The design and management of groundwater control for the construction of a railway box culvert

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1. Introduction

Rochdale and Littleborough are communities in Greater Manchester which are at risk of significant flooding events, with several such events occurring in the past 20 years (Environment Agency, 2009). As a consequence, the River Roch, Rochdale and Littleborough Flood Risk Management project has been set up in partnership between the Environment Agency (EA) and Rochdale Borough Council to improve infrastructure necessary to reduce the risk of flooding in the future. Part of the scheme involves the construction of two large attenuation reservoirs in Gale, Littleborough, that collect and store river water from the River Roch and nearby tributaries during storm events. For river water to reach the attenuation lagoon on the west side of the railway line, the construction of a culvert was required beneath the Network Rail Calder Valley Railway Line.

The Calder Valley Railway Line is a busy line, with passenger and freight trains travelling between Manchester and Leeds, passing at least every 15 minutes. The culvert construction required a 4-day rail blockade during which the track was removed, the ground excavated, the culvert installed and the railway line reinstated. Due to the strict 4-day blockade for the completion of the main works, there was no time available for design modifications once the construction works commenced. Hence, a robust and resilient groundwater control system was required to ensure that the hydraulic groundwater head in underlying alluvium (clay, sand, gravel) and buried glacial channel (sand and gravel) was maintained below the excavation level in advance of and during the blockade works.

Network Rail had the responsibility for undertaking the construction works. Their framework contractor J. Murphy & Sons was appointed to build the culvert, and their permanent designer Arcadis to design the culvert. The design included the construction of a 45m-long precast concrete box culvert beneath the railway line (Figure 1).

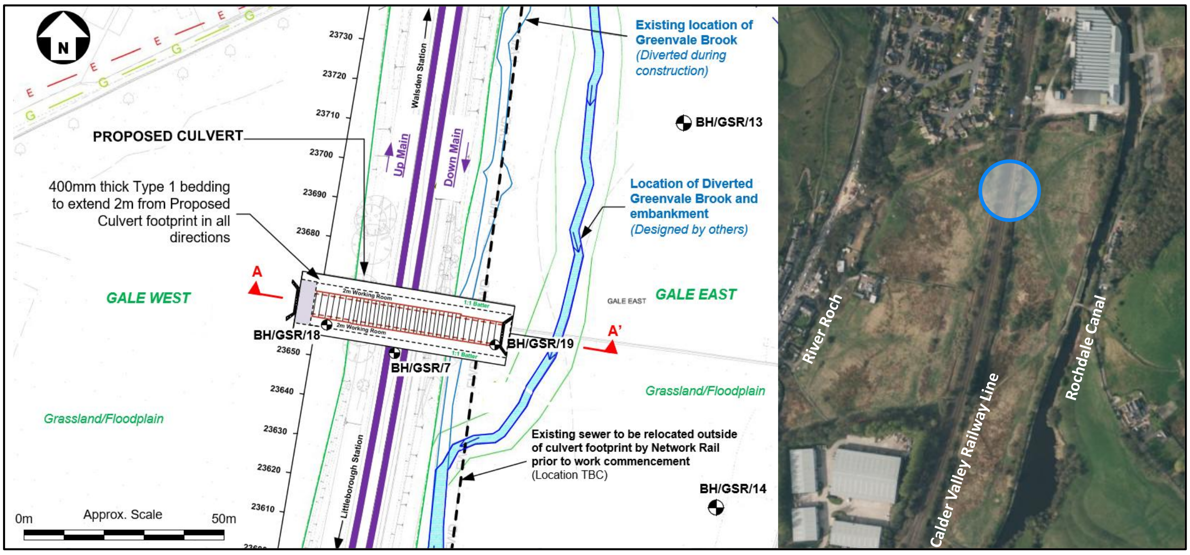


Figure 1: Site plan showing location of the box culvert in relation to the Network Rail Calder Valley Railway Line and Greenvale Brook.

3. Identification of Groundwater Risks

The construction site lies within the centre of the upper Roch Valley, which was formed during the last ice age (Pearson *et al.*, 1985). The River Roch, together with a smaller tributary named Greenvale Brook, flow through the valley. Figure 1 depicts the location of the Greenvale Brook relative to the box culvert. The River Roch is located c. 100m west of the box culvert. The geology at the site has been heavily influenced by the last ice age, with a thick buried glacial channel (sand and gravel deposits) encountered at a depth greater than 4.5m below ground level. Above this channel lies alluvium (sand, gravel, clay & peat) which was deposited by the meandering course of the River Roch, together with associated tributaries that also flowed through the valley.

