Horton Kirby Aquifer Storage and Recovery

testing of the Lower Greensand aquifer required constructing a 250m deep production borehole, monitoring boreholes and associated infrastructure

by Jo Shipley

In the South East of England, there is long term strain on water resources due to a number of factors including population increase and climate change. Thames Water supplies over 9 million people with clean water on a daily basis. Ensuring supply capability meets demand in an environmentally sustainable manner requires strategic planning. Historic droughts in the South East of England have placed real strain on Thames Water's supply capability and both population growth and climate change are unlikely to improve the situation. In order to manage the drought risk and maintain supply in the region, the existing sources of water will have to be optimised. Aquifer storage and recovery (ASR) is an innovative water resource management technique that potentially offers a resilient solution to water supply in the Thames Water catchment.

Construction of ASR3 Booster pump kiosk
Courtesy of Mott MacDonald

Existing ASR1 LV substation and MCC at ASR1 - Courtesy of Mott MacDonald

Background

Horton Kirby WTW is located in the Darent Valley where the significant droughts of the 1970s, 80s and 90s led to extreme low flows in the River Darent and, in certain reaches, a total drying up of the river bed. Working closely with the Environment Agency and the Darent River Preservation Society, Thames Water has reduced the volume of groundwater abstracted from the chalk aquifer which underlies the Darent Valley, by over 50% since 1995, reducing the impact of groundwater abstraction on the River Darent.

Currently Horton Kirby and Eynsford WTWs are licensed to abstract 6.8Ml/d from the chalk aquifer, a figure that was previously 25.2Ml/d prior to 2005. Both treatment works abstract water via 120m deep boreholes. The Lower Greensand (LGS) aquifer, which is approximately 250m below ground level at Horton Kirby, is separated from the chalk aquifer by a 70m thick layer of low permeability clay. This layer of clay importantly prevents abstraction from the LGS from impacting flows in the River Darent.

The Horton Kirby ASR project is an operational scale test of the capacity of both abstraction and recharge of the LGS aquifer beneath the Darent Valley. Use of the aquifer to store surplus water during periods of high ground and surface water is a resilient water resource management technique as regards both climate change and seasonal variations. ASR enables environmentally sustainable abstraction during the summer months and potentially offers a technique to manage high river flows during the winter months.

The purpose of the project is to establish the capacity of the LGS aquifer. Testing will confirm to what extent the Lower Greensands can be used to store and then abstract water in a highly water sensitive area.

ASR3 Borehole in artesian conditions - Courtesy of Mott MacDonald

Pipe work and booster pumps fitted in ASR1 - Courtesy Mott MacDonald

Undertakings

MGJV (Morrison Galliford Try Joint Venture) has constructed the 250m deep production borehole, two monitoring boreholes (275m and 135m deep) and the associated infrastructure to test the capacity of the confined aquifer. MGJV worked closely with Thames Water and Mott MacDonald to develop designs which consider the site operation at both the testing stage and with a view to extend the set up to full scale operation. The capacity over the aquifer is not yet known and operational scale testing will give insight into the future requirement of full scale operation.

Previous testing of the LGS in AMP4 demonstrated the LGS aquifer is confined and appears feasible for ASR. Pilot testing at an operational scale, following the construction of the new boreholes in AMP5 is required to consider longer term use and higher volume recharge and abstraction.

Scope

The design, construction and commissioning of the two production boreholes required a slightly different scope for the each borehole. ASR1, an initial exploratory borehole was previously constructed in AMP4 to a depth of 275m, and is located at Horton Kirby WTW and was partially equipped prior to this project. ASR3 is located just over 1km to the south west of ASR1 in agricultural land. Two monitoring boreholes were constructed, to complement the existing AMP4 borehole, to measure water level and water quality changes in response to ASR operation.

At ASR3 the borehole construction included drilling to a depth of 250m using water flush rotary method, with the first 185m drilled to a diameter of 710mm to allow a 610mm steel casing to be installed and grouted. Below 185m the borehole was drilled to 557mm diameter to allow a 457mm steel casing to be installed to a depth of 230m. The loose sands of the LGS aquifer, encountered between 230m and 248m below ground level, were stabilised by the installation of stainless steel screen.

A MuniPak™ screen was installed in the base of the ASR3 borehole, and is comprised of an inner and outer wire wound screen that is pre-filled with a tightly specified filter media. The screen permits the water to pass through but prevents the fine to medium sand of the LGS aquifer from passing, thereby protecting the submersible pump and borehole integrity.

