Interreg

EUROPEAN UNION

2 Seas Mers Zeeën

FRESH4Cs

European Regional Development Fund

Investment 2.2: Managed Aquifer Recharge Demo at Felixstowe (UK)

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Table of contents

Executive Summary

Demo setup

The FRESH4Cs MAR demo site is located at Bucklesham Suffolk, UK. Water is pumped from the Kingsfleet river, approximately 11km to the south east, and infiltrated into the Crag aquifer via a recharge field consisting of 600m of perforated pipe, buried 2.7m below ground level and fed by a small header lagoon. Water is re-abstracted using two 18m deep boreholes located adjacent to the recharge field.

Two trials were carried out as part of the demo, summarised below:

1. Initial pumping test: Nov to Dec 2021. Water infiltrated: 5,630m^3, Water recovered: 520m^3
2. Operational trial: Jun to Sep 2022. Water infiltrated: 12,262m^3, Water recovered: 12,301m^3

Water quality analysis of the source water was carried out for 590 compounds and groundwater levels were monitored at 8 observation boreholes in the 18-month period leading up to the trial and during the trials themselves. No hazardous contaminants were found to be of concern either within the source water or the receiving aquifer. Elevated concentrations of chloride (126Mg/l) and NO3 (1Mg/l) were found in the source water, however, these were generally lower than concentrations found in the receiving aquifer. Hydrological analysis of the trial indicated that up to 40,000m^3/year could be infiltrated and re-abstracted without causing adverse water resources impacts on nearby properties, rivers or springflows.

Non-technical aspects

As FRESH4Cs project partners, the UK regulator, the Environment Agency (EA) were able to provide significant regulatory support during the demo. The initial pumping test and operational trial were carried out under 'groundwater investigation consents' with two further permits; a discharge consent and an abstraction licence, required to run the MAR demo on an operational basis. Data collected during the initial test and trial allowed the EA to issue both consents for an infiltration and recovery quantity of 40,000m^3/yr, subject to mitigating conditions.

Lessons learned

The maximum **recovery rate** from the demo was limited by the hydraulic properties of the aquifer. This meant that water could not be delivered at a sufficient rate to operate a typical field scale irrigation system. Instead, it was necessary to transfer water into an existing reservoir and then re-abstract it at a higher rate for irrigation. This adds to the operational cost and reduces the flexibility of the demo.

The capital **cost** of setting up the MAR demo was approximately 10% lower than the cost of an equivalent sized reservoir. Approximately 57% of the demo costs were associated with data collection and permit applications. This is a significant contrast to reservoir construction, where only 14% of the capital costs are associated with monitoring and regulatory compliance.

The **lack of an established regulatory pathway** and the difficulty of meeting regulatory concerns added to the cost and time taken to collect data and prepare consent applications for the demo. This could prove to be a significant barrier to the further uptake of field scale agricultural MAR.

Introduction

Agricultural irrigators in coastal Suffolk are facing reduced supply of freshwater resources (groundwater supply reduction by 16% by 2027), due to regulatory requirements to meet environmental (Water Framework Directive) thresholds. High flow surface water is pumped into the North Sea by the Internal Drainage Board, from below sea level pumping stations along the Suffolk coast, to meet their national drainage responsibilities.

The obvious opportunity is to recycle this freshwater to farm based winter storage, to use for summer irrigation, instead of wasting this scarce resource to the North Sea. To achieve this Felixstowe Hydrocycle (FHC) was formed to develop a shared water abstraction and distribution system with a capacity of 600,000m3 per year, and servicing six land holdings. This was constructed and tested between 2020 and 2021 under FRESH4Cs investment 2.

Most of the water is supplied during the winter at periods of high flow. This means that storage facilities are required to hold it until the summer irrigation season. Traditionally farmers have used plastic lined reservoirs to store the water. These take up large areas of potentially productive land and involve high capital and environmental costs. The Managed Aquifer Recharge (MAR) project is an innovative proposal which aims to provide a cost effective and sustainable alternative storage solution by holding the surplus water in the underlying Crag aquifer instead of reservoirs.

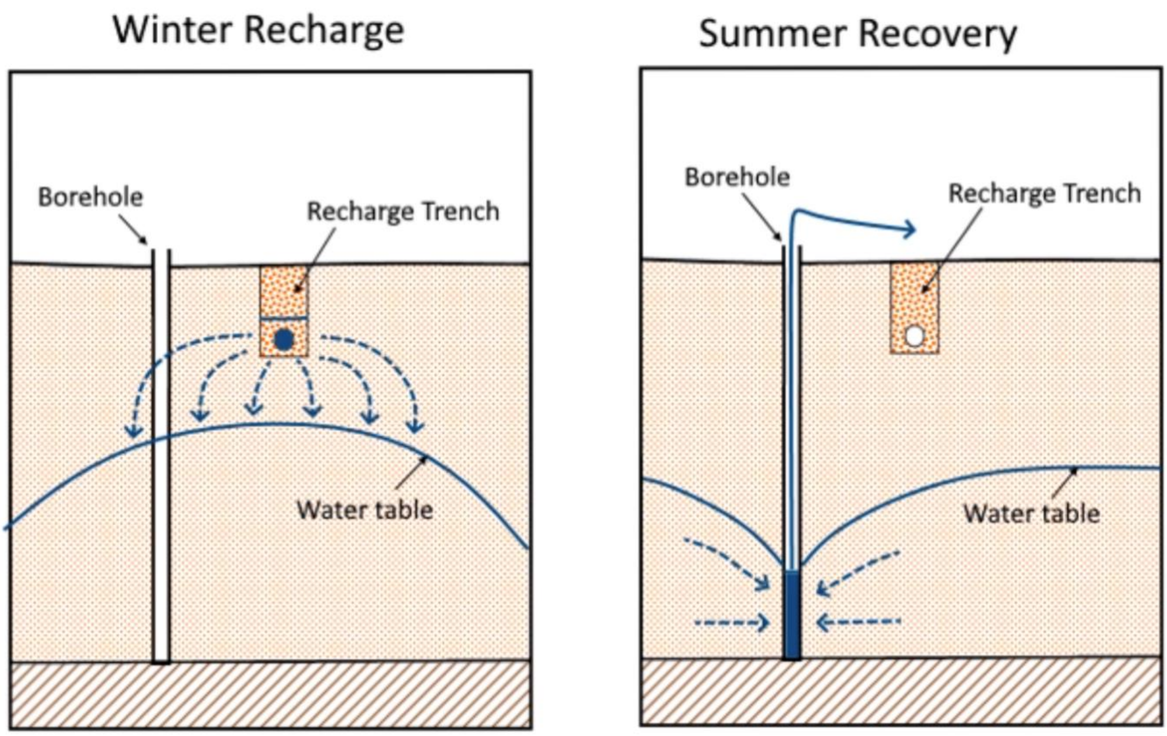

Figure 1. Schematic showing seasonal operation of MAR and recovery

The Red Crag aquifer which extends across the Suffolk Coastal area, has a high-water holding capacity (porosity) and lies close to the surface beneath permeable topsoils which makes it appropriate for MAR, using low cost infiltration solutions such as, drainage trenches, soakaways or pipes or shallow lagoons.