Groundwater monitoring took place during site investigation works in the lead-up to the project. In the alluvial deposits, the phreatic surface (water table) was measured between 0.0m and 1.0m below ground level. In the underlying buried glacial channel deposits, the groundwater level was measured as flowing artesian (natural piezometric groundwater head above ground level), with a head up to +300mm above ground level. This high head in the confined underlying glacial channel deposits indicates a vertical upward groundwater flow direction.

As a result of this upward groundwater flow direction, the site has always resulted in boggy ground adjacent to the railway line. The artesian groundwater conditions and highly permeable ground at the site combine to form clear groundwater risks that pose a significant risk to the safe implementation of the construction works.

Three significant groundwater risks identified were:

(i) Groundwater flooding caused by shallow perched groundwater in the alluvium

(ii) Soil destabilisation caused by high porewater pressure relative to the total stress, which results from the ingress of groundwater into the excavation from both below and from the sides of the excavation, and

(iii) Uplift failure of the clay layer at the base of the alluvium caused by the artesian groundwater pressure in the underlying buried glacial channel.

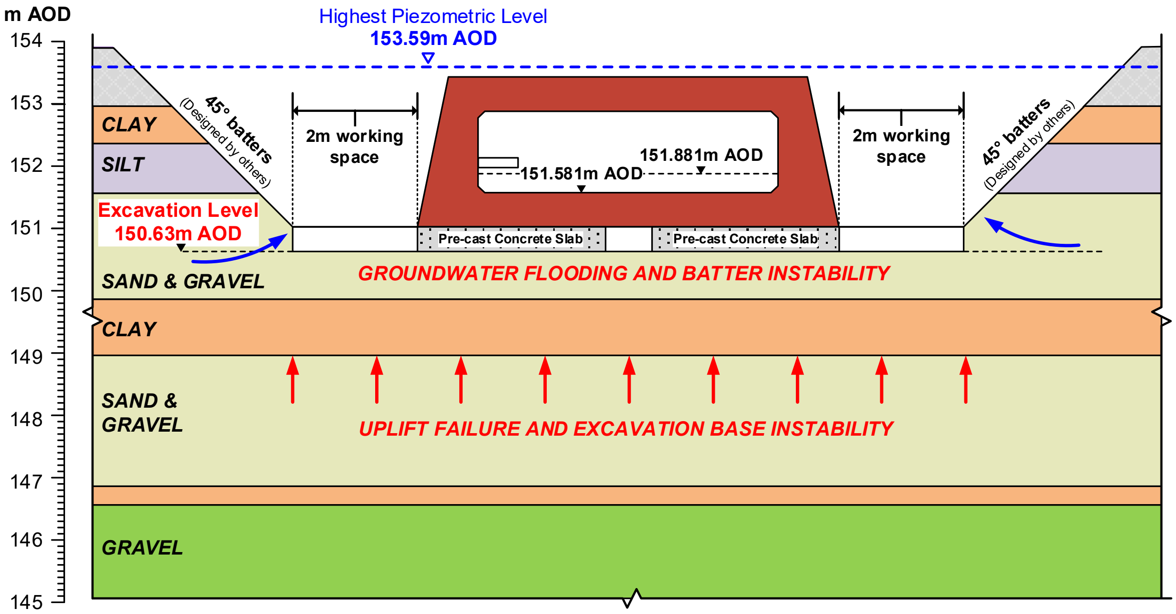


Figure 2: Conceptual model drawing showing the geology, groundwater level and culvert construction details.

4. Mitigation of Groundwater Risks during the Temporary Works

To mitigate against the risk of the groundwater risks identified, OGI was commissioned by JMS to develop a strategy for groundwater management in the lead-up to the railway blockage. Due to the pre-planned 4-day railway blockage that was scheduled for the end of October 2021, the mitigation measures had to be robust and resilient to ensure that not only the design was complete and approved by JMS and Network Rail, but also all licences and permits were in place.

