Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-666

Advances in groundwater recharge during construction dewatering

Avancées dans la recharge des nappes phréatiques lors de l'assèchement des chantiers

S.D. Thomas*, J. Watson, G.R. French
OGI Groundwater Specialists Ltd, City of Durham, UK

**stephen.thomas@ogi.co.uk*

ABSTRACT: Abstraction of groundwater for consumptive use, such as for drinking water, agriculture, and industrial purposes, regularly requires the granting of a permanent abstraction licence from environmental regulatory bodies. Temporary abstraction of groundwater required for construction, however, has not historically required an abstraction licence. More recently, due to the conservation of groundwater in Europe now being a major challenge, it is becoming more common in European countries that licensing for the temporary abstraction of groundwater during construction dewatering, known as groundwater control, is now required from the environmental regulators of each country. Due to this requirement for licensing, the development of effective techniques for reducing the overall loss of groundwater has become more important. In particular, such conservation techniques include increased use of artificial recharge of groundwater back into the same strata from which it was abstracted. This paper presents three case studies describing a number of groundwater abstraction and recharge systems implemented on major infrastructure construction projects in the United Kingdom.

RÉSUMÉ: Le captage d'eau souterraine à des fins de consommation, par exemple pour l'eau potable, l'agriculture et l'industrie, nécessite régulièrement l'octroi d'un permis de prélèvement permanent auprès d'organismes de réglementation de l'environnement. Toutefois, le prélèvement temporaire d'eau souterraine nécessaire à la construction n'a pas toujours nécessité de permis de prélèvement. Plus récemment, en raison de la conservation des eaux souterraines en Europe qui est maintenant un défi majeur, il est devenu de plus en plus courant dans les pays européens qu'une licence pour le prélèvement temporaire d'eau souterraine pendant l'assèchement des constructions, connue sous le nom de contrôle des eaux souterraines, soit désormais exigée des régulateurs environnementaux de chaque pays. En raison de cette exigence de licence, le développement de techniques efficaces pour réduire la perte globale d'eau souterraine est devenu plus important. En particulier, ces techniques de conservation comprennent l'utilisation accrue de la recharge artificielle des eaux souterraines dans les mêmes strates d'où elles ont été extraites. Cet article présente trois études de cas décrivant un certain nombre de systèmes de captage et de recharge des eaux souterraines mis en œuvre dans le cadre de grands projets de construction d'infrastructures au Royaume-Uni.

Keywords: Groundwater control; water conservation; construction dewatering.

1 INTRODUCTION

Total global groundwater abstraction was estimated to be circa 1000 km^3/annum in 2010; 72 km^3/annum of which was within Europe (Margat and van der Gun, 2013). Although significantly less than estimated global natural recharge (Dillion, Stuyfzand, and Grischeck, 2019), the concentration of abstractions in urban and dry areas has led to substantial groundwater quantity and quality deterioration in a number of regions.

Where abstraction exceeds recharge, water table lowering results in a reduction of baseflow to surface water features, ground subsidence and deterioration of water quality through mechanisms such as saline intrusion and contamination mobilization.

The rapid rise in global groundwater abstraction over the past century has resulted in groundwater resource sustainability concerns. This in turn has led to an increased drive to advance and adopt intentional artificial recharge systems, also referred to as managed aquifer recharge: MAR (Dillion, Stuyfzand, and Grischeck, 2019). This focus has generally been on long term and permanent operations, as opposed to temporary works such as construction dewatering.

Although not regularly utilised in the United Kingdom, artificial recharge during temporary construction dewatering operations is not a new concept (Bock and Markussen, 2007; Cashman and

Preene, 2013; Powrie and Roberts, 1995; Preene, Roberts, and Powrie, 2016). The additional monetary costs of implementing artificial recharge have historically been a deterrent to construction companies, unless there is a site-specific requirement.

However, in England and Wales, the Water Abstraction and Impounding (Exemptions) Regulations 2017 (Statutory instrument, 2019) came into force in January 2018. These regulations made construction dewatering a licensable activity (abstraction during engineering works was exempt from abstraction licensing prior to this date).

