents (pesticides), will in most cases require a costly pretreatment before actual infiltration can start. These low levels do not give notice of the fact that freshwater is only temporary stored and definitely more research and evaluation is needed to assess meaningful limits for naturally infiltrated water (the current practice of farmers is to irrigate their premises with

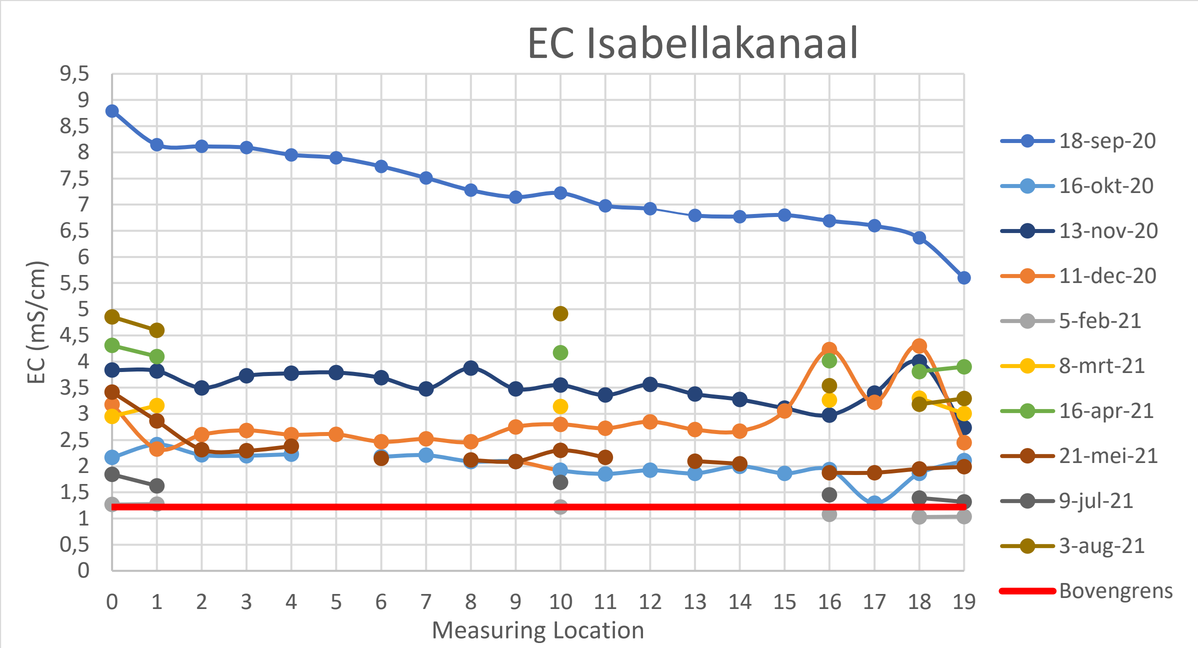
surface water available in ditches nearby – this water essentially has the same quality as water used for natural infiltration at -0.5m).

On the business aspects of the demo learnings comprised:

- communication with (potential) partners (farmers) and stakeholders is key (although several workshops were held more individual approaches may have been worthwhile);
- farmers quickly 'think' according to their 'individual business model', thereby requesting answers which are not available yet, especially on pricing of water to be used for irrigation;
- practical collaboration models should be on the table in an early stage to allow sufficient input and confidence of partners involved;
- assessment of costs for full-scale implementation is difficult since many factors relate to local circumstances, like distances to the freshwater source and end-users and differences in elevation across the area, freshwater quality, local permit requirements, and availability of reliable models for the area.

Full scale development

Future plans involve the assessment of a larger system suitable to store about 1,000,000 m^3 of freshwater in subsurface bubbles annually in order to withdraw 500,000 m^3 for industry and agriculture use during drought seasons. Therefor an area of about 300 hectares (3 km^2) is needed with the required infrastructure for infiltration and abstraction. To identify a suitable area existing models have to be refined and supplemental monitoring of fresh and saline interfaces is required. Also, an extension of the current demo with three more cycles of infiltration/abstracted is foreseen to build a more solid data base on the performance of the entire system.
Parallel to the demo itself an extensive study was carried out on the availability of suitable sources in the region (both with respect to quantity and quality) in view of a significant scale up (by a factor 100 – 1Mm³ per year infiltration The graph below shows detailed salinity levels over the length of the nearby Isabella canal in 2020/2021)).
The measurements show that only for circa six weeks in one year time the values were under the threshold of 1.22 mS/cm representing the chloride concentration of 160 mg/l. From these measurements it can be concluded that the water of the Isabellakanaal contains a too high chloride concentration to be used as a reliable source of fresh water for infiltration into the groundwater.