The groundwater management plan included a staged approach with each step shown in Figure 3 in the sequence they were undertaken.

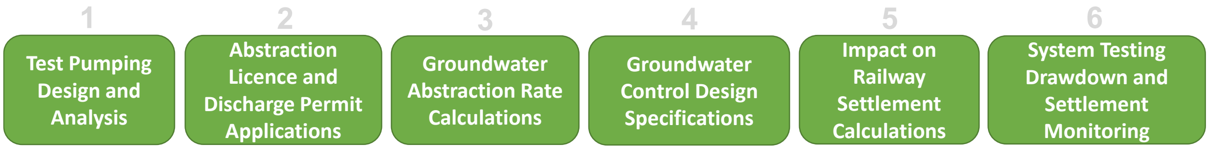


Figure 3: Sequence of steps developed as part of the groundwater management strategy for the works.

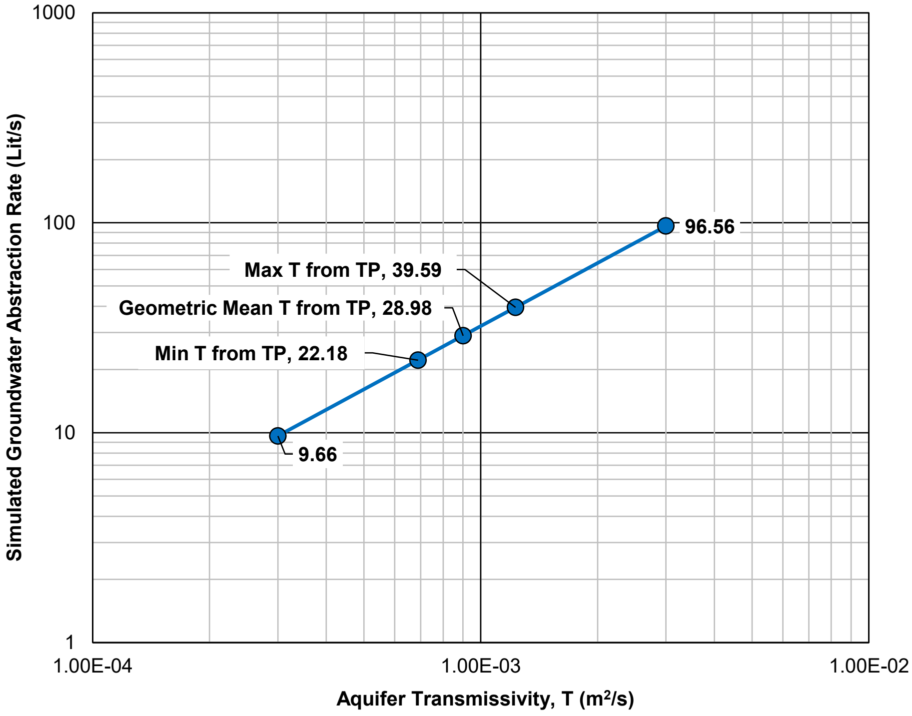
4.1 Test Pumping Works

Undertaking test pumping is critical to understanding the hydrogeological properties of the soils beneath the site, and to support applications to the Environment Agency for an abstraction licence and discharge permit.

For a known water table/artesian head drawdown, it is the aquifer transmissivity, T, that is the most important parameter to establish, as this enables the calculation of the total abstraction rate from the dewatering system.

Five separate tests were undertaken over four days, with a daily groundwater abstraction of less than 20m^3.

Test pumping was undertaken from wells on both sides of the railway line because the ground conditions vary across the site. The results from the test pumping demonstrate highly transmissive soil deposits, with transmissivity values ranging between 7.0 x 10^{-4} m^2/s to 1.2 x 10^{-3} m^2/s. Simulations of the proposed dewatering system resulted in calculated abstraction rates from the dewatering system within the range of 22 to 40 Lit/s (Figure 4), with a central estimate of 29 Lit/s.



Using the test pumping results, the expected dewatering system abstraction rate was calculated to be within the range of 22 Lit/s to 40 Lit/s

Figure 4 Sensitivity analysis calculation of expected groundwater abs

4.2 Environment Agency Permitting

Groundwater abstraction for temporary dewatering became a licensable activity in England in 2018. Construction sites that plan to abstract more than 20m^3/day of groundwater over a period of more than 6 months, must have an abstraction licence from the Environment Agency in place. In addition, if the abstracted groundwater is to be discharged to a surface water feature such as a river or stream, then a discharge permit is also required.

