Managed aquifer recharge (MAR) to enhance groundwater resources for irrigation in a coastal agricultural catchment in the Crag aquifer, Suffolk

Research Summary 1: MAR concept, construction and operation

Kevin Hiscock[1], Natalia Balashova[1], Paul Bradford[2], John Patrick[2], & Matt Hullis[3]

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Background

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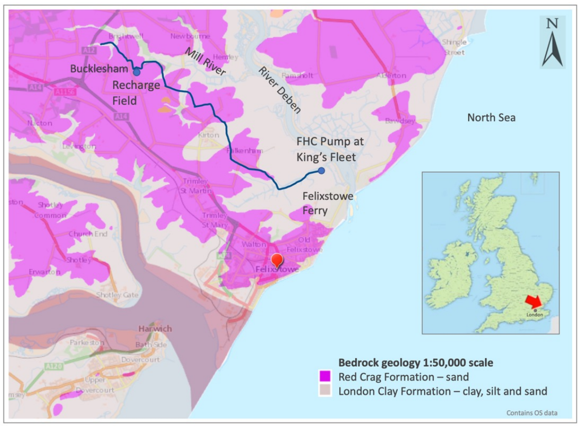

Fig. 1 Location map showing surface geology and the King's Fleet pumping station (FHC Pump) at Felixstowe Ferry and the MAR site at Bucklesham. The blue line shows the dual-pipeline to transfer water inland to farm reservoirs and the MAR site.

Methods of construction and operation

The FHC distribution system relies on two high-volume, low-head abstraction pumps located at King's Fleet at Felixstowe Ferry before it is otherwise discharged to the River Deben via an Internal Drainage Board pump. Each pump delivers 30 L s^{-1} and can operate individually or together. Water is transferred inland via two, 14-km length, 200 mm-diameter pipelines to supply surface storage irrigation reservoirs and the MAR scheme. The supply to the MAR site is discharged into a recharge header lagoon from which it drains to a buried pipe array. In the header lagoon (dimensions of 10 × 5 × 2.8 m), the water level is kept at 0.5 m below ground level (bgl) during operation (**Fig. 2**).

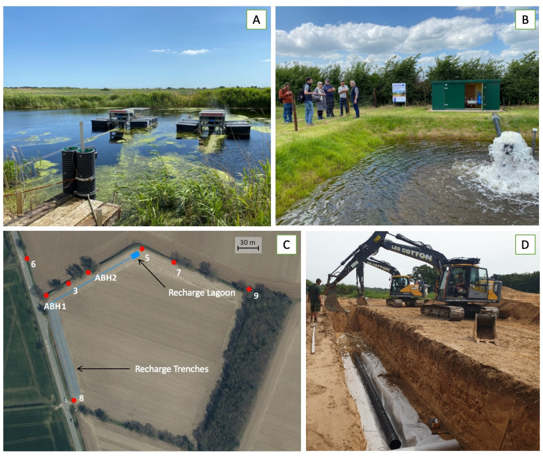

Fig. 2 A: Surface water abstraction location in the King's Fleet showing the eel-friendly, Riverscreen source-water pumps. B: Recharge lagoon at the Bucklesham MAR site in operation. C: Abstraction borehole (ABH1, ABH2) and observation borehole location plan, including the position of the recharge lagoon and layout of infiltration trenches. D: Recharge distribution trench under construction.

Type of recharge and recovery

Recharge at the Bucklesham MAR site is induced through the recharge lagoon connected to an array of backfilled infiltration trenches positioned in the Crag unsaturated zone, in which pipes are installed. The infiltration array (recharge field) comprises a main 225-mm diameter micro-perforated PVC pipe (laid in a 700-mm width trench) running adjacent to the northwest field boundary (approx. 10 m distant from the King's Fleet pipeline), which then splits into four, 125-mm diameter perforated pipes laid in 300-mm width trenches (**Fig. 3**). All the pipes are installed at a depth of around 2.7 m and are installed in a bed of gravel, with up to 0.7 m of gravel over the top.