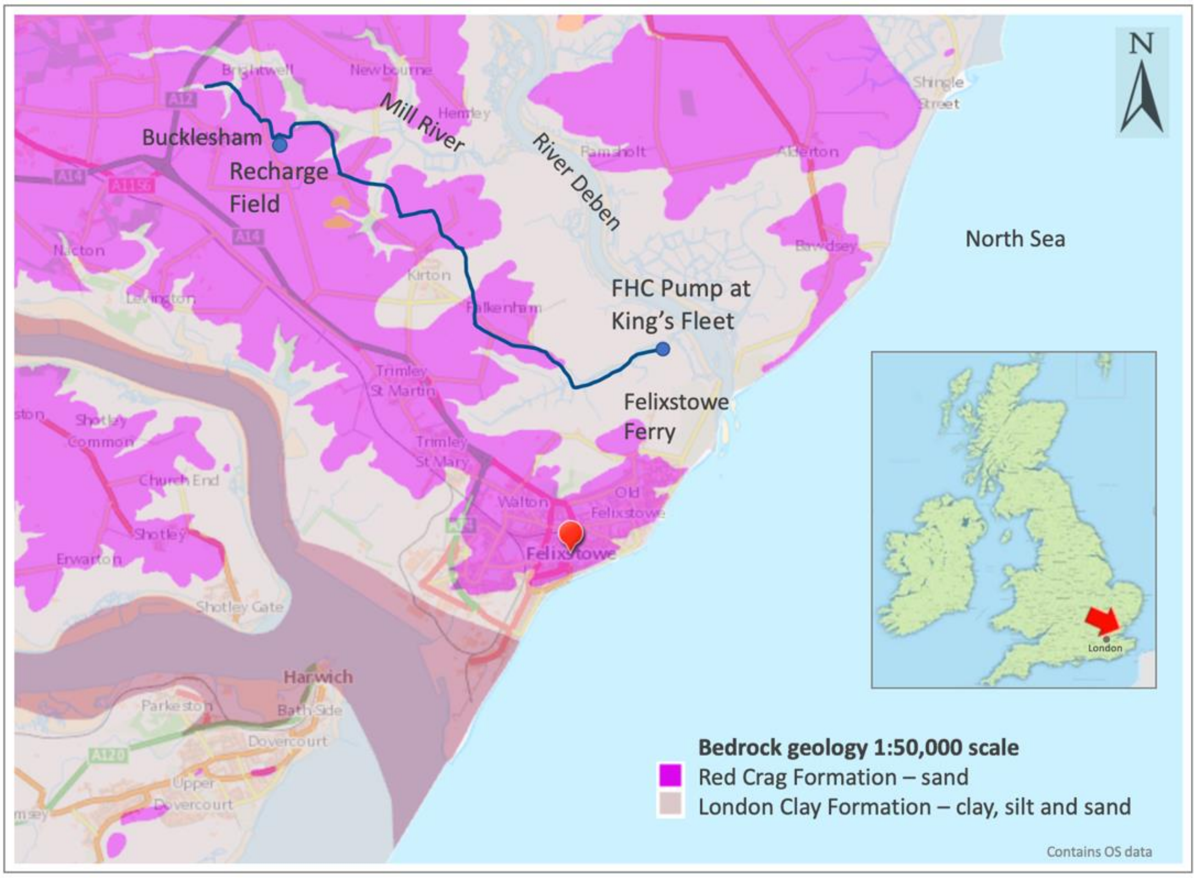

Figure 2. Map showing geology and location of the FHC water transfer and MAR site.

MAR for agricultural use is not practiced in the UK due to regulatory concerns about ground water quality, hydrogeology and the absence of regulatory support or systems. Without practical examples and clear regulatory guidance, farmers and environmental groups are unconvinced about its benefits.

This demonstration was intended to investigate whether it is technically and economically viable to recharge and store water within the shallow aquifer for subsequent re-abstraction for irrigation. It also tested the regulatory framework and provided a template for carrying out similar projects elsewhere.

Technical aspects of the demo

System overview

The MAR scheme was designed to work in conjunction with existing FHC farm reservoirs, providing supplementary capacity when these are full. Water is taken from the Kings Fleet and pumped up the Felixstowe Hydrocycle (FHC) pipeline and delivered to the Managed Aquifer Recharge (MAR) recharge system located to the east of Bucklesham village (see figure 1).

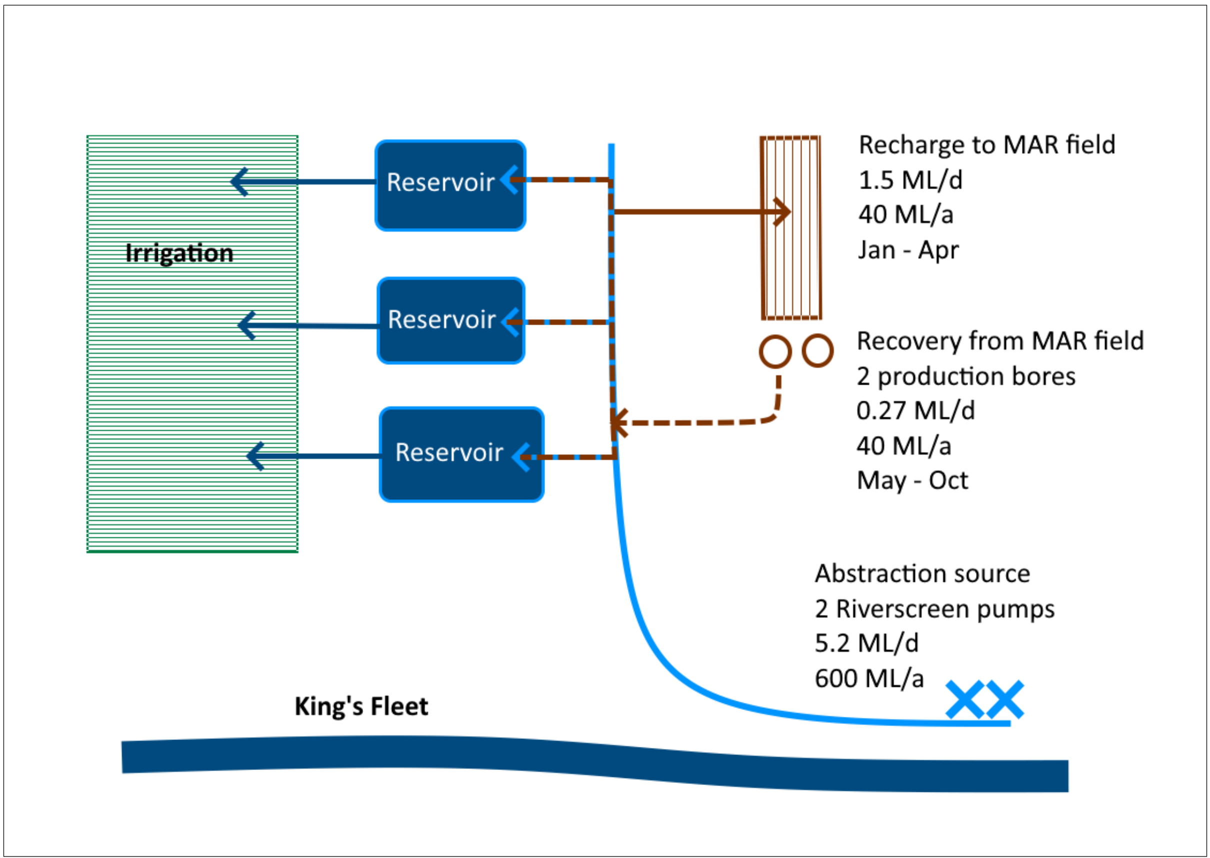

Figure 3.Schematic of FHC transfer and MAR system

MAR System Design

The system is designed to apply 40 ML of artificial recharge to the Crag aquifer between January and April (120 days) at a maximum rate of 1500 m3/d. Water is recovered from the Crag aquifer through two boreholes during the subsequent May to October (184 days) and piped to the FHC storage reservoirs as they are drawn down. The maximum daily rate of water recovery is 270 m3/d. This is constrained by the sustainable combined yield of the scheme's two Crag abstraction boreholes.