As the ground beneath the site comprised a sand and gravel aquifer, it was clear from the start of the project that an abstraction licence and discharge permit would be required from the EA to legally permit the dewatering to be implemented on the project. Using the results from the test pumping, the likely abstraction and discharge rates for the dewatering system were calculated and used to specify a maximum abstraction and discharge rate for the EA applications. The abstraction licence and discharge permit were both obtained in the months before the construction works.

4.3 Dewatering System Design

Following the test pumping works, the groundwater control system was designed to lower the groundwater level and artesian pressure to enable the construction of the box culvert in dry and stable ground conditions, thereby minimising the risk of the groundwater hazards identified in Section 3.

With groundwater head at/above ground surface, the groundwater control dewatering system had to meet the following primary objectives:

1. Lower the groundwater level in the upper 4.0m of ground i.e., the alluvium deposits, to minimise groundwater inflows entering the excavation during construction of the box culvert and causing groundwater flooding.
2. Lower the artesian pore water pressure in the deeper buried glacial channel to prevent hydraulic heave failure during excavation and construction of the box culvert.
3. To lower the groundwater level and artesian groundwater pressures in the two weeks before the 4-day railway blockade whilst the railway line remained active to traffic.

To achieve these primary objectives, the groundwater control system design comprised:

1. Active suction dewatering system with drilled suction wells located around the perimeter of the excavation and outside the Network Railway boundary fence.
2. Monitoring wells to assess both the performance of the system and the groundwater levels beneath the live railway line by measuring the groundwater drawdown across the site.

Figure 4 depicts the locations of the dewatering wells and monitoring wells together with the dewatering system set up including suction pumps and header pipe. Dewatering suction wells were strategically placed along the sides of the excavation batters and parallel to the railway line to ensure sufficient drawdown at the centre of the railway line where wells could not be placed.

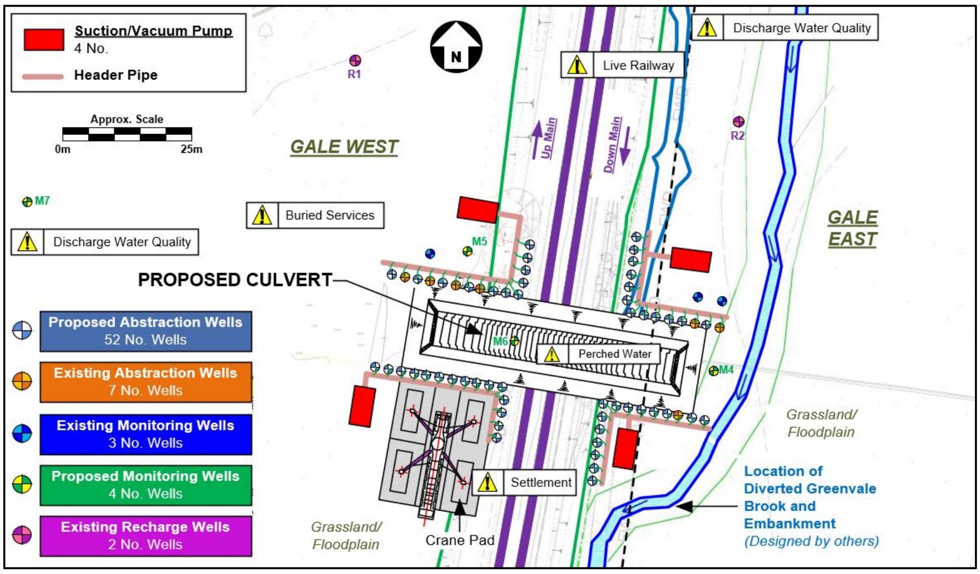


Figure 5: Site plan showing well locations and dewatering system pumping set up at the site.