For both ASR1 and ASR3 recharge flow is taken from water mains located close to the boreholes, of diameter 800mm and 355mm respectively. To ensure recharge rates are finely controlled an actuated needle valve also included at both sites to control the rate of recharge specifically when flow rates are low (5l/s). To ensure recharge rates reached the required maximum of 25l/s against varying pressure conditions, recharge booster pumps (duty/standby) are included at both sites downstream of the connection to the water network and prior to the needle valve.

Additionally, a reduced pressure zone (RPZ) valve was installed between the mains network and the production borehole to provide compliant backflow prevention between the borehole and mains network. At ASR1, the RPZ valve was already in situ following the previous testing in AMP4. The order of configuration varies slightly from ASR1 to ASR3, however at both, the needle valve is downstream of the booster pumps, to ensure low flow recharge against artesian pressure can be achieved using the booster pumps and finely controlled using the actuated needle valve.

Variable speed drive (VSD) controlled borehole pumps are fitted in both boreholes at 140m below ground level, and are capable of pumping at a rate of 32l/s from that depth, against varying pressures. This provides efficient operation across a range of water levels and pump rates, as well as optimising the power usage of the pumps thereby reducing the carbon footprint of the scheme. The modelling and selection of the variable speed pumps undertaken by Mott MacDonald sought to optimise the operation and power consumption of the pumps in these varying scenarios. Pressure transmitters are included in both boreholes and measure (to an accuracy of 0.1%) the water level in the boreholes during both recharge and abstraction stages. Flow meters, sampling points and pressure transducers are installed on both the recharge and abstraction lines for complete control and monitoring of the boreholes.

Challenges

There were several ongoing challenges during both design and construction which were overcome by the team. These include:

Avoiding contamination: Horton Kirby WTW relies entirely on groundwater abstraction from the chalk aquifer that is encountered at ground level to a depth of around 180m below ground level. Whilst drilling through the chalk to reach the LGS the potential to contaminate the existing supply required close supervision of the drilling operation with enhanced monitoring of the operational WTW. Furthermore all work at ASR1 was completed on a live site, construction sequencing and work to existing electricity supply had to be coordinated whilst maintaining current output.

Artesian pressures: The aquifer at ASR3 is artesian, which can cause difficulties when drilling through unconsolidated material, such as the sands of the LGS. A pressure differential across the borehole during drilling can undermine or lead to repeated collapse of the borehole walls.

To overcome the artesian pressures the drilling contractor had to weight the drilling mud, and in order to do so effectively a clay based drilling mud was required. As a clay based drilling mud was used another agent was required to remove the clay based drilling mud once the borehole was established, to mitigate any clogging which would occur in the borehole if clay was to remain within the operational borehole.

The artesian pressure also required a modified head plate on the borehole to ensure it could cope with the pressure during testing.

Flood plain: Surface water level was also problematic; both production boreholes are located within the River Darent flood plain. Design of above-ground infrastructure ensured equipment is located above the 1 in 100 year flood level; however construction did require excavation work throughout the seasons in very wet conditions.

Mitigating surface water at ASR3 was difficult; pumps were used to lower water levels during the connections to the existing sewer and construction of drainage which were both over 1.5m deep. ASR3 and both monitoring boreholes are located on third party land requiring landowner agreement. Although not strictly required for the testing phase of the project, planning permission was applied for and granted for the permanent works. Planning permission controlled the size of the site, and kiosks prior to detailed design; furthermore these restrictions constrained the layout of the MEICA equipment within the kiosks.

Electrical supply: The electrical supply at ASR1 had to be augmented; this was facilitated by the existing on-site low voltage (LV) substation. A new LV distribution board was installed as an intermediate between the existing substation and existing motor control centre on site. At ASR1 an electrical shutdown of the LV Substation to connect the supplies required a shutdown of Horton Kirby WTW.

LV distribution panel post installation prior to connection to existing LV substation - Courtesy of Mott MacDonald

As such, coordination with Thames Water, UKPN, MGJV and all subcontractors was critical.

A totally new electrical supply was required for ASR3. This was supplied via a connection off the A20 just to the west of the scheme. Connection at ASR3 required the involvement of UKPN, MGJV and the Highways Authority to facilitate the work on the A20.

Backflow prevention: As part of the initial brief Thames Water requested consideration of the issue of backflow prevention to ensure it would be functional whilst recharging during artesian conditions. Other recharge schemes use a physical air gap to provide the required backflow prevention; however in artesian conditions this requires excessive pumping which would be both costly and inefficient. The specification of a RPZ valve within the initial brief ensures a relatively small pressure loss from the mains the borehole whilst protecting the integrity of the existing potable network.