	Period	**m^3/yr**	**m^3/d**
Recharge	January to April	40000	1500
Recovery	May to Oct	40000	270

Table 1. Design recharge and recovery rates and periods

Recharge Field

Following several design iterations, FHC chose to use buried perforated pipes to infiltrate the water in preference to less expensive open trenches or drains. The reason for this was to:

- reduce clogging and biofilm build up
- minimize land take
- avoid the lower permeability soils close to the surface
- avoid low temperatures that decrease water viscosity.

The recharge field is comprised of perforated pipes which are supplied from a 70 m^2 filling lagoon. The lagoon is topped up with recharge water supplied via the FHC pipeline and maintained at a head of approximately 300mm bgl. Water enters the pipes from the filling lagoon via a gravel and rock filled filter bed and gabion. The lagoon provides a head of approximately 2.5m above the base of the recharge trenches.

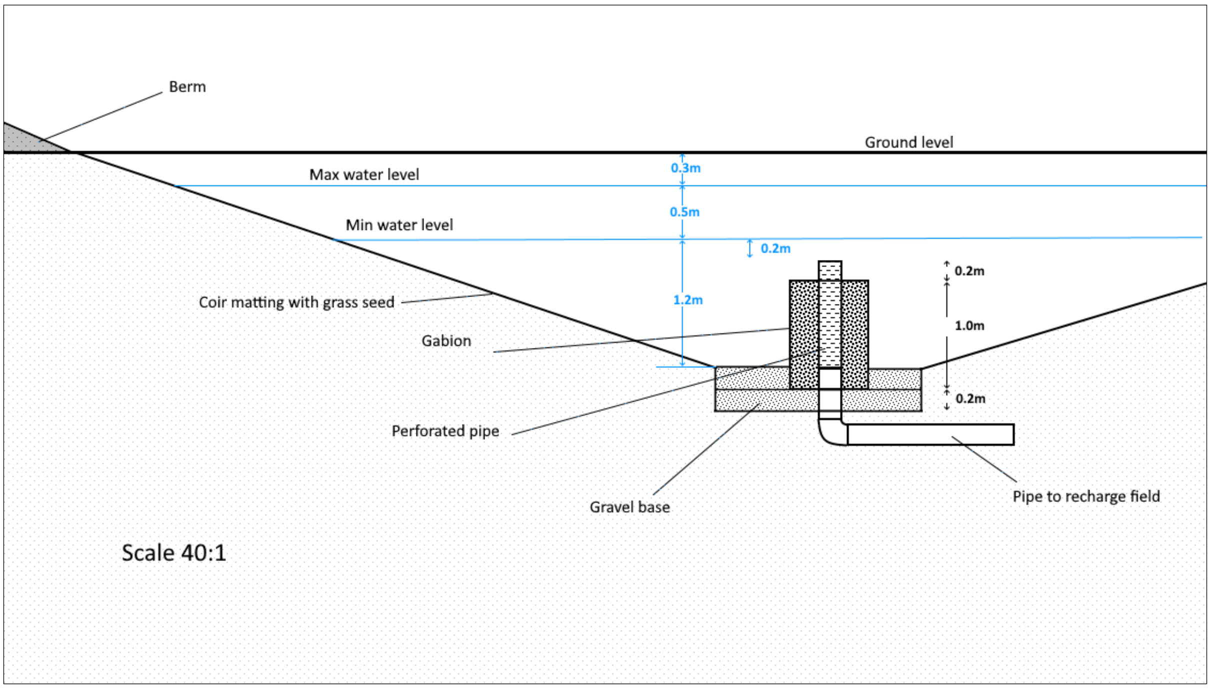

Figure 4. Cross section of recharge lagoon

Figure 5. Photograph of recharge lagoon in operation

Figure 6. Recharge trench under construction and perforated recharge pipe

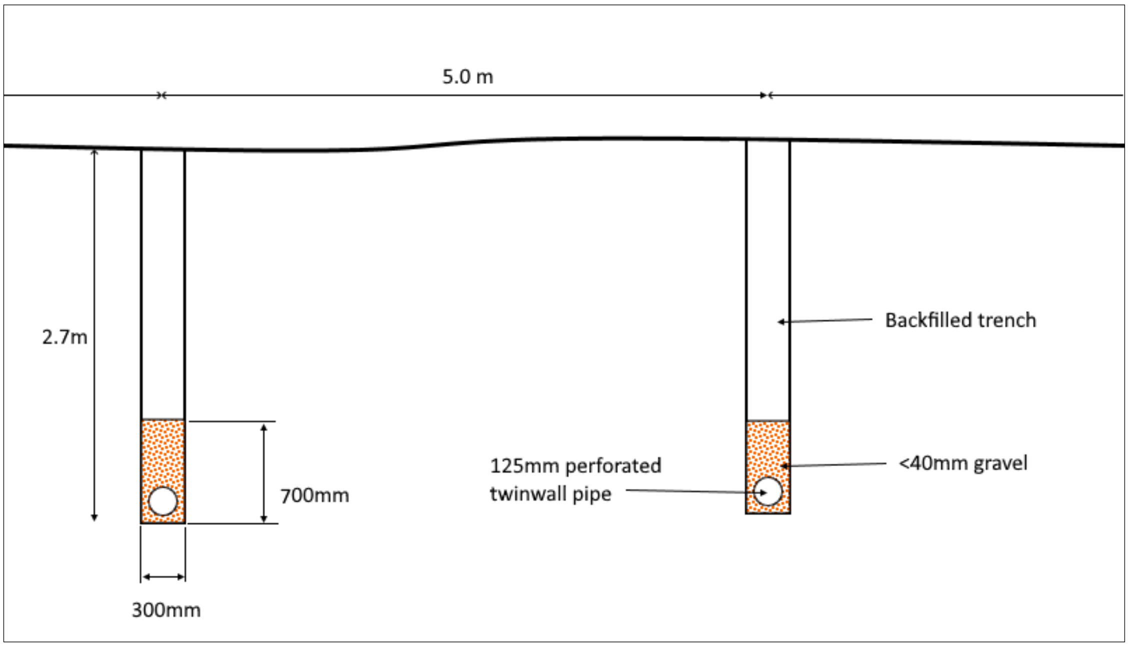

Figure 7. Section showing recharge trench construction and dimensions

The total length of pipes in the drainage field is about 565m. These are comprised of a 125m length of 225mm 'primary drain' connected to four 110m 'secondary drains' of 125mm diameter pipe as shown in figure 2. The pipes are set in gravel filled trenches which are laser levelled to about 2.7 m bgl, with a 50mm fall towards the filling lagoon. The main trench is 700mm wide and the secondary trench about 300mm wide. Both are backfilled with up to 700mm depth of washed gravel. A schematic showing the recharge lagoon, and photographs of the trenches are shown in the figures.