4.4 Calculation of Ground Settlement along the railway embankment

The alluvium deposits at the site consist of a mix of soil types, including clays, silts, peats, sands and gravels. The site investigation works identified clay and silt soils within the top 4m of ground that had low strength, and which were highly compressible. As a result, the soils were identified at risk of ground settlement when the groundwater level was reduced as a consequence of the increased effective stress caused by the reduction of porewater pressure, which was the very purpose of groundwater control dewatering. This risk of potential ground settlement was raised with Network Rail, and as a result, this risk needed to be thoroughly investigated by undertaking calculations of settlement before the implementation of the dewatering works on site.

OGI undertook modelling of the groundwater control system to simulate the predicted groundwater level beneath the railway embankment during dewatering (see Figure 6). This groundwater head profile was then used as an input to the settlement calculations.

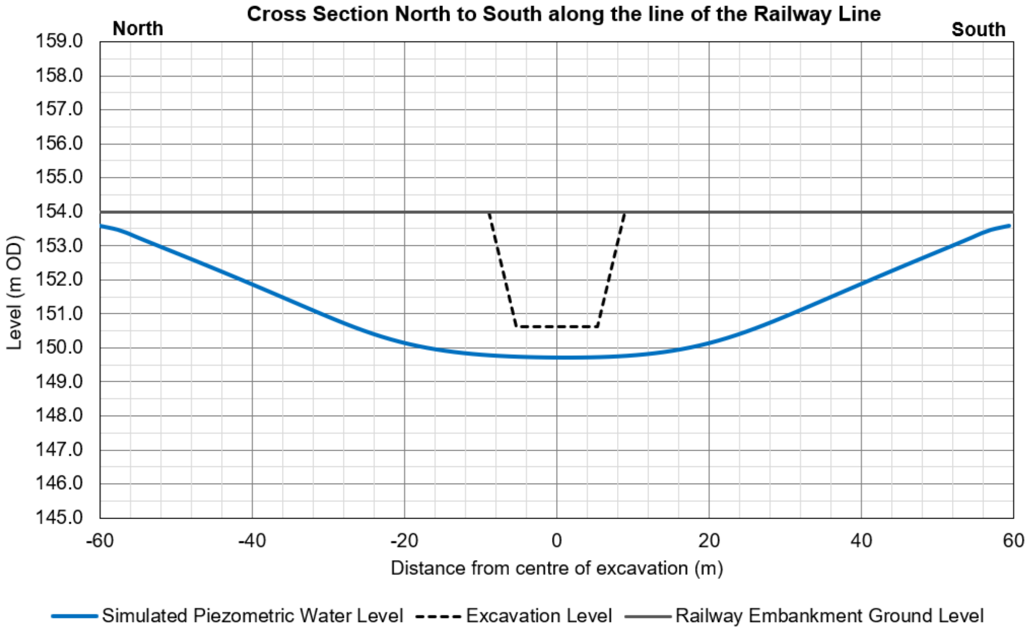
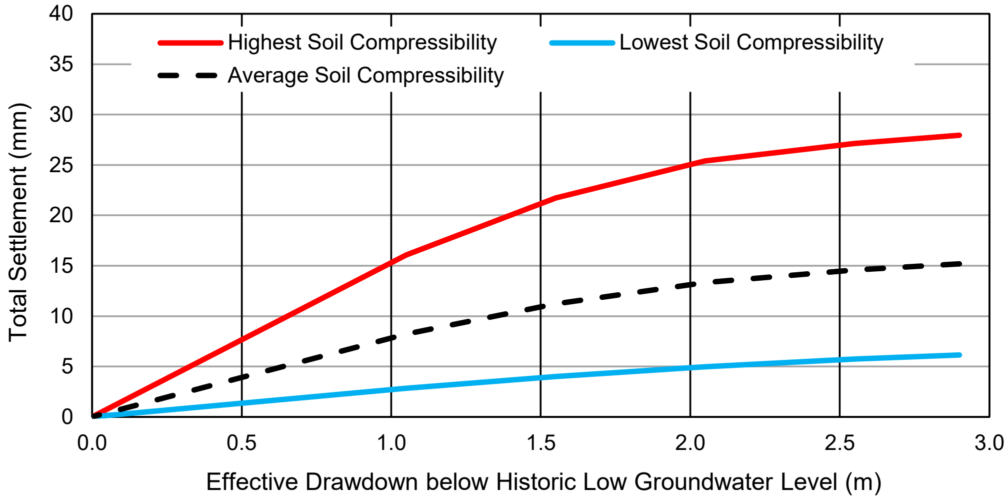


Figure 6: Cross section north to south along the line of the railway embankment showing the modelled piezometric groundwater head level during the dewatering works.