With construction dewatering abstraction now regulated by the Environment Agency (England) and Natural Resources (Wales), contractors are having to revise and refocus their approach to groundwater control and management.

A focus on minimising the environmental impact of construction dewatering operations, to enable a smooth licensing process, is becoming a more economically viable option. The introduction of the regulations has resulted in recharge and cut-off systems, that were previously not contemplated due to cost, now being considered more regularly.

With artificial recharge systems being increasingly designed and utilised as part of temporary construction dewatering operations, this paper aims to document the authors' experience of implementing temporary dewatering recharge systems, together with key advantages and disadvantages. Three recent case studies are also presented.

2 GROUNDWATER CONTROL RECHARGE SYSTEMS

2.1 Recharge system design

Groundwater recharge during temporary construction dewatering involves the recirculation of abstracted groundwater back into the same geological strata by reinjection (via wells) or infiltration (via trenches or shallow wells) (Preene and Fisher, 2015), generally without any intervening use. The recharge system needs to be at an appropriate distance which is logistically feasible, whilst not close enough to prevent the dewatering system from maintaining the water table below the target level.

If designed and implemented appropriately, the groundwater quality remains constant, drawdown at distance is reduced, with negligible net water abstraction from the aquifer.

Abstraction wells need designing to enable water table lowering to the target level, taking into account the reduced radius of influence due to artificial recharge. Wells need to be designed with appropriate filtration to prevent mobilization of ground fines which could clog the recharge wells or cause ground loss.

Recharge wells need careful designing to allow groundwater to readily discharge into the aquifer without causing localized flooding around the well. Wells need to have sufficient slotted length, and a free-flowing annulus filter pack. This is to mitigate water quality issues from clogging (Cashman and Preene, 2013). This becomes more critical the longer the duration of the dewatering operation.

Appropriate pipework is installed from the abstraction wells to the recharge wells. Closed pipework systems are generally utilised to reduce the clogging risks associated with the groundwater being exposed to the atmosphere (e.g. iron ochre precipitation, gas binding etc.). Discharge to recharge wells can be via gravity, or under pumped pressure. Settlement/inspection tanks, sample taps, and/or flowmeters may be installed within the connecting pipework depending on the site conditions and requirements.

A construction dewatering groundwater recharge concept is illustrated in Figure 1.

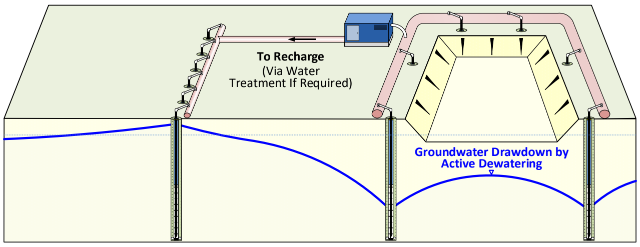

Figure 1. Concept groundwater control recharge system.

2.2 Benefits of utilising a recharge system

The primary benefits of utilising a recharge system on a temporary construction dewatering project are to adhere to legislation, protect surrounding infrastructure by mitigating settlement risk, reduce water disposal costs, conserve water and to protect vulnerable water features from drawdown impacts.

Drawdown at distance is also reduced, preventing the alteration of head gradients, which could lead to reduction in baseflow to surface water systems, deterioration of existing abstractors, and contamination/saline interface migration. A reduction in drawdown also mitigates the risk of settlement from pore water pressure reduction.

With an appropriate recharge system specified, obtaining the relevant abstraction license and discharge permit can be simplified as environmental risks are minimized. This reduces the risk of delays to the project programme.

2.3 Disadvantages of utilising a recharge system

Historically, the main disadvantage to contractors of recharge systems is the cost associated with both their installation and implementation, including their design costs. Access to suitable land to locate recharge wells can be a constraint, particularly in urban areas.