Borehole efficiency: Variable rate testing, both during recharge and abstraction, is carried out to understand the efficiency of the borehole. During ASR operation it is very important to understand whether the borehole efficiency changes with time. Prior to each recharge or abstraction test a variable rate test will be carried out to understand the water level at varying abstraction/recharge rates.

Recharge of the borehole is controlled using both a needle valve and recharge booster pumps. The needle valve allows fine control of the lower end of the flow rates from 5l/s and onwards, and when necessary the recharge booster pumps allow the flow rate to reach 25l/s. The needle valve is used as it offers fine flow control at low flow rates required for this installation.

Abstraction pressures: Abstraction pressures are more difficult to control, with varying rates of abstraction (from 10-30l/s) across varying levels of back pressure. As such the pump has been designed for the most extreme case, pumping against 140m of pressure at 30l/s.

To ensure less onerous conditions can be met by the pump several mitigations are in place. Firstly as part of the testing procedure an initial variable rate testing stage occurs which drops the water level within the borehole and secondly during testing the pump will be throttled using valves located at ground level, which can be gradually reduced as water level is lowered. The pumps have been designed as variable speed so a lower speed of the pump can be used to reach all water levels and flow rates by one pump.

Ecology/environment: The ecology and environment in the area of all four boreholes required care and consideration as all sites were near wildlife corridors and the River Darent. At ASR1 the existing discharge line (from Horton Kirby WTW) connects directly to the River Darent and as such anticipated pressure levels needed to be controlled and minimised.

Testing

On completion of both boreholes in the summer of 2015 ASR cycle testing will be carried out over 2 years to investigate the operational scale feasibility of ASR at Horton Kirby. An ASR cycle comprises a period of recharge, a period of storage and a final period of re-abstraction. Previous cycle testing of ASR1 in AMP4 confirmed that the LGS aquifer was capable of receiving treated water, storing it and allowing re-abstraction without water quality deterioration. The previous testing was carried out on a single production borehole for a relatively limited duration; this investigation will conduct operational scale testing at both production boreholes over a two year period giving more rigorous data.

Switchgear installation at ASR1
Courtesy of Mott MacDonald

Installation of VSD, Control panel and switch gear above flood plain
Courtesy of Mott MacDonald

Prior to the long term testing by Thames Water, MGJV is required to complete a one day variable rate test followed by a 10-day constant rate test. Variable rate testing requires abstraction at increasing rates from 10l/s up to 30l/s over five 100 minute intervals. After the variable rate testing the borehole is rested for a 24 hour prior to constant rate testing at 30l/s over 10 days.

On completion of the initial testing by the contractor, long term operational testing will commence. This will involve two recharge/storage/abstraction cycles with the final cycle comprising over 4 months of recharge, two months of storage and 3 months of abstraction. During the operational scale testing, the feasibility of ASR will be confirmed and the scope for conversion of the scheme to full operation will be finalised. During AMP6 further works will be required to connect the scheme into the existing water treatment works at Horton Kirby in time for the scheme to be available for supply in 2019.

Added value

This project is a pilot operational-scale operational test; however all plant has been designed with a long term perspective. Once the feasibility of ASR, without environmental issues, has been confirmed transformation to a fully operational scheme will not require a significant change in any instrumentation or plant. The use of the existing Horton Kirby WTW site for ASR1 removed the need to construct an additional borehole as well as reducing the cost of infrastructure associated with this borehole as a significant amount was already in place at Horton Kirby WTW.

The use of VSD pumps with the throttling mechanism ensured that each pump could work over 140m of differing pressure at a rate of 0-30l/s mitigating the need to increase the number of pumps. The VSD pumps allow the optimisation of the power consumption across varying scenarios, whilst maintaining the condition of the borehole and mitigating any borehole contamination.

Conclusion

The key driver behind this project is the predicted shortfall in supply capability in the London Water Resource Zone due to an increasing population and a future affected by climate change. Significant reductions in the groundwater abstraction from the chalk aquifer have been implemented in response to low flows in the River Darent.

Development of ASR at Horton Kirby will enable spare water resources to be treated and stored underground in natural reservoirs until the water is needed for supply. This allows for the mitigation of both seasonal variation in surface water and climate change, improving water supply resilience and the flexibility of water resource management.

Environmentally, economically and socially the use of confined aquifers to store and abstract water mitigates ongoing climate and seasonal changes whilst requiring minimal infrastructure and associated footprint. This solution makes sustainable use of water resources; ASR provides a sustainable method of increasing potential groundwater abstraction, with minimal environmental impacts which is vital to ensure continued protection of the iconic River Darent.

Using innovative and transferable water resource techniques will ensure effective management of the water cycle, helping Thames Water achieve a socially responsible, sustainable business.

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