However water quality of the Leopold canal and polders near to the Evides' pumping station is more promising. Especially the "Evides" water is of interest in case of scale-up, since the quality is similar to what was infiltrated at the demo, and a quantity balance has revealed that most likely sufficient excess of water is available during most winter periods.

The water of the Leopoldkanaal showed to be fresh enough for infiltration. However, the metals cupper and manganese exceed the threshold for infiltration, 2.4 µg/l and 31 µg/l respectively, when biological agriculture would be performed. Also the total sum of pesticides exceeds the threshold of 0.5 µg/l with the individual pesticides BAM, glyphosate and AMPA exceeding the threshold of 0.1 µg/l. Finally the PACs phenanthrene and fluoranthene also exceed the threshold for infiltration of 0.003 µg/l. The water quality of the Leopoldkanaal is therefore insufficient for direct infiltration in the groundwater.

The water of the 'Evides water' (originating from the Zwarte Sluispolder and the Isabellapolder) seems slightly better than the water of the Leopoldkanaal, however also cupper, manganese, BAM, AMPA, glyphosate and phenanthrene exceed the thresholds mentioned in the Nota Grondwater. Direct infiltration therefor is not a viable option – some pretreatment needs to be done prior to subsurface storage.

Conclusions and replication potential

The Creek Ridge Infiltration demo at Braakman Zuid (the Netherlands) has successfully demonstrated that freshwater can be infiltrated by means of gravity at a rate of at least 3,000 m3/ha per season. Although the demo was operated during a single cycle only about 50% of the infiltrated water could be reused for irrigation without negatively impacting the size of the freshwater lens and the surrounding area.
The quality of the infiltration water (originating from the Evides basins) was barely meeting the limits of some pesticides, which may require a pre-treatment of supply water when scale-up takes place. This is in line with the findings in the previous sections.

The permitting process is cumbersome, since technologies for temporary subsurface storage of freshwater are new and appropriate legislation is still in development – it is suggested to set up a workshop specifically devoted to permitting aspects in relation to water storage in the underground.
The area of Braakman Zuid seems suitable for large scale implementation of CRI by using excess surface water from Flemish polders.
Socio-economic aspects are important to enable cross sector collaboration and to set-up a viable cooperation between different actors in the field.
The demo and related studies can be used as a template for replication at other locations.

References

Bleyenberg, S., & van Maldegem, A. (2021). *FRESH4Cs D3.2.2 Non technical assessment top 5 locations.* Vlissingen: FRESH4Cs.

Letterie, B. (2022). *Water quality and quantity: Freshwater sources for infiltration in the Braakman-Zuid area.* Middelburg: FRESH4Cs.

Oude Essink, G., Pauw, P., van Baaren, E., Zuurbier, K., de Louw, P., Veraart, J., . . . Groen, M. (2018). *GO-FRESH: valorisatie kansrijke oplossingen voor een robuuste zoetwatervoorziening : rendabel en duurzaam watergebruik in een zilte omgeving.* Utrecht: GO-FRESH.

Rozema, J., Pauw, P., Arts, M., van Baaren, E., Nikkels, M., & Moermans, T. (2019). The Water Farm: collaborative water system measures and governance approach to increase self-sufficiency of freshwater availability for agriculture. *Saline Futures: Addressing climate change and food security* (pp. 50-51). Leeuwarden: waddenacademie.

Siemon, B., van Baaren, E., Dabekaussen, W., Delsman, J., Karaoulis, M., & Steuer, A. (2019, January). Automatic identification of fresh–saline groundwater interfaces from airborne electromagnetic data in Zeeland, the Netherlands. *Near Surface Geophysics, 17*(1), 3-25. doi:https://doi.org/10.1002/nsg.12028

Waterschap Scheldestromen. (2019, July 2). Nota Grondwater. *Nota Grondwater*. Middelburg, Zeeland, the Netherlands: Waterschap Scheldestromen.

Wiersma, A. (2022). *FRESH4Cs: Analysis Infiltration Pilot.* Utrecht: Deltares.