Furthermore, recharge systems are not always a feasible groundwater management strategy, as they are dependent on the hydrogeological conditions encountered. In addition, the recharge system may need to be implemented in tandem with other groundwater control methodologies such as cut-off walls, to work effectively.

Where recharge is feasible, the advantages of a recharge system can only be realised if the groundwater control system is appropriately designed and monitored by competent and experienced personnel (due to the additional risks as documented previously).

Without appropriate design, recharge systems can be overwhelmed resulting in localised flooding around the recharge wells, or the target drawdown not being met. In addition, as groundwater is being directly recharged into the aquifer, it is vital that the system is protected to prevent the possibility of contaminants entering the groundwater body.

3 GROUNDWATER RECHARGE CASE STUDIES

3.1 Tunnel boring machine drive pit, England

The River Humber gas pipeline replacement is a major infrastructure project to replace an existing gas pipeline which stretches circa 5 kilometres beneath the River Humber; a large tidal estuary on the eastern coast of Northern England.

To construct the pipeline, a slurry tunnel boring machine (Figure 2) was driven from the southern bank of the Humber. The depth of the tunnel drive pit, together with a relatively shallow water table (circa 1 m below ground level), required a temporary groundwater control system.

During the Development Consent Order stage (planning permission for developments categorized as Nationally Significant Infrastructure Projects in the UK), the sensitivity of the chalk aquifer on the southern bank of the Humber to any dewatering was identified. The primary concerns of the Environment Agency were (i) the risk of the saline interface mobilizing inland, and (ii) the regional water resource status. The Catchment Abstraction Management Strategy (CAMS) status of the south Humber bank is 'no water available for abstraction except at extremely high flows. Groundwater resources in the Lincolnshire Chalk are fully committed to existing users and the environment' (Environment Agency, 2013).

Figure 2. Tunnel boring machine used to construct the Feeder 9 gas pipeline.

The geology of the site comprised low permeability alluvial and glacial deposits (Superficial Deposits) to circa 10 m below ground level. These deposits were underlain by the Flamborough Chalk, which was highly weathered in the top several metres and recovered as a chalk gravel, and is termed by Chalk Bearings. This highly weathered stratum was highly permeable with sub-artesian groundwater encountered during the site investigation. This stratum was underlain by the intact Fractured Chalk, of significantly less permeability than the weathered chalk (Figure 3).

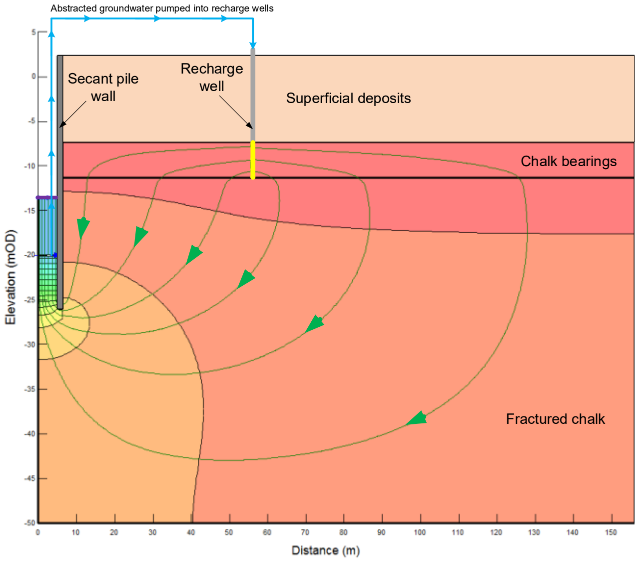

Figure 3. Finite element modelling of dewatering and recharge system for Feeder 9 gas pipeline.

To mitigate the risks, a groundwater control strategy utilising a partial cut-off and recharge system was developed (Figure 4). This resulted in abstraction being non-consumptive, and prevented drawdown towards the River Humber, so mitigating saline water intrusion.

Figure 4. Pressurised wells to recharge abstracted groundwater back to the aquifer.