Settlement calculations for a range of vertical ground compressibility values were undertaken based on the results of laboratory oedometer tests, together with a range of modelled groundwater drawdown levels below possible historic low groundwater levels. The historic low groundwater level is the lowest groundwater level that has occurred in the soil in the past and is therefore the point at which the soil begins to compress along the virgin consolidation line as effective stress increases. Because the historic low groundwater level is unknown at the site, a sensitivity analysis of soil compressibility and drawdown below the historic low groundwater level was undertaken. The results of this sensitivity analysis indicated possible ground settlements up to 30mm for the most compressible soils, and up to 6mm for the least compressible soils (Figure 7).

The findings resulted in JMS implementing a thorough track monitoring plan that would monitor any movement in the railway embankment during the dewatering operation. A traffic light system was implemented, whereby the dewatering works would be halted if the railway embankment settled beyond the trigger levels.



Calculated Settlement vs Drawdown below Historic Low Groundwater Level

Calculated Settlement along Railway Embankment – Average Soil Compressibility

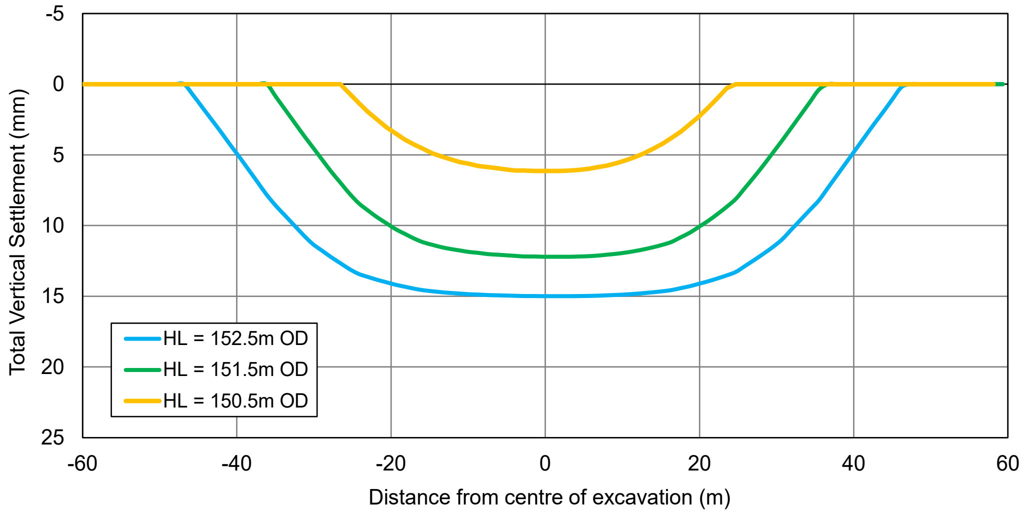


Figure 7: Calculated total settlement vs effective drawdown below historic groundwater level.

5. Implementation of Dewatering System on Site

In the four weeks leading up to the railway blockade, the wells for the dewatering system were drilled and installed by the specialist dewatering contractor. Before switching on the dewatering system, a phased approach to turning the system on was agreed upon between OGI and JMS to minimise the risk of differential settlement.

Wells on the north side of the railway were switched on first, (quadrants Q1 & Q2 shown in Figure 8), with one hour of groundwater monitoring undertaken before the wells on the south side of the railway were turned on (quadrants Q3 and Q4). After two to three days of pumping, the groundwater level was reduced to 1.0m below the proposed excavation level, as shown in Figure 8.

