

Groundwater Control for the Construction of a Railway Box Culvert

George R. French, Stephen D. Thomas

OGI Groundwater Specialists Ltd, Durham, United Kingdom, george.french@ogi.co.uk

ABSTRACT: The two English towns of Littleborough and Rochdale have suffered significant flooding over the past 20 years, with the frequency of these events increasing as a result of climate change. To mitigate the impact of flooding, the English environmental regulator, the Environment Agency (EA), commissioned the construction of two large storage reservoirs in the Gale district of Littleborough, to collect and store river water during storm events. To divert the river water from Greenvale Brook, a tributary of the River Roch, to the storage reservoirs, a storm culvert was constructed beneath the Calder Valley Railway Line. The culvert construction required a four-day railway blockade during which the tracks were removed, the ground excavated, the foundation laid, the culvert constructed, and the railway line reinstated. Following the site investigation works, it was identified that groundwater posed a major risk to the temporary construction works, with the risk of groundwater flooding, ground destabilisation and heave, together with uplift failure, all identified as hazards. To ensure that the ground at the site did not destabilise during the excavation process, a robust groundwater control system was designed and constructed to maintain both the water table and artesian head in the underlying soil deposits to a level below the excavation formation level in advance of the blockade. The groundwater management required careful planning in the lead-up to the railway blockade, which involved obtaining a groundwater abstraction licence and discharge permit from the EA, undertaking test pumping works and analysis, undertaking settlement calculations, and then implementing a comprehensive groundwater and settlement monitoring plan. Despite the challenges posed by the groundwater at the site, implementing a robust groundwater control system helped lead to a successful project outcome where the culvert was constructed within the timescale of the four-day blockade, and the railway line was back operational within the planned schedule.

KEYWORDS: Groundwater design and control system,

1 INTRODUCTION

Flooding is projected to intensify globally as a result of climate change, posing increasing risks to infrastructures and communities, particularly those historically established along rivers. In the United Kingdom, recurring flood events have underscored the vulnerability of such areas, with railway lines, vital for regional connectivity, frequently affected (Dieco et al., 2022). As public awareness of flood-related impacts grows, local and national governance structures have become increasingly engaged in managing these risks (Garvey and Paaola, 2022).

Rochdale and Littleborough, towns within Greater Manchester, are among the UK's high-risk flood areas, having experienced multiple significant flood events over the past two decades (Environment Agency, 2009). In response, a comprehensive flood risk management project has been developed by the Environment Agency (EA) in partnership with Rochdale Borough Council. Central to this scheme is the construction of two attenuation reservoirs in Gale, Littleborough, designed to temporarily store stormwater from the River Roch and its tributaries.

To enable water transfer to the western side of the site, a storm culvert was constructed beneath the operational Calder Valley Railway Line, a key route linking Manchester and Leeds with high train frequency. The works required a fixed four-day rail blockade, during which the track was lifted, the ground excavated, the culvert installed, and the railway reinstated. Due to the immovable timeline and operational constraints, no design adaptations could be made once construction began. A robust groundwater control strategy was therefore essential to maintain sub-excavation hydraulic head in the underlying alluvium and glacial materials, ensuring safe and timely completion of the works.

2 PROJECT OVERVIEW

The flood overflow channel comprises a 45m long box culvert connecting two storage reservoirs on either side of the railway line in Gale, Littleborough (Figure 1). These reservoirs are designed to store large volumes of river water during storm events, reducing downstream flow and preventing flooding.

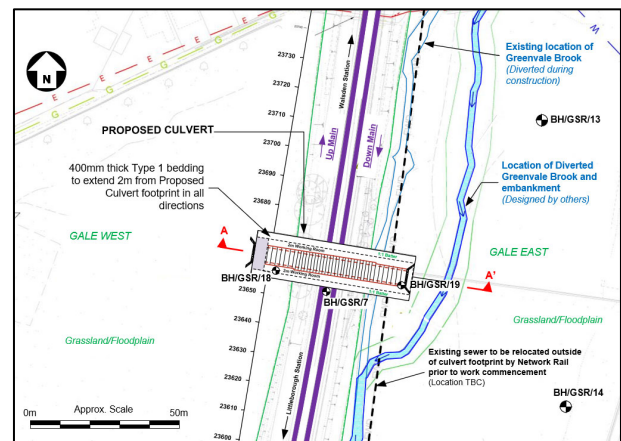


Figure 1. Site plan showing location of the box culvert in relation to the Network Rail Calder Valley Railway Line and Greenvale Brook.

Network Rail, responsible for the works beneath the line, appointed their framework contractor build the precast concrete box culvert.

3 IDENTIFICATION OF GROUNDWATER HAZARDS

The construction site is situated in upper Roch Valley, a glacial sculpted landscape formed during the last ice age (Pearson et al., 1985). The valley hosts the River Roch and its tributary, Greenvale Brook, both of which contribute to the complex fluvial and hydrogeological dynamics. Greenvale Brook flows in close proximity to culvert location, while the River Roch is located approximately 100m to the west.