As the weathered chalk was very high permeability, a cut-off wall was required to penetrate through these deposits. Full cut-off of the weathered and underlying fractured chalk strata was originally considered; however, this was deemed impractical due to the fractured chalk extending circa 40 m to 50 m below ground level. Internal dewatering was specified within the Drive Pit (borehole pumps within designed wells). These internal wells abstracted groundwater from the more competent underlying fractured chalk.

Abstracted groundwater was then recharged back into the weathered chalk outside the Pit, reducing the radius of influence of the groundwater control operation and reducing the net abstraction from the aquifer to almost zero. The recharge system was fully enclosed, preventing the groundwater from coming into contact with the atmosphere, which helped prevent dissolved iron in the groundwater from precipitation and discolouring the groundwater.

Further project detail is described in Proceedings of the Chalk 2018 Conference (Goodfellow & Thomas, 2018; Holmes, Roberts, & Lee, 2018).

3.2 Microtunnel reception shaft Glasgow, Scotland

During construction of a Microtunnel reception shaft in Scotland, larger and more frequent boulders were encountered than expected.

These unexpected ground conditions resulted in the construction methodology being changed from jacked caisson to underpinning. The previous construction methodology could be undertaken in the wet, however the new methodology would require active dewatering.

Concerns were raised by key stakeholders about the potential risk of settlement from dewatering as the shaft was in close proximity to both a live railway, and bridge piers on frictional piles for a major road bridge spanning the River Clyde (Figure 5).

Figure 5. Photo of micro-tunnel reception shaft located close to the bridge piers.

The geology at the site generally comprised silty sands and gravels, overlying glacial till containing cobbles and boulders (Figure 6). Stakeholders were concerned with two main mechanisms for ground settlement at the site, settlement from ground loss, and settlement from a reduction in pore water pressure in shallow deposits.

To mitigate the concerns of stakeholders, a groundwater control system that included recharge was designed to minimize drawdown at a distance, as well as reduce water ingress into the shaft which could mobilise the soil.

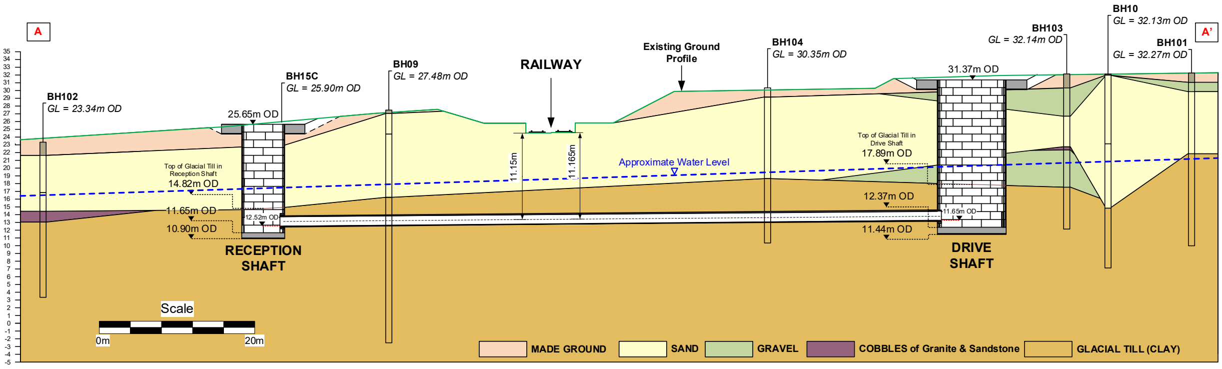

Figure 6. Conceptual model at the location of the reception shaft & drive shaft.

Site logistical constraints required recharge wells constructed within relatively close proximity to the shaft, and as such an assessment was required to confirm the system's feasibility.

Finite element modelling was undertaken to ascertain the flow rates required to minimize groundwater ingress into the shaft, and to prevent excessive drawdown below the railway and bridge piers by recharging into wells between the shaft and sensitive structures.

The finite element model head contours (Figure 7), demonstrated that a recharge system was feasible, and would prevent drawdown of more than 500 mm at the bridge piers and railway track.