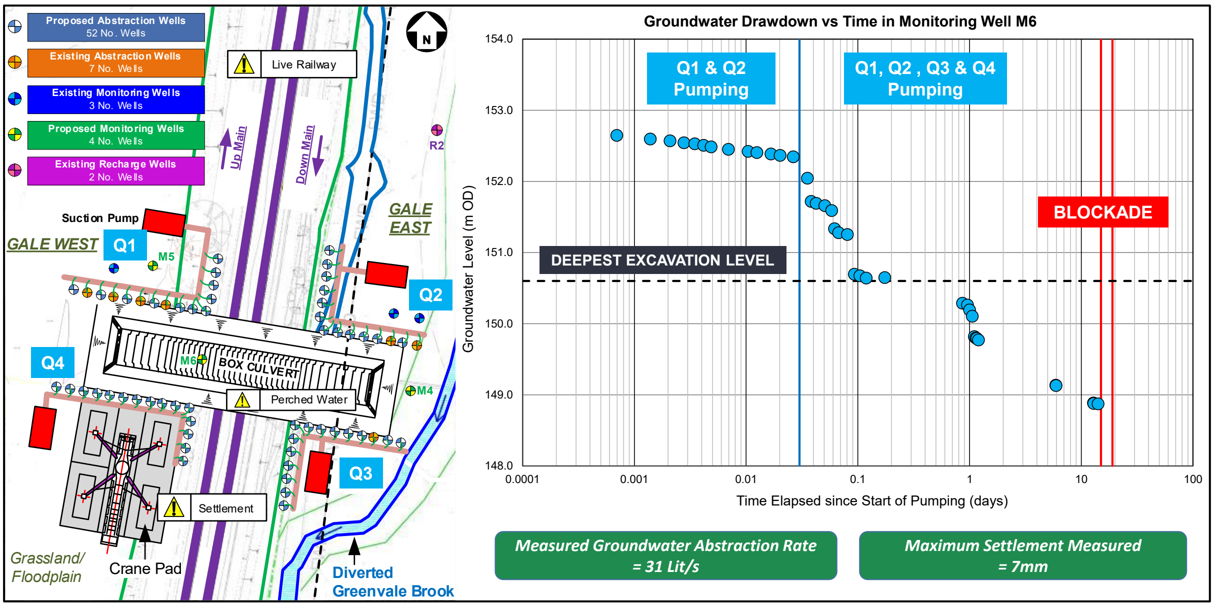
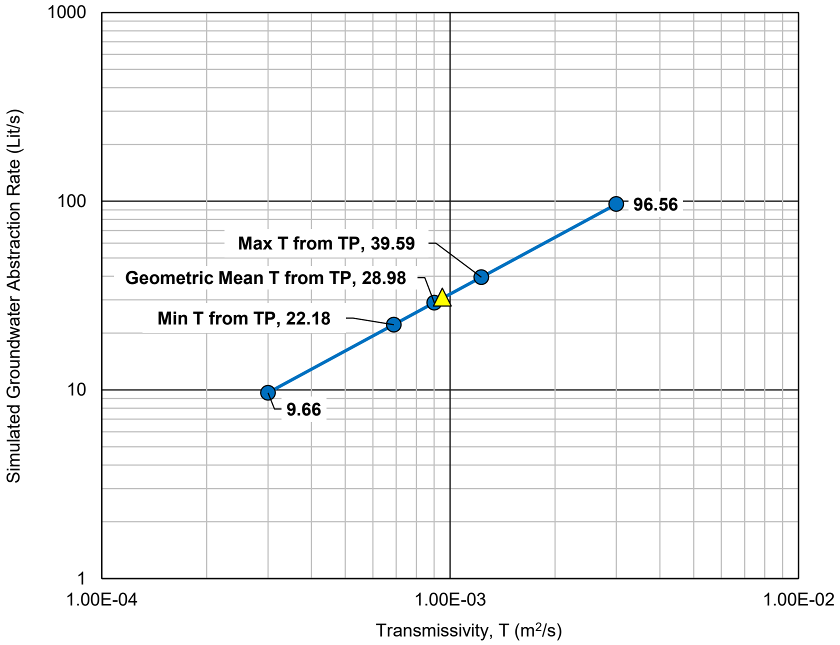


Figure 8: Measured groundwater drawdown in the days leading up to the railway blockade.

The steady-state abstraction rate recorded by the dewatering system was circa 31 Lit/s (shown by the yellow marker in Figure 9). This value was close to the central estimate calculated following the test pumping (29 Lit/s), which demonstrates the value of undertaking pre-construction test pumping works.



Measured Groundwater Abstraction Rate = 31 Lit/s

Figure 9: Measured groundwater abstraction rate (yellow triangle) from the dewatering system in comparison to the predicted groundwater abstraction rates undertaken following the test pumping.