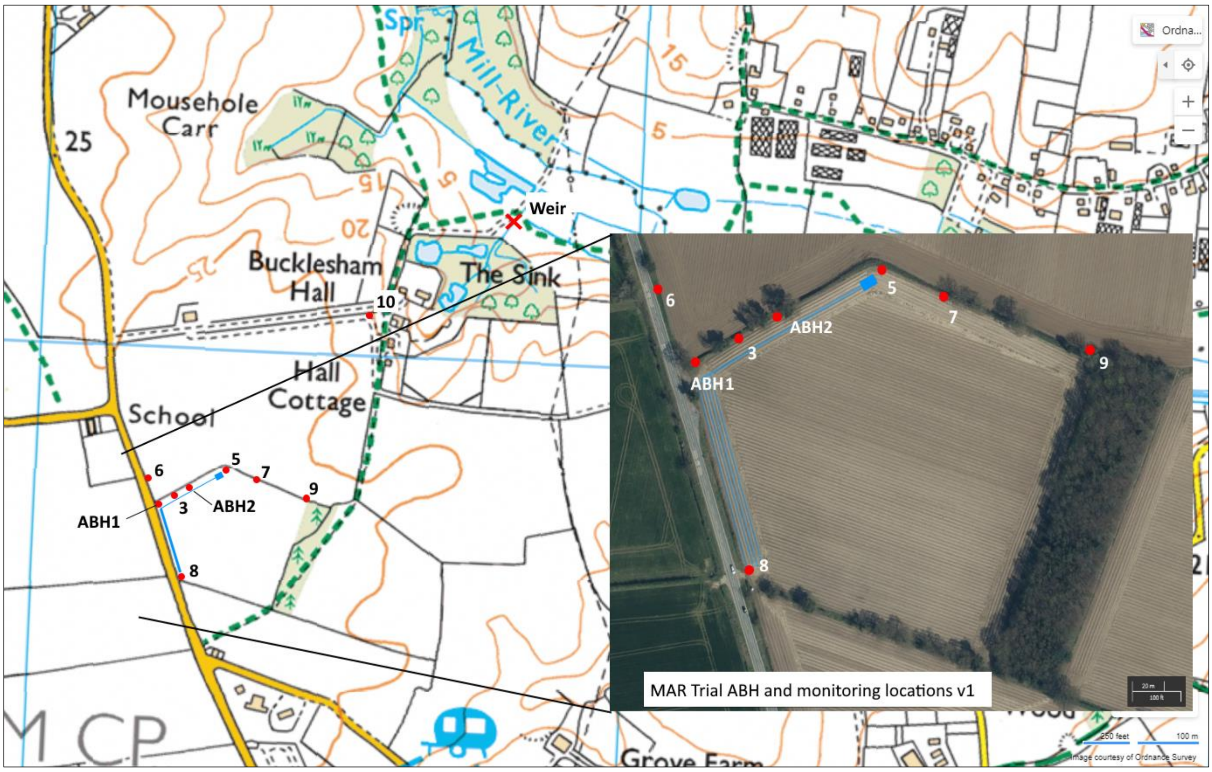

Figure 8. Map of recharge field and monitoring locationsfield and monitoring locations

Discharge into the MAR field is controlled by manually operated gate valves which are located in kiosks along with EM 'Mag-meters' which record the instantaneous and total flow. Water levels are maintained in the header lagoon at approximately 1 m bgl with a solenoid level control which automatically switches the pumps off when levels reach 0.5 mbgl, and restart when levels drop to below 1.5 mbgl.

Re-abstraction (recovery) boreholes

Water is re-abstracted from two 165mm diameter production boreholes which are located adjacent to the recharge field shown as ABH1 and ABH2 on the map at figure 1. The boreholes were drilled to a depth of about 18.5m below ground level to the base of the Crag aquifer where it meets the underlying London Clay. The first 9m was lined and the lower 9.5 screened with a 300 micron slotted screen.

Submersible electric pumps, with the intake set at about 18 m depth, pump water into the FHC irrigation main from where it is transferred to storage reservoirs. Abstraction meters are located on each of the rising mains. The pumps are fitted with automatic cut outs to prevent them running if the boreholes run dry. In the event of a pump cut out an alarm is sent by SMS to an operator.

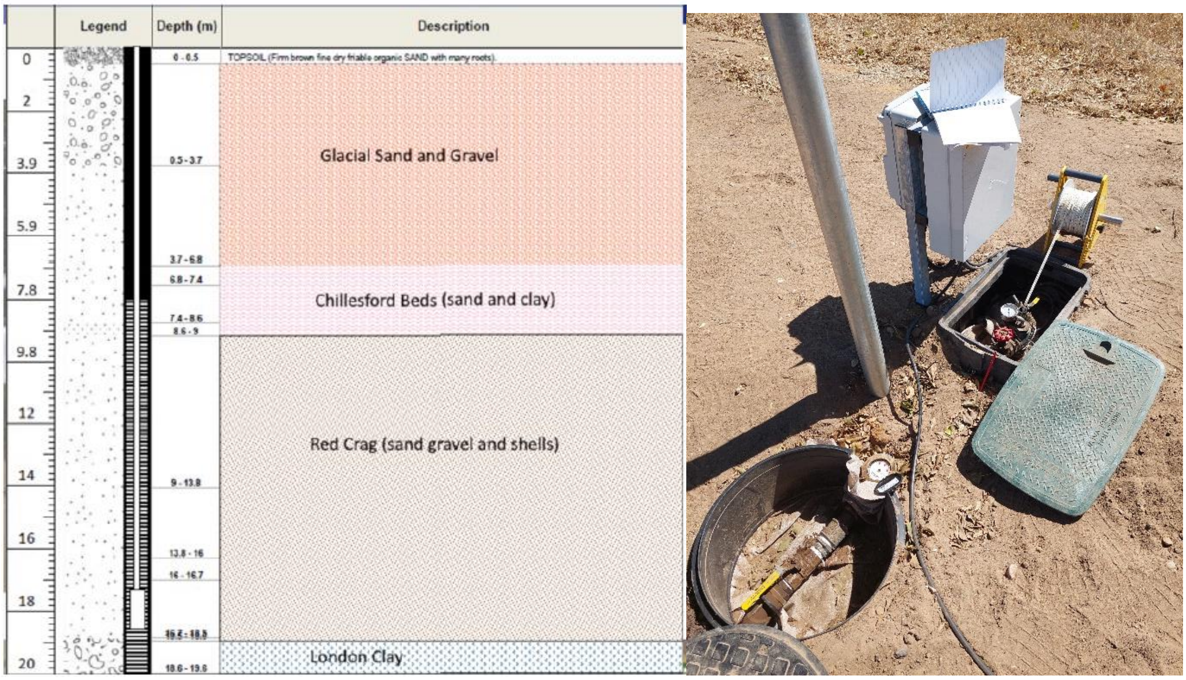

Figure 9. Abstraction borehole construction details

Water quality

The quality of the infiltrated water is important from an environmental and regulatory viewpoint, while the quality of the recovered water is also important for the farmers. The potential for inputs of polluting materials is high although the dilution and biotic attenuation potential within the KIngsfleet dyke / drainage system is also believed to be significant, though variable throughout the year.

Prior to the trial, the chemical quality of the King' Fleet water was characterized by 13 sampling events with subsequent analysis for a comprehensive range of more than 590 chemicals between July 2020 and June 2022.

The main contaminants of concern were chloride (primarily believed to be derived from salt washing from the major road), nitrate (agricultural, high background groundwater concentrations) and herbicides (pesticides). Of less concern were polynuclear aromatic hydrocarbons (PAH) and metals (road run-off). Polyfluoroalkyl substances (PFAS) were added to the list of analyses during the project, as these are an emerging contaminant of concern.

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Figure 10. Source water Chloride and Nitrate concentrations 2020-2022

The composition of the receiving Crag groundwater is typical of the area although both nitrate and chloride are elevated. This is likely to be the result of road salting for de-icing and agricultural land use.

MAR Demo Testing

Two tests were run during the project demo:

- An initial recharge and pumping test in November and December 2021 to confirm that the system operated as expected and to inform design improvements to the MAR system and monitoring arrangements and an
- Operational trial between June and September 2022, to test and monitor the system under operational conditions.

	Infiltration (recharge)			**Recovery**		
	Period	**Days**	**Infiltrated (m^3)**	**Period**	**Days**	**Recovered (m^3)**
Initial pumping test	06.11.21 to 21.11.21	15	5,630	09.12.21 to 14.12.21	5	520
Operational trial	09.06.22 to 20.06.22	11	12,262	18.07.22 to 10.09.22	54	12,301

Table 2. Summary of MAR initial test and operational trial dates and quantities

Initial Test pumping

The initial pumping test was conducted with a single abstraction borehole and 4 observation boreholes. The test demonstrated that the recharge field was capable of infiltrating up to 1,500m3/d and that the single recovery borehole could yield about 100m3/d. Groundwater level data recorded during and following the test showed that recharge of the aquifer was observable approximately two weeks after the infiltration phase. Recovery of groundwater levels within the aquifer following the trial was rapid returning to pre-test levels within hours.