Subsurface investigation revealed stratigraphy shaped by glacial and post-glacial processes. The ground profile comprises made ground and topsoil overlying alluvium, which in turn overlies a thick buried glacial channel composed predominantly of sand and gravel. Beneath these unconsolidated sediments lies bedrock of the Lower Pennine Coal Measures Formation, consisting of interbedded sandstone and mudstone. The geology is summarized as follows:

- **Topsoil/Made Ground:** A shallow layer up to 0.5m thick, present on both sides of the railway embankment.
- **Alluvium:** Comprising soft to firm silty clay with interbedded silt, sand, gravel, and peat layers. The thickness varies between 4.0m and 5.0m across the culvert area.
- **Buried Glacial Channel:** A highly permeable unit consisting primarily of sand and gravel, with occasional clay layers. The closest borehole to the culvert recorded a thickness of 1.93m.
- **Bedrock:** Lower Pennine Coal Measures Formation (sandstone and mudstone) underlying the glacial deposits.

Groundwater monitoring conducted during pre-construction investigations revealed complex hydrogeological conditions. In the shallow alluvial deposits, the phreatic surface ranged from 0 to 1m below ground level. In contrast, the deeper glacial channel exhibited artesian conditions, with piezometric heads up to 0.3m above ground level, indicating an upward vertical groundwater head gradient (Figure 2).

This upward pressure manifests visibly at the southeastern site margin, where a natural spring discharges into Greenvale Brook, creating persistently waterlogged ground adjacent to the railway line. The combination of artesian groundwater and highly permeable soils presents significant groundwater hazards that threaten construction safety.

Three principal groundwater hazards: groundwater flooding, soil destabilization and uplift failure, challenged the safe culvert construction beneath the railway line. The following section describes the specific engineering responses required to mitigate these groundwater hazards.

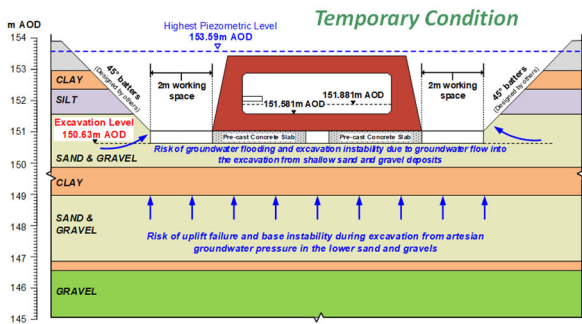


Figure 2. Conceptual model drawing depicting geology, groundwater level, culvert construction details, and groundwater hazards.

3.1 Groundwater Flooding

At this site, groundwater flooding poses a significant risk due to elevated water levels in the perched alluvial deposits. With observed groundwater levels between 0 and 1m below ground, and the excavation formation extending to depths of 2-3m, groundwater ingress would have inundated the excavation in the absence of dewatering. Flooding from the base and sides would render construction unfeasible without prior groundwater level control.

3.2 Soil Destabilization from High Porewater Pressure

Soil instability arises when porewater pressure exceeds total stress, resulting in negative effective stress and consequent strength loss, particularly in granular soils. This condition known as hydraulic heave (BS EN 1997-1:2004, 2004), manifests as soil boiling and slope failure of the excavation slopes. Even minimal vibrations from construction plant can trigger soil liquefaction under these conditions. Given the high artesian pressure at the site, this hazard represented a major geotechnical hazard requiring control.

3.3 Uplift Failure

The high artesian head in the buried glacial channel presents a risk of uplift failure, particularly beneath the low-permeability clay base of the Alluvium. Excavation reduces the overburden pressure, potentially leading to pore water pressure that exceeds the stabilizing forces. Such conditions can lead to geotechnical failure of the excavation base.

4 MITIGATION OF GROUNDWATER HAZARDS DURING TEMPORARY WORKS

OGI was commissioned to develop groundwater management strategy before the October 2021 railway blockade. These plans included:

4.1 Test Pumping Works

To understand the hydrogeological properties and support EA abstraction license applications, five separate tests were conducted over four days. Due to the changing ground conditions across the site, test pumping was undertaken from wells on both sides of the railway line. Twelve test wells were drilled: seven to 8m depth, three monitoring wells to 4m, and two recharge wells to 8m.

Results showed highly transmissive ground, with transmissivity values ranging between $7.0 \times 10^{-4} \text{ m}^2/\text{s}$ to $1.2 \times 10^{-3} \text{ m}^2/\text{s}$. Using a multi-well analytical groundwater flow model, the simulated abstraction rate by the required temporary works dewatering was estimated between 22-40 Lit/sec (Figure 3).