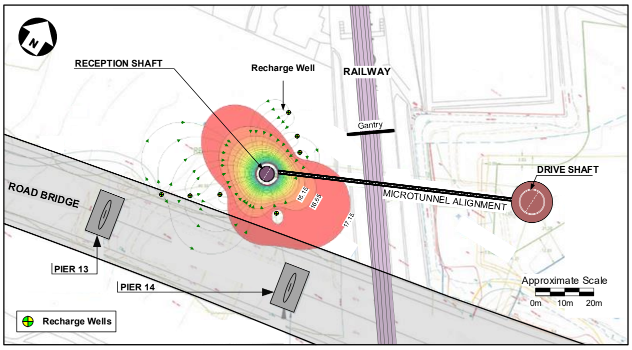

Figure 7. Finite element simulation of the dewatering and recharge system.

Figure 8 demonstrates the well design with slot sizes and filter material specified to prevent ground ingress into the wells, to mitigate ground settlement. Figures 9 and 10 depict the wellhead of a pumping well and recharge well respectively.

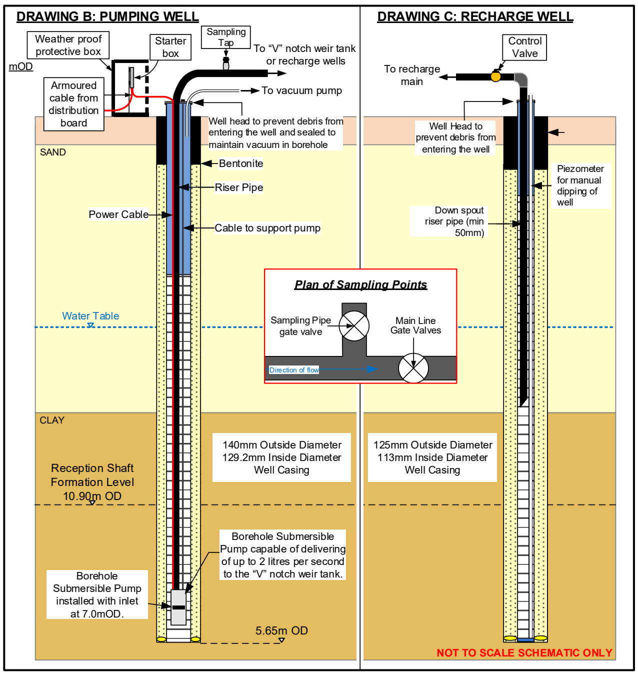

Figure 8. Specification of pumping and recharge wells.

Figure 9. Pumping well.

Figure 10. Recharge well.

3.3 The Commonwealth Games Aquatics Centre, Sandwell, Birmingham

The 2022 Commonwealth Games Aquatics Centre in Sandwell, Birmingham, was under construction over the period 2018 to 2022 (Figure 11), and required excavation for the competition pool, dive pool, plant room, down to a depth of 7 m below ground level.

The dewatering operation would have been less complex if the abstracted groundwater could be discharged directly to a watercourse. However, this approach would have resulted in the loss of groundwater from the aquifer resource in the order of 250 million litres.

Figure 11. The Birmingham Commonwealth Games Aquatic Centre during construction.

Due to the over-abstraction of groundwater from the aquifer underlying Birmingham (the Chester Formation), the Environment Agency specified a "net zero" abstraction rate during the construction of the Commonwealth Games Aquatics Centre Project. This meant that one hundred per cent of the groundwater abstracted during the construction period was required to be recharged back to the same aquifer from which it was abstracted.

The Aquatic Centre system required over 120 drilled suction abstraction wells and 50 recharge wells; with each well individually specified so that groundwater abstraction and recharge were targeted at the appropriate strata. Figure 12 presents the location of the numerous abstraction and recharge wells, and the cross-sectional output of the two-dimensional mixed confined-unconfined aquifer model GEMOS (Authors' Software).