Operational Trial

The operational trial was conducted following the construction of an additional abstraction borehole to increase recovery yields and three additional observation boreholes (OBs). Two of the OBs (OBH 9 and OBH 8 were intended to record groundwater level changes at the limits of the recharge bubble and the third OBH10 was installed to act as a sentinel borehole adjacent to a sensitive site. A map showing the location of the OBHs and a stream flow recording weir is shown at figure 8 on page #.

Monitoring conditions for the operational trial were set out in the EA's Groundwater Investigation Consent. These are summarised below:

Receiving aquifer (recharge field) 1. Groundwater level monitoring at 15m intervals at all OBHs and ABHs 2. EC monitoring at 15 minute intervals at OBHs 3, 6, 5, and 7 3. Sampling for major ions at ABHs 1 and 2 and OBHs 5 and 8 (4 sites in total) a) immediately prior to infiltration b) at the end of infiltration c) immediately prior to recovery (beginning of May) d) monthly during recovery (beginning of June and July) e) at the end of recovery (end of July) 24 samples in total
Source water (Kingsfleet) 1. Sampling for the full suite (590 chemicals at the source (Kingsfleet) a. Prior to and at the end of the infiltration period 2. Daily samples for Cl-

Table 3. Monitoring conditions specified for the MAR operational trial

Technical performance

Water resources

The infiltration of artificially recharged water in June 2022 caused a clear increase in levels at all sites with the exception of OBH9 around 155 m to the east of the lagoon, and OBH10 around 315 m to the north near Bucklesham Hall, where no response was seen (see figure 4). This was against the background of only a gradual minor natural recession in levels over the period.

The responses to artificial recharge began after around 3 days of application, with a gradual increase following until around the end of June at most sites, with levels remaining elevated overall thereafter. The greatest increases were seen at ABH1 and OBH3 (0.3 and 0.4 m, respectively), with slightly lesser rises seen at ABH2, OBH6 and OBH 8 (0.2 m), and the lowest at OBH 5 near the lagoon and OBH 7 45 m to the east of it. This implies a good delivery of artificial recharge to the area of the ABHs for recovery and to end of the pipe array near OBH8, but lesser receipt to the east of the lagoon, perhaps due to localised decreases in aquifer permeability at the latter location.

The rate of re-abstraction pumping varied during recovery; pumping commenced at 150 m3/d, rising to around 255 m3/d for the rest of the test (with some outages); the early low rate may reflect a period when ABH2 only was pumping (based on the drawdown response) – 'bulk' re-abstraction data only was available at time of writing i.e. no split for individual ABHs.

Marked drawdown responses were seen at the ABHs, with that at ABH2 being in the order of 3.5 m compared to only 1 m at ABH1 indicating lesser use of the latter bore. Clear responses can also be seen at the OBHs with the greatest, 0.7 m, occurring at OBH3 near the ABHs as would be expected. The degree of drawdown at OBH5, 6, 7 and 8 was around 0.2 m. The response at these bores clearly varies with changes in pump rate/cut-outs with the exception of more distant OBH8 where the response to these events is muted. The muted response may be the result of pressure effects overprinted on a gradual decline following the receipt of recharge.

No data was available to assess post-abstraction groundwater level recovery. Recovery after every pumping outage was rapid such that it is reasonable to assume that a good recovery occurred after re-abstraction had ceased.

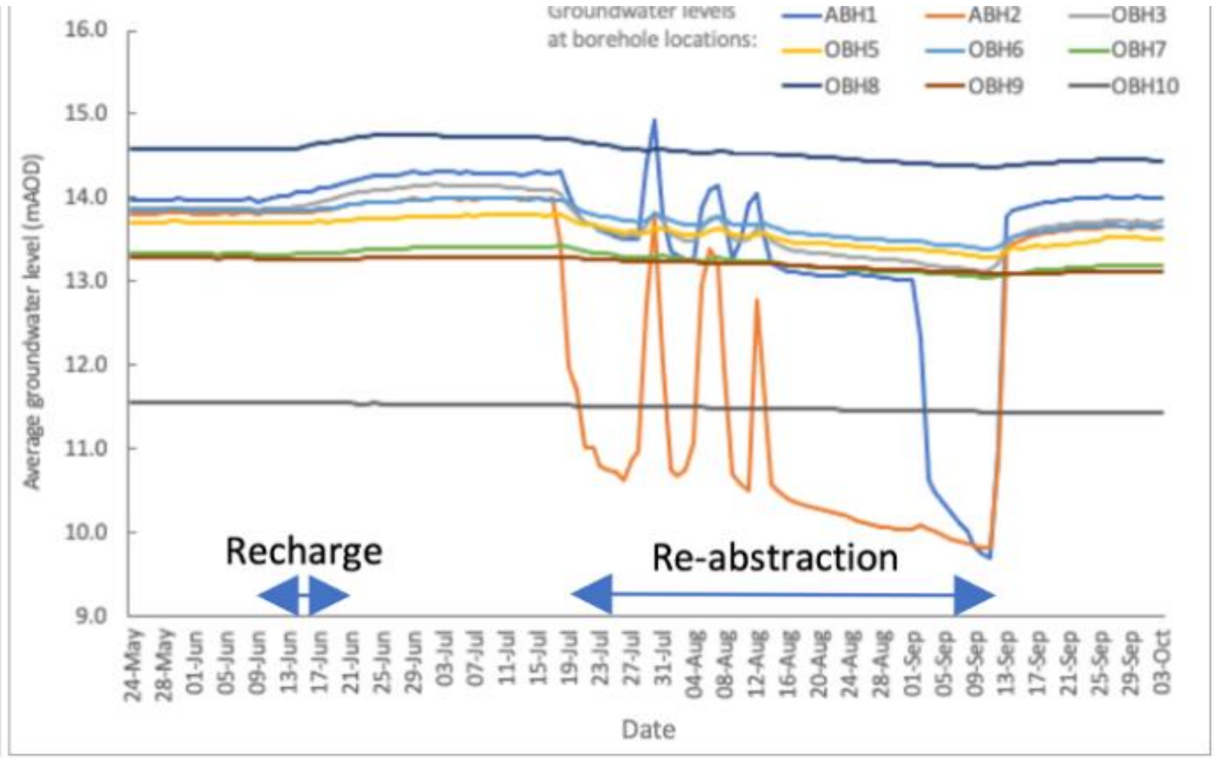


Figure 11. Groundwater levels during MAR operational trial

The results from the trial indicate that the infiltration equipment is capable of delivering artificial recharge to the Crag aquifer. Whilst it's possible that clogging of aquifer pores may occur and reduce the effectiveness of the scheme over more prolonged operation, such issues do not appear to have developed over the period of the trial.

The trial data also indicates that that the two ABHs can pump out the same volume of water as artificially infiltrated within a number of weeks. Schemes reported in the literature typically cannot re-abstract 100% of stored volumes, but the equivalent volume of storage will be removed i.e. potentially including native groundwater.

The residence time of the recharge bubble at the site during the trial was a maximum of approximately one month. Under the potential recharge and recovery dates of the application, the operational residence time could be significantly longer e.g recharge in January and re-abstraction in October. This could mean some flow of artificial recharge water away from the site prior to re-abstraction, and lead to an increase in flows to local watercourses as a result. However, it is likely that the infiltration will not significantly increase the saturated thickness of the Crag aquifer and therefore will not mean any significant increase in discharge; similarly any reduction in the hydraulic gradient on re-abstraction late in the natural recession period is unlikely to engender any significant change in the hydraulic gradient to local water features, and therefore no significant reduction in flows.