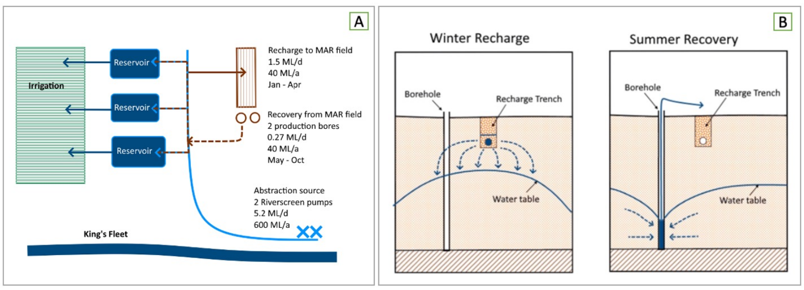

Fig. 3 A: Diagram of the design components of the MAR scheme, including abstraction of surface water from the King's Fleet and pumping of water 14 km inland to Bucklesham where the water is recharged to covered infiltration trenches for later abstraction. B: Concept of the MAR scheme showing winter recharge and summer recovery phases.

Summary

The outputs of the study enabled the scheme to sufficiently inform a roadmap for similar MAR initiatives in the UK, particularly in those aquifers with properties that enable the recharge and recovery of fresh groundwater. If implemented, these initiatives would contribute towards a range of goals set in the UK's 25 Year Environment Plan, such as ensuring interruptions to water supplies are minimised during prolonged dry weather and drought.

Further details

More information about the project is available at https://www.fresh4cs.eu. For specific enquires, contact Prof. Kevin Hiscock (email: k.hiscock@uea.ac.uk).

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Research Summary 2: Quantity of aquifer recharge and recovery

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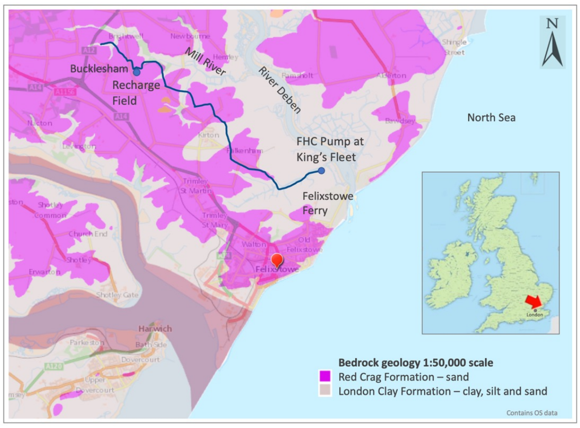

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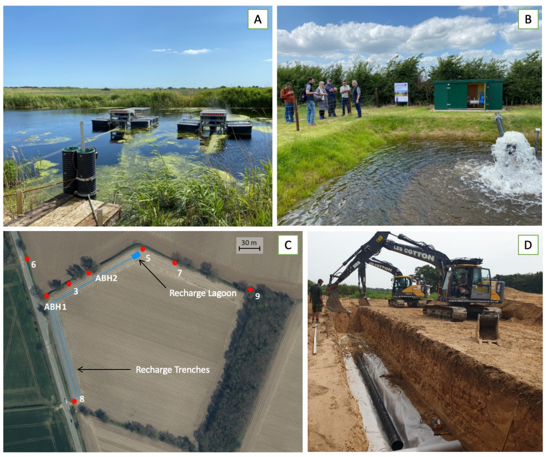
Design of the MAR scheme

Water is sourced from the King's Fleet at Felixstowe Ferry (**Fig. 1**), where the East Suffolk Internal Drainage Board pumps more than 1 x 10^6 m^3 of water each year into the River Deben. Following construction, water is transferred 14 km inland to participating farms where it is stored in reservoirs ready for irrigation and also to supply the MAR scheme at Bucklesham (**Figs. 1, 2**).