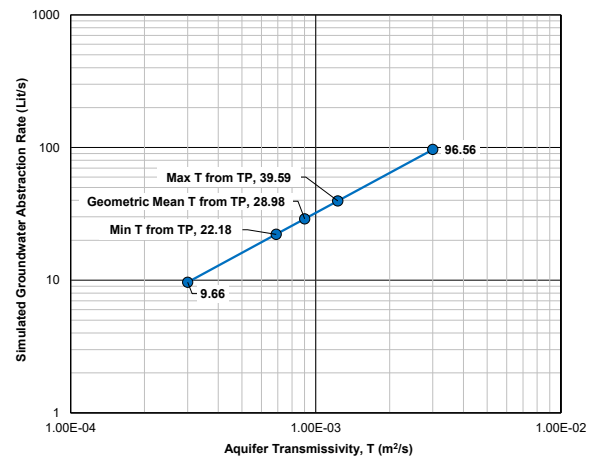


Figure 3. Predicted abstraction rates from the dewatering system based on the test pumping transmissivity results.

4.2 Dewatering System Design

The key objective was to lower both the groundwater level and pore water pressure, enabling the excavation to proceed in dry and stable ground conditions.

The site presented a challenging hydrogeological environment, with groundwater heads at or above the existing ground surface. As such, the groundwater control and dewatering system needed to deliver on the following primary objectives:

- Lower the groundwater level in the upper 4.0 m of ground (alluvial deposits) to reduce groundwater inflows into the excavation, thereby preventing water ingress that could cause flooding during culvert construction.
- Lower pore water pressures within the deeper, buried glacial channel to prevent the risk of hydraulic heave failure, which could otherwise destabilise the excavation base.

- Achieve the required groundwater drawdown and pressure reduction in advance of the critical construction window, by operating the system for two weeks prior to the 4-day railway blockade, while maintaining normal rail traffic over the live railway line.

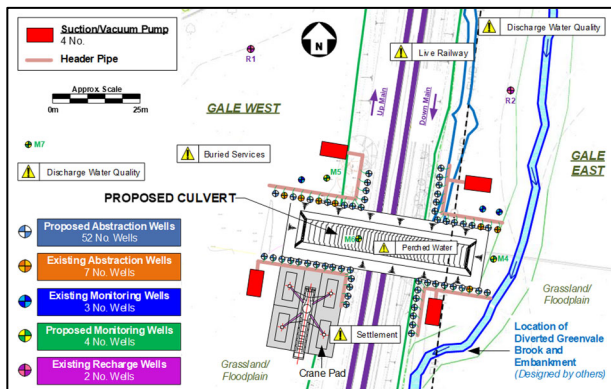


Figure 4. Site plan showing well locations and dewatering system pumping set up at the site.

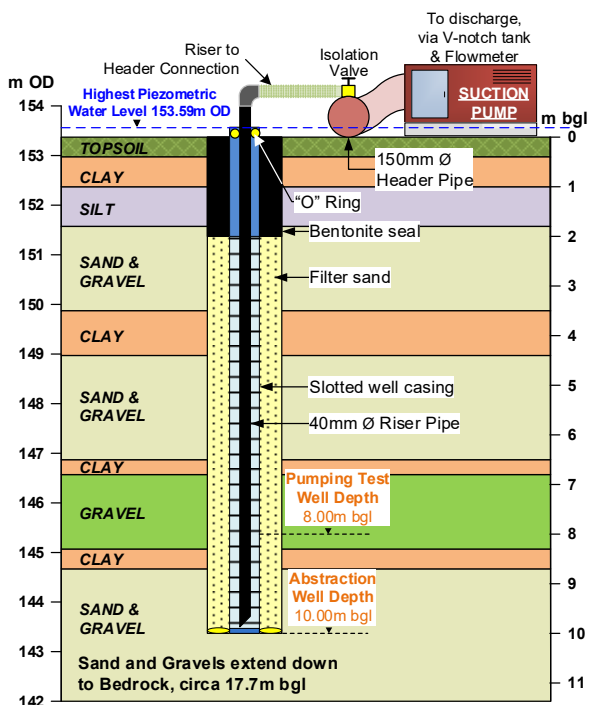


Figure 5. Design of the abstraction well and dewatering system set up.

To achieve these objectives, the groundwater control system, depicted in Figure 4 and 5, incorporated the following key design elements:

- Active suction dewatering network – 59 drilled suction wells (design shown in Figure 5) positioned around the excavation perimeter (see Figure 4) and strategically located outside the Network Rail boundary fence to avoid operational disruption.
- Performance and safety monitoring – 7 dedicated monitoring wells installed to measure groundwater drawdown across the site, assess system performance, and verify safe groundwater levels beneath the live railway line.
- Recharge capability – 2 recharge wells included to allow controlled discharge of abstracted water back to the ground, ensuring compliance with Environment Agency

abstraction licence conditions and maintaining environmental balance.

- Inspection, Testing, and Monitoring (ITM) Plan – a structured programme implemented to oversee the operation, verify the effectiveness of the system, and promptly address any deviations from the design performance.

Dewatering wells