Water Quality

The source water was monitored for more than 590 compounds over an 18 month period prior to the trial. Concentrations of hazardous substances in the King's Fleet source water (discharge) were below the relevant minimum reporting values with very few organic compounds detected. All were below Drinking Water Standards and only the metabolytes Chloridazon-desphenyl and 2,6-Dichlorobenzamide (BAM) were found regularly, as were the PFAS. The herbicides Simazine, Pendimethalin, Triallate and Propyzamide were also detected on only a few occasions.

Elements of concern in the source water were Cl- and NO3, probably derived from road salting and agricultural land use. Cl- concentrations remained below 126mg/l and NO3 as N below 1 Mg/l (although concentrations had peaked at 7.5 Mg/l earlier in the year.

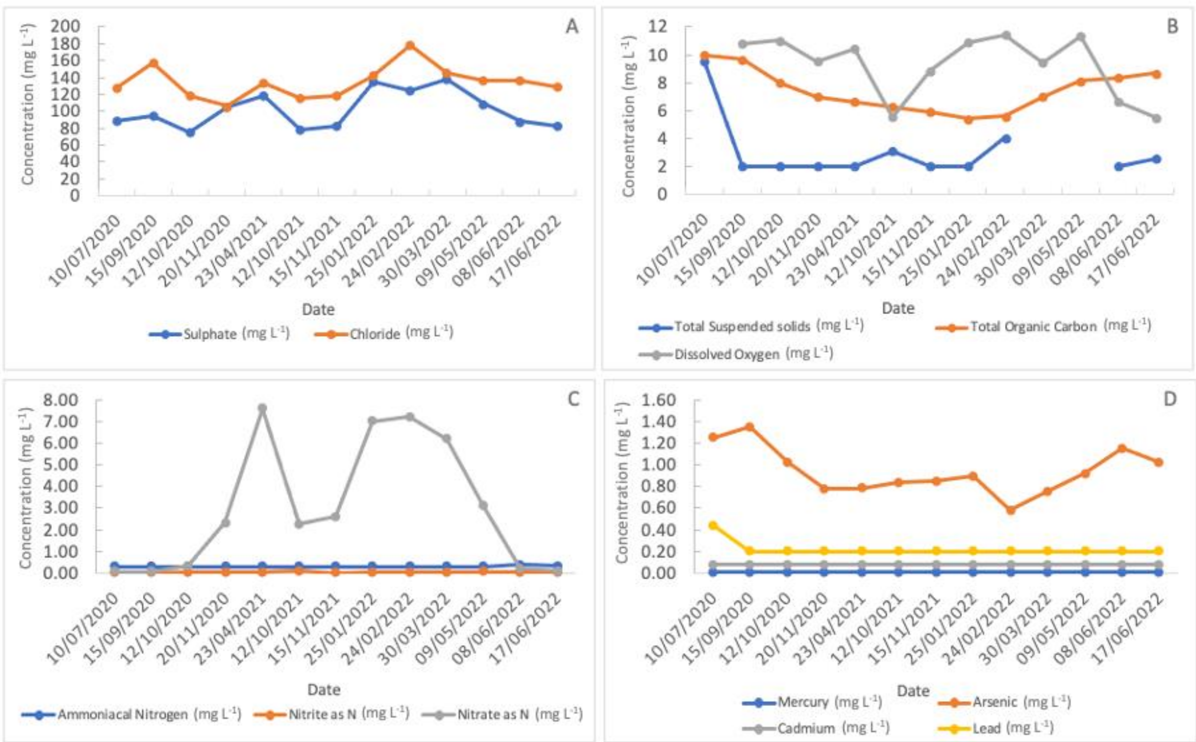


Figure Source Water Quality

Notable concentrations of SO4, CL- and NO3-N were detected in the ground water during the trial with levels higher than found in the source water. Following recharge, concentrations of Cl and NO3 fell in some of the boreholes close to the recharge field, suggesting that the source water provided a diluting effect.

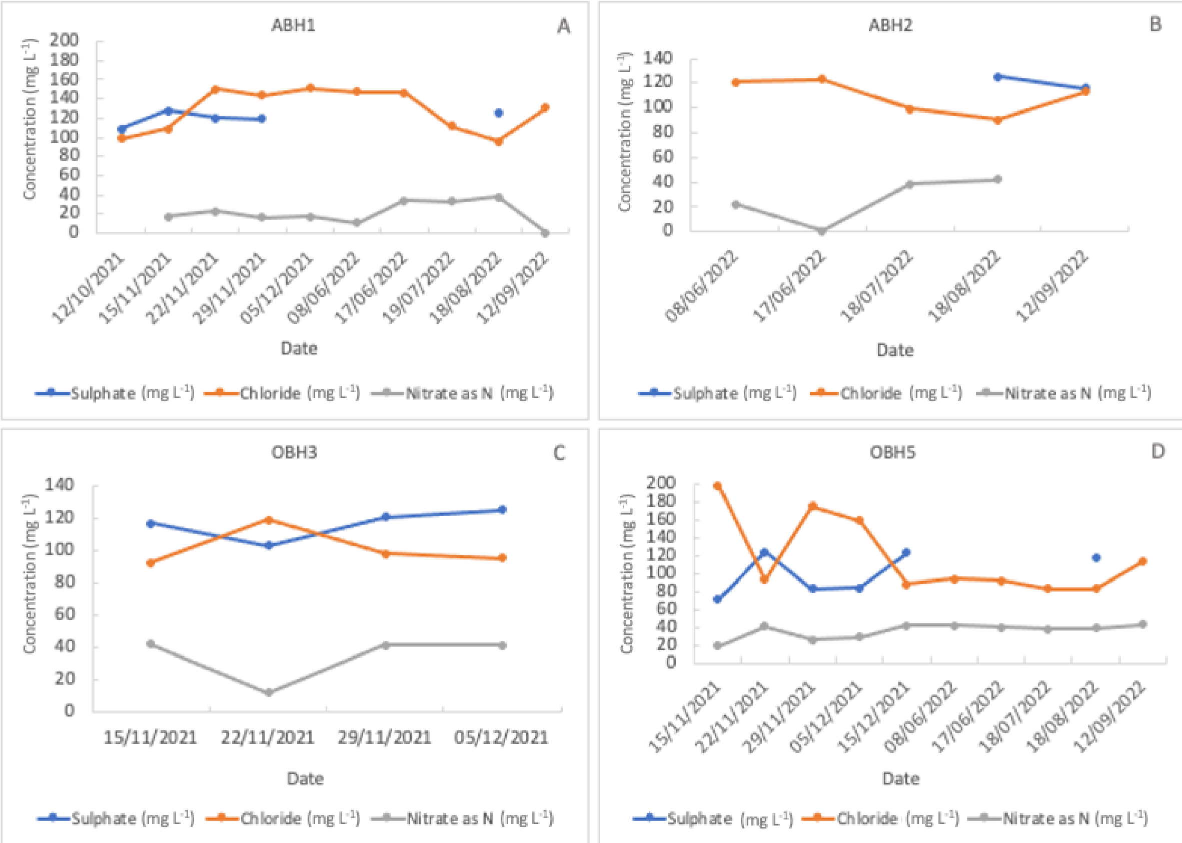


Figure 12. Receiving aquifer water quality

Lessons learned

The location of sites available the MAR scheme was limited to areas adjacent to the FHC pipeline and in the ownership of members. These were not ideal due to the presence of low permeability deposits and limited information about the hydraulic properties of the underlying aquifer.