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Further details

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Water quantity aspects

Between 9-20 June 2022, 12,262 m^3 of source water were recharged to the aquifer (**Fig. 3**). During this period, the source water quality was stable with a mean electrical conductivity value of 673 µs cm^{-1} and mean chloride of 123 mg L^{-1}, reaching a maximum of 126 mg L^{-1} on 20 June, below the threshold value of 165 mg L^{-1} set by the Environment Agency. The recharged water was successfully abstracted from the Crag aquifer from 18 July to 10 September 2022, augmenting surface storage irrigation reservoirs during an exceptionally dry period.

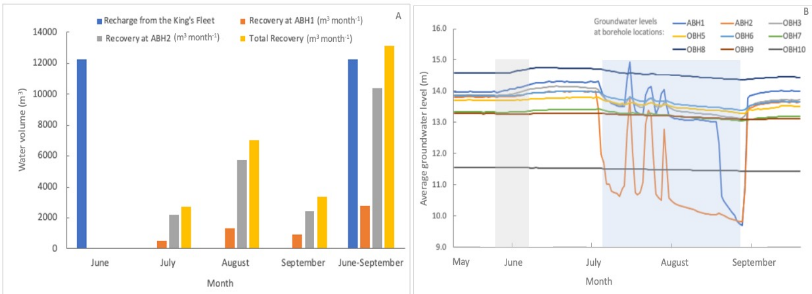

Fig. 3 A: Cumulative volumes (m^3) of recharged surface water and re-abstracted groundwater during the MAR recharge trial, June–September 2022. B: Daily average groundwater levels at abstraction and observation boreholes (ABHs and OBHs, respectively) recorded during the period May–October 2022. Grey and blue panels indicate recharge and recovery periods, respectively. Peaks in water levels (ABH1, 2) show pump power supply outages.

Summary

The MAR scheme proved technically feasible under current groundwater regulations but the Crag aquifer hydraulic conductivity at the Bucklesham site was found to be a limiting factor. Although it is relatively easy to recharge the aquifer, the combined abstraction rate from the two abstraction boreholes (250 m^3/day consented maximum) restricted the yield from the scheme. However, installing additional boreholes to increase abstraction has the disadvantage of making the MAR scheme economically less viable, as too does the cost of water quality sampling and analysis for complying with groundwater regulations.

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Research Summary 3: Quality of source water and Crag groundwater

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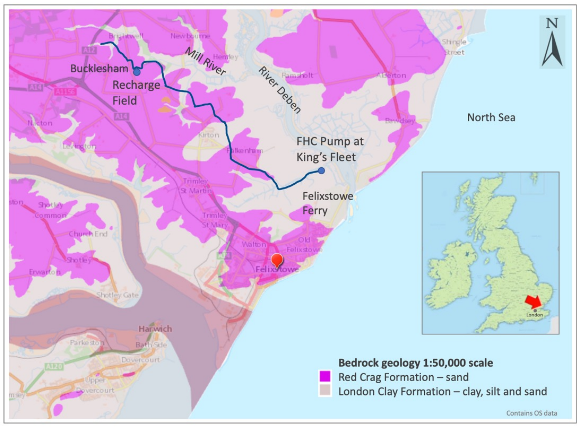

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Design of the MAR scheme

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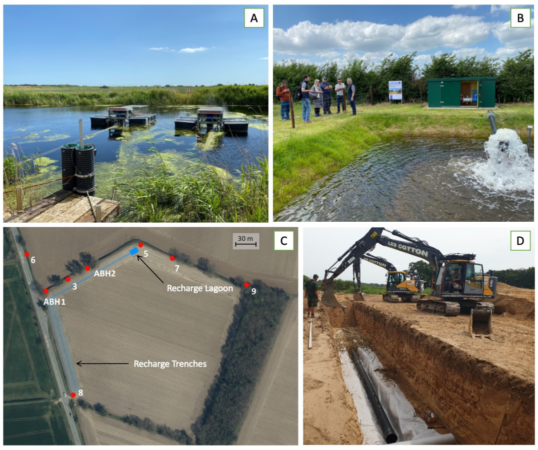

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Further details

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Water quality aspects

Groundwater in the receiving aquifer at the MAR site was monitored for major ions during the period November 2021–September 2022 (**Table 1**). The Crag groundwater composition is typical of the area. Apart from nitrate-N concentrations, no exceedances of regulatory limits were observed in the groundwater samples during the monitoring period. During the recharge period of the MAR trial, the source water quality was stable with a mean electrical conductivity value of 673 µs cm^{-1} and mean chloride of 123 mg L^{-1}, reaching a maximum of 126 mg L^{-1}, within the threshold value of 165 mg L^{-1} set by the EA.