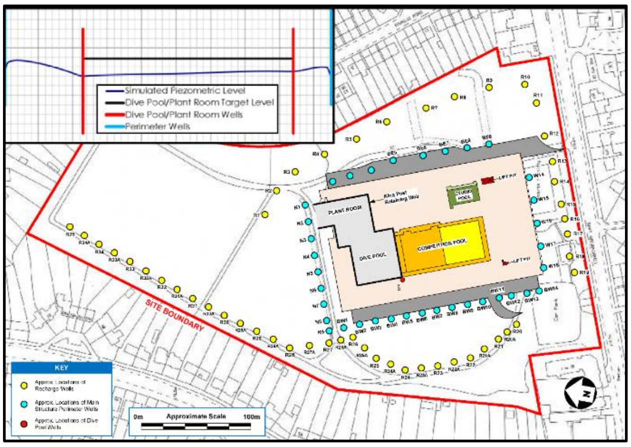

Figure 12. Location of abstraction & recharge wells during construction.

It was essential to abstract clear filtered groundwater (Figure 13), to prevent silts from being removed from the ground, and so allowing recharge of clear water to avoid frequent blockage. Note that regular maintenance and cleaning of the recharge wells was still required.

Figure 13. Abstraction of clear groundwater.

The recharge system required the pressurisation of the water with a circa 3 m head above ground level at each recharge wellhead. This was achieved by pumping the abstracted groundwater uphill to a water holding tank (Figure 14) at an elevated location. This then fed the recharge pipes to maintain a pressure of 30kPa to overcome the artesian head in the aquifer.

Figure 14. Water holding tank before discharging to the multiple-well recharge system.

REFERENCES

Bock, M., & Markussen, L. M. (2007). Dewatering control in central Copenhagen. *In Proceedings 14th Conference on Soil Mechanics and Geotechnical Engineering 2* (bls. 715-720). Amsterdam: Geotechnical Engineering in Urban Environments.

Cashman, P. M., & Preene, M. (2013). Groundwater Lowering in Construction: A Practicle Guide to Dewatering 2nd edition. *CRC Press.* Boca Ranton.

Dillion, P., Stuyfzand, O., & Grischeck, T. (2019). Sixty years of global progress in managed aquifer recharge. *Hydrogeology Journal 27(1)*, 1-30. http://dx.doi.org/10.1007/s10040-018-1841-z.

Environment Agency. (2013). *Ancholme and Louth Catchment Abstraction Management Strategy* Grimsby.

Goodfellow, T. L., & Thomas, S. D. (2018). Groundwater resource protection from construction groundwater control in Lincolnshire chalk. *Engineering in Chalk: Proceedings of the Chalk 2018 Conference* (bls. 669-674). London: ICE Publishing.

Holmes, G. J., Roberts, T. O., & Lee, M. (2018). A case study of construction dewatering in Northern Province Chalk. *Engineering in Chalk: Proceedings of the Chalk 2018 Conference* (bls. 147-153). London: ICE Publishing.

Margat, J., & van der Gun, J. (2013). *Groundwater around the world.* Lisse, The Netherlands: Balkema. http://dx.doi.org/10.1201/b13977.

Powrie, W., & Roberts, T. O. (1995). Case history of a dewatering and recharge system in chalk. *Geotechnique 45(4)*, 599-609.
https://doi.org/10.1680/geot.1995.45.4.599.

Preene, M., & Fisher, S. (2015). Impacts from groundwater control in urban areas. *Impacts from groundwater control in urban areas. Proceedings of the XVI European Conference on Soil Mechanics and Geotechnical Engineering* (bls. 2847-2852). London: ICE Publishing.

Preene, M., Roberts, T. O., & Powrie, W. (2016). *Groundwater Control: Design and Practice, 2nd Edition. Construction Industry Research and Information Association.* London: CIRIA Report C750.

Statutory instrument. (07. May 2019). *The Water Abstraction and Impounding (Exemptions) Regulations 2017*. Sótt frá legislation.gov.uk: http://www.legislation.gov.uk/uksi/2017/1044/made.