The yield from the boreholes was lower than expected. Initial estimates were extrapolated from pumping test results published on the British Geological website borehole records, their Minor Aquifer Properties report (see references) and the Environment Agency's groundwater modelling exercise. It is possible that water could have been abstracted at a higher rate with the construction of additional boreholes and abstraction pumps but this would have entailed costs in excess of the available budgets. It is also likely that higher yields could have been achieved in other parts of the Crag aquifer. We would recommend carrying out borehole yield tests at an early stage in project development.

Aquifer infiltration rates were higher than expected. Initial infiltration tests indicated that more than 1km of recharge pipe would be required to infiltrate the planned quantity of water into the aquifer. In practice, we were only able to install 565m due to restrictions on the area of land available for the test. This array, however, provided infiltration rates in excess of 1500m3/d which was more than required. The most likely reason for the higher than expected infiltration rate was that the base of the recharge trench, at 2.7m below ground level, avoided the lower permeability horizons found in the upper soil horizons found during the infiltration testing.

This depth is below the normal operating depth of a commercial trenching and pipe laying machines. It was therefore necessary to excavate a wide, 1m deep trench for the trenching machine to run in before laying the pipe. This added to the cost of construction. Ideally the recharge sites would be selected with relatively high shallow aquifer conductivity. In these conditions, we would recommend laying recharge pipes at the maximum depth of a commercial trenching machine (approximately 1.7m) to minimise construction costs.

Although initial, broad sweep water quality characterization samples indicated that there was a low risk of introducing damaging concentrations of contaminants to the aquifer, water quality concerns remained one of the major regulatory obstacles to the project progress.

Non-technical aspects of the demo

Regulatory framework

MAR presents a potential risk to the environment through changes to groundwater quality and changes to quantity (resources). These risks are managed by the UK environmental regulator, the Environment Agency, using a range of permits.

UK water resources and water quality regulations were not drafted with MAR in mind. Consequently there is no regulatory guidance or pathway available to help either the regulator or user secure the correct permits for MAR. The consenting process was therefore difficult at times. Fortunately, the regulator was a project member within the demo, and so was able to work iteratively with FHC, taking an iterative approach to the regulations and providing guidance and technical support.

The initial construction, testing and subsequent operational trial were authorised under **Groundwater Investigation Consents (GIC)**. The GIC application process is relatively quick and is provided by the regulator free of charge. Formal **discharge consent** and **abstraction licence** permits are required for the ongoing operation of the MAR system as set out in table 5 below.

Permit Type	**MAR activities authorised**
Groundwater investigation consent GIC	Construct and test infiltration and re-abstraction capacity and to collect water quality and groundwater level data
Discharge Consent	Operational (ongoing) infiltration of water into the aquifer
Abstraction licence	Operational recovery of water from the aquifer. The abstraction licence also covers the abstraction of the source water).

Table 4. Consents required for the MAR demo and subsequent operation

Groundwater Investigation Consents

Two separate GICs were issued for the demo. The first, issued in November 2021, was a 'low risk' consent, which authorised the construction of the initial abstraction borehole and four observation boreholes and an infiltration and recovery test limited to a maximum quantity of 6,300m3 over a period of 14 days.

The second GIC authorised the larger scale infiltration and recovery of up to 18,000m^3 of water for the operational trial and the construction of the second abstraction borehole and four additional observation boreholes. It also set out water quality and groundwater level monitoring requirements required to ensure that,

i. the test itself would not pose a risk to the environment and,
ii. that it would provide sufficient data to allow the determination of formal applications for a discharge consent and abstraction licence.

Water quality monitoring carried out prior to the trial had indicated that Cl- concentrations in the source water could pose a risk to groundwater quality. In addition to data collection for analytical purposes, the GIC included the requirement to monitor Cl- concentrations in the source water daily and to stop the test if concentrations rose above 165mg/l.
The monitoring conditions for this consent are summarised in table 4.

Discharge Consent

A discharge consent, issued under the Environmental Permitting (England and Wales) Regulations 2016, was required to allow the water to be infiltrated into the ground for the purposes of MAR. This is issued by the Environment Agency following a formal application process which involves an assessment of the likely environmental risks associated with the operation and consultation with statutory bodies such as Natural England.

A discharge consent application must be accompanied by an analysis of the likely risks, based on the data collected during the GIC. The consent is only issued if the regulator considers the risk to be within acceptable thresholds. As project partner the EA carried out the qualitative risk water quality risk assessment for the MAR scheme.

The regulator concluded that concentrations of non-hazardous pollutants in the source water were less than the relevant environmental standard (DWS (Drinking Water Standard) or EQS (Environmental Quality Standard)) and although there is no exceedance of the EQS/DWS for chloride and nitrate discharging concentrations equal to the DWS and EQS (250mg/l and 50mg/l, respectively) would be a significant level of deterioration from natural background levels. A more suitable maximum allowable discharge concentration is therefore desirable. This would allow the improvement of groundwater quality and be consistent with the overall aim of environmental improvement.

WFD classification uses a value equal to 75% of DWS concentration to identify sites that need to be considered for classifying a groundwater body as poor under the General Chemical test. Based on this, a maximum acceptable limit of 65% of DWS is proposed (suggested by the Area GW&CL team, to be agreed in the determination of the permit by NPS) to allow a margin of safety before the 75% of DWS limit is exceeded.

The qualitative risk screening shows the discharge has acceptably low concentrations of hazardous substances and concentrations of non-hazardous pollutants that are generally within the relevant environmental standards. Provided this situation remains (with the conditions set out above), both the groundwater and surface water will not be impacted to an unacceptable extent. An important feature of the scheme and one that mitigates any impact, is the re-abstraction (removal) of the water discharged to the ground. A perfect scheme would remove 100% of the water stored; an inefficient scheme would not be commercially viable.

To ensure the acceptability of the discharge quality the regulator required a full analysis including all organics to be conducted prior to the infiltration commencing and at its cessation.

Also, owing to the variability of chloride and nitrate, and to ensure no deterioration and an improvement of groundwater quality, continuous monitoring with limits was set as below:

Chloride 160mg/l (65% x 250mg/l = 1603mg/l)
Nitrate 33 mg/l as NO3 (65% x 50mg/l = 33mg/l)

FHC submitted a formal application for a discharge consent on this basis in February 2023.

Abstraction Licence

Based on the outcome of the operational trial, an application was made to vary FHC's existing abstraction licence to include the following measures to allow ongoing operation of the MAR system:

	Period	**m^3/yr**	**m^3/d**
Recharge	January to April	40000	1500
Recovery	May to Oct	40000	270

An abstraction licence is required to ensure that MAR scheme would not cause environmental problems such as river or spring-flow depletion or interfere with nearby wells or property.

The licence sets out the source of the abstraction, its purpose and the quantities and periods that water can be used. It also includes any other limiting conditions such as the requirement to recharge the aquifer by the same quantity that would be abstracted in that year.

The data collected under the GICs was used by the EA to establish that the MAR scheme would not have adverse impacts on the environment or other users.

The EA's assessment of the hydrological risks to the environment or nearby water users concluded that no significant 'escape' of artificial infiltration was likely to occur. However, the confidence in this could be increased by having monitoring data available for the full recovery period after re-abstraction. For this reason, any licensed scheme should include the continuation of groundwater levels monitoring at all ABHs and OBHs.

The licence was therefore issued as applied for but with additional monitoring conditions. Following further discussion between the EA and FHC, the recommendation was changed to groundwater level monitoring at the two abstraction boreholes and 4 observation boreholes.