Table 1 Mean values of key water quality determinants measured for surface water and groundwater quality monitoring of the MAR scheme.

	Mean value	
Determinant	Surface water	Groundwater
Conductivity at 20 °C (µS cm^{-1})	890	900
Dissolved oxygen (mg L^{-1})	9.26	7.36
Total organic carbon (mg L^{-1})	7.42	3.00
Sulphate (mg L^{-1})	102	114
Chloride (mg L^{-1})	134	117
Nitrate-N (mg L^{-1})	3.00	29.5

Summary

The risks of other contaminants are considered low in the case of the Suffolk MAR scheme. The source water was monitored 13 times over 18 months for over 590 compounds of potential concern and none was found to be problematic. Overall, the MAR scheme demonstrated that water quality and water resource requirements were successfully met, and that the MAR system could be managed to augment water resources for irrigation in addition to providing an alternative means of storing high surface flows.

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Research Summary 4: MAR scheme regulation

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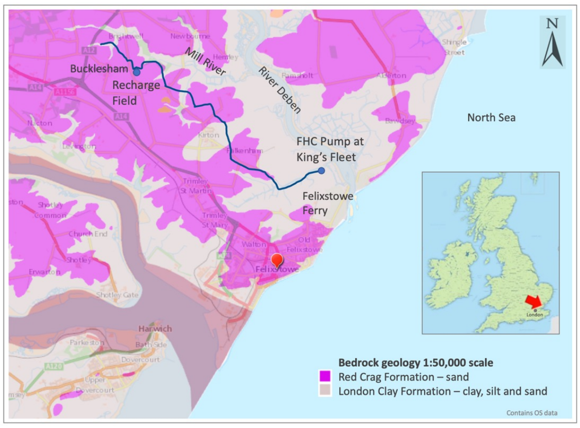

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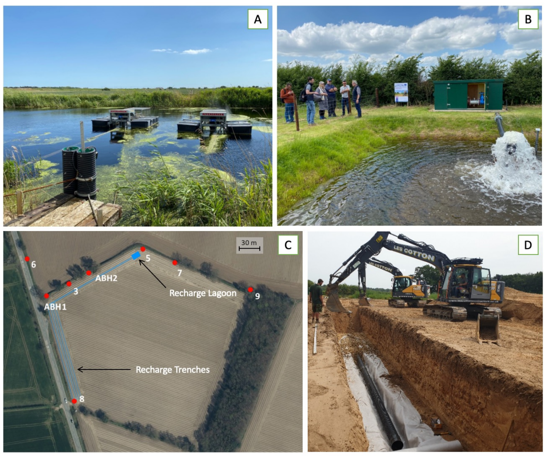

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Regulatory aspects

For the approval of MAR schemes in England, the Environment Agency (EA) requires: (i) an abstraction licence or a groundwater investigation consent for the abstraction of water from an aquifer or surface water; and (ii) an environmental permit or exemption for the discharge of any water to surface water or groundwater. Data collection followed by discussion with the EA indicated that the primary regulatory concern was the potential impact of the MAR scheme on chloride concentrations within the receiving Crag aquifer.

For permitting purposes an 'absolute threshold' for chloride of 250 mg L^{-1} based on the Drinking Water Standard, and a 'relative threshold' limiting chloride levels in the aquifer to an increase of no more than 10% from base levels were set by the EA. Additional regulatory concerns related to other potential contaminants and potential water resource impacts on nearby water features (streams, licensed abstractions and protected rights). The risks of other contaminants were considered low in the case of the Suffolk MAR scheme.