During the initial days of pumping, settlement monitoring of the railway embankment measured maximum settlements of 7mm. This was below the trigger levels set by the track monitoring plan, confirming that the dewatering system could continue operating whilst the railway line remained operational in the lead-up to the blockade.

After the dewatering system had been operational for several days, a large trial pit was excavated to check the ground conditions. The ground was shown to be dry, which demonstrated the effectiveness of the dewatering system and that the design objectives had been achieved. During the blockade, the dewatering system continued to work effectively, resulting in a dry and stable excavation environment, enabling the construction works to proceed in line with the planned construction schedule.

This case study demonstrates how the detailed planning of the groundwater control strategy during the project, combined with the clear identification of the groundwater risks, led to the successful implementation of a robust and resilient groundwater control dewatering system.

Two weeks after the railway blockade, the criticality of the groundwater control operation became observable when the dewatering system was switched off. Within only 24 hours, the water table rebounded to close to the original water level and all parties were able to see first-hand the importance of the groundwater control system in enabling the successful completion of the project. The flooded and saturated ground after the groundwater rebounded is depicted in Figure 10.

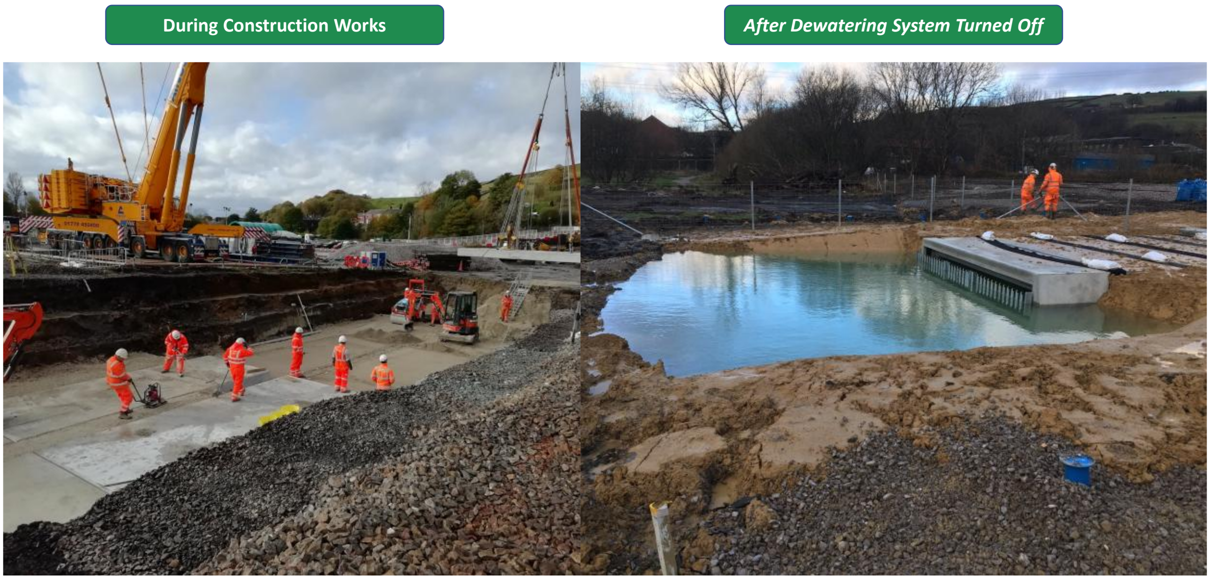


Figure 10: Photos of the box culvert during construction (left), and after construction when the dewatering system was turned off and the groundwater level had rebounded (right).

6. Conclusions

The construction of the box culvert in Littleborough was required to reduce the risk of flooding in Littleborough and Rochdale in Greater Manchester. The culvert construction required a railway blockade during which the track was removed, the ground excavated, the culvert installed, and the railway line reinstated within four days. Following the site investigation works, the impact of groundwater on the temporary works was identified as a risk. Groundwater flooding and saturated soil destabilisation were identified as one of the most significant risks to the works. To mitigate against these risks, OGI developed a groundwater management plan which included undertaking test pumping design and analysis, dewatering system design, EA permitting, settlement calculations and the monitoring of the groundwater levels during the works. The robust and resilient approach to groundwater management led to the implementation of a groundwater control dewatering system, with the construction of the box culvert completed during the 4-day railway blockade.

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