Because Felixstowe Hydrocycle already hold an abstraction licence which allows up to 600Ml/yr to be pumped for the water transfer scheme (Demo 2.1) it was possible to 'vary' this licence to allow some of the water to be discharged into the aquifer and to be recovered. The cost of the application to include the MAR aspect of the demo was covered by the initial Felixstowe Hydrocycle transfer licence. If the MAR scheme had required an abstraction licence in its own right, this would have cost approximately £3,600 with annual subsistence charges of

Permit costs

The cost of the application to include the MAR aspect of the demo was covered by the initial Felixstowe Hydrocycle transfer licence. If the MAR scheme had required an abstraction licence in its own right, this would have cost approximately £3,600 with annual subsistence charges of

Business setup

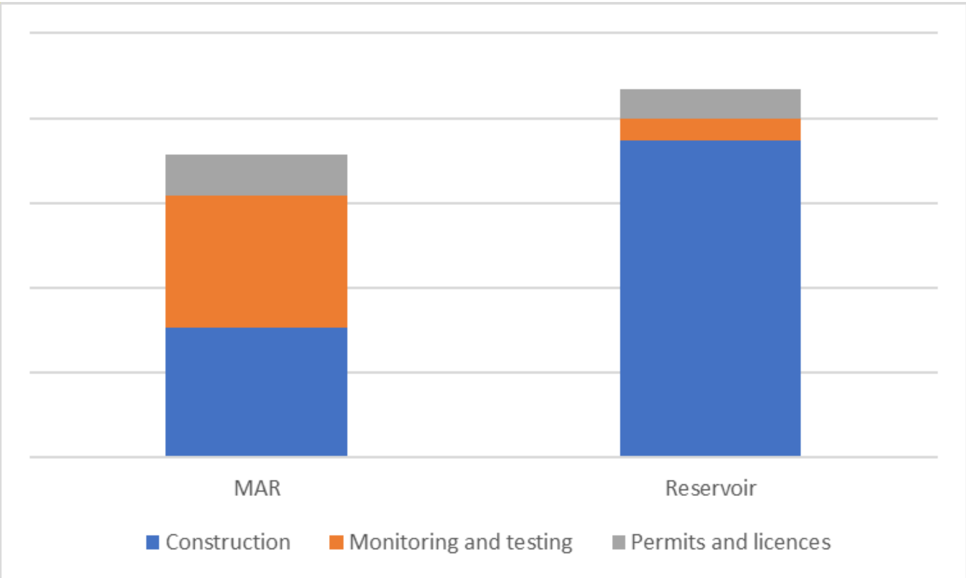
The MAR demo was set up and run by Felixstowe Hydrocycle Ltd, a partnership of six farmers who rely on water for irrigation on the Felixstowe Peninsula. The land for the trial and operational support, eg fuel bowsers, irrigation mains and transport, were provided by members. Costs for the trial were shared amongst the members. Water recovered from the MAR system was delivered to members' reservoirs for subsequent irrigation use.

Business case

The business case objective of the MAR demo was to review its potential as a cost effective alternative to agricultural winter storage reservoirs in East Suffolk.

The set up costs for the FRESH4Cs MAR demo were approximately 10% lower than for a lined, overground storage reservoir of an equivalent size. The largest component of these was for monitoring and provision of data in support of permit applications, which together accounted for approximately 57% of the total budget. The costliest elements were the 8 observation boreholes and loggers followed by water quality testing and analysis. Construction costs, including the recharge field, abstraction boreholes and pumping systems accounted for 43% of the capital costs.

This cost breakdown for MAR differs significantly from that of an equivalent sized reservoir project where construction accounts for up to 86% of the overall budget. Reservoir permitting and licence application costs typically come to only 14% of the total budget although planning and archaeological investigation costs vary widely and can add significantly to the capital costs.



The higher data collection and permitting costs for MAR reflect the steeper regulatory challenges facing these projects. Aquifer recharge is relatively novel in England and Wales and the permitting regime is required to address potential impacts both on groundwater quality and water resources. Agricultural storage reservoirs, by contrast, have a long history of development and permit considerations are limited to water resources impacts only. Water resources mitigation measures, such as hands off flows, are well understood and the licensing regime has matured to accommodate reservoir abstraction permits. This is not the case for aquifer recharge and recovery.

MAR annual operational costs are estimated at 12% of the total capital costs. The greatest proportion of these are due to the additional costs of pumping the recovered water into a balancing facility so that it can be re-abstracted at higher rates sufficient to run an irrigation system. Regulatory permit subsistence charges and compliance with permit monitoring conditions account for the bulk of the remaining operational costs (37%) with system maintenance making up the balance.

The annual operating costs for an equivalent reservoir are equivalent to about 7% of the capital costs. These are comprised of, in diminishing order of size, of; power supply, maintenance costs and loss of income due to land-take.

Although construction costs for the MAR system were comparatively low, the high costs of data collection and securing regulatory permits brought the overall capital costs to within 10% of an equivalent storage reservoir. From a farmers' perspective, this marginal difference is unlikely to outweigh the perceived difficulties and uncertainties involved in constructing and operating a MAR system. it is likely, however, that if more MAR schemes are developed, the regulatory process will become more streamlined, reducing permitting overheads and making MAR more attractive to agricultural irrigators.

Lessons learned

Although the capital costs of setting up the MAR demo were less than for an equivalent agricultural storage reservoir, the water resources outputs were not directly comparable. The maximum instantaneous output of the MAR scheme was approximately 3.5 l/s. This is not sufficient to run a field scale irrigator which typically requires an instantaneous delivery rate of between 10l/s and 15 l/s. MAR, therefore, needs to be used in conjunction with a reservoir storage system where water can be stored before being re-abstracted at a higher rate for use with field scale irrigation equipment.

Alternatively, MAR could be used for low volume irrigation systems such as trickle tape or mini sprinklers.

The requirement to construct deep soak-away drains in the recharge array added to the capital costs of the project. We estimate that overall costs could have been reduced by up to 20% by using standard land drainage techniques.

As a project partner the regulator provided significant guidance and support during the demo. This included some water quality analysis and technical and procedural advice. Despite this the cost and workload required in support of permit applications and subsequently to operate the scheme comprised almost 35% of the total project investment and running costs. This does not include technical expertise provided by other project partners, including Suffolk County Council and UEA .

Without this support, project costs would have been significantly higher. The high cost and technical difficulties of applying for and complying with regulatory permits significantly reduced the potential benefits of the scheme.

Additional regulatory barriers to the development of further MAR schemes is the level of technical expertise required to collect and prepare the necessary data and length of time required to secure permits.

Conclusions and replication potential

The demo has shown that MAR is technically and economically feasible in shallow unconfined aquifers in coastal Suffolk. It also demonstrates that there is an effective regulatory solution for permitting MAR. The permitting challenges are however, significant, adding significant costs and uncertainty to the process and potentially acting as a barrier to the development of similar schemes in the future.

The cost of constructing the recharge array and abstraction boreholes was approximately 10% lower than that of building an equivalent reservoir, the main alternative for storing surplus high flow winter water. More than half of the capital cost of the demo was associated with installing water quality and ground water monitoring systems and the preparation and submission of data in support of the permits required to operate the demo.

Field scale MAR for agricultural irrigation is relatively novel in the UK and there is currently no regulatory pathway or guidance available. As the regulator, and project partner, the Environment Agency were required to take a relatively precautionary approach to ensure that the demo complied with current regulations. This added significant costs and uncertainty to the regulatory processes. A regulatory framework and guidance could help potential developers understand the regulatory costs and risks of MAR and help them to make informed investment decisions about this technology.

Our understanding of the hydraulic properties of the aquifer was limited at the project outset. As a result the rate of re-abstraction from the boreholes was lower than anticipated and FHC members were unable to use the system for direct irrigation. The water can however be transferred to existing reservoirs to supplement supplies during the summer, in effect providing increased reservoir capacity at a lower cost. Early stage test pumping is recommended to estimate potential borehole yields and to determine whether a conjunctive MAR/reservoir storage is required to meet user requirements.

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