Summary

Water resource impacts were considered to be a low risk with any effects on the nearest water feature, the spring-fed lakes at Bucklesham Hall, likely to be below detection thresholds. The MAR trial showed that the risk of threshold exceedance for chloride can be minimized by: (i) setting a limit to the chloride levels in the source water; and (ii) introducing relatively small volumes of water into the aquifer and ensuring that a high proportion of this is re-abstracted. The EA would likely include limits and operational requirements to reflect these measures in future discharge consent/abstraction licence determined for this and similar MAR schemes.

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Research Summary 5: MAR scheme economic evaluation

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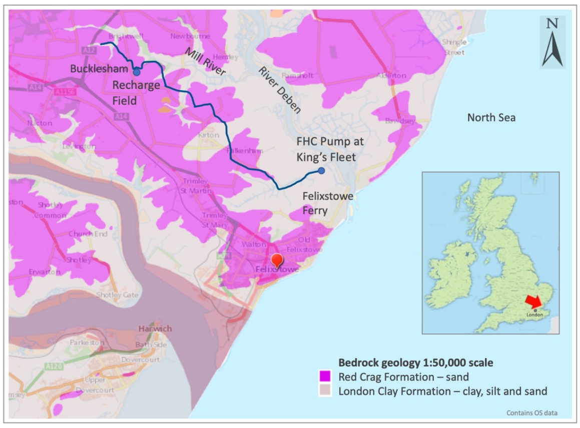

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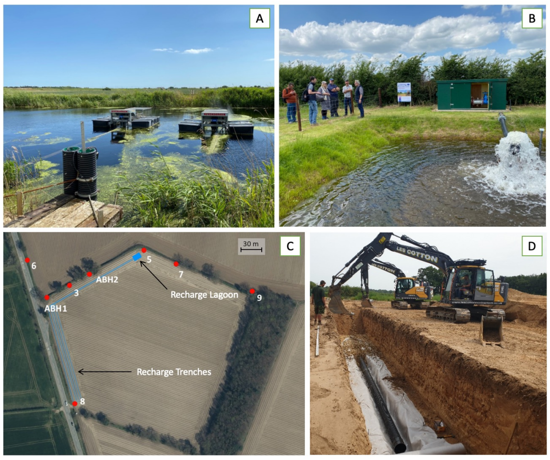

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Economic aspects

The largest cost component of the scheme was for monitoring, data collection and permitting, which together accounted for approximately 57% of the total budget. Construction costs including the recharge field, abstraction boreholes and pumping systems accounted for 43% of the capital costs (**Fig. 3**).

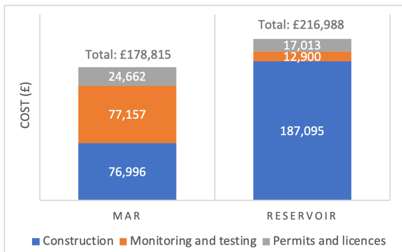

Fig. 3 Cost comparison of the MAR scheme *vs.* surface storage reservoir.

The cost of construction works for an equivalent surface storage reservoir account for up to 86% of the overall budget. Design, reservoir permitting, environmental assessment, fencing and landscaping costs typically come to only 20% of the total budget[2]. Construction costs for the MAR system were comparatively low but the high costs of data collection and securing regulatory permits brought the overall capital costs to within 10% of an equivalent storage reservoir (**Fig. 3**).

2. Weatherhead, K., Knox, J., Daccache, A., Morris, J., Groves, S., Hulin, A. and Kay, M. (2014). *Water for agriculture: collaborative approaches and on-farm storage*. Water for Agriculture (FFG1112) Final Report, March 2014. Cranfield University, Cranfield, 59 pp.

Summary

The higher data collection and permitting costs for the MAR scheme reflected the greater regulatory challenges. Aquifer recharge is relatively novel technique in the UK and the permitting regime is required to address potential impacts both on groundwater quality and water resources. In contrast, agricultural storage reservoirs have a long history of development and permit considerations and are limited to water resources impacts only. Water resources mitigation measures, such as protected minimum flows, are well understood and the licensing regime has matured to accommodate reservoir abstraction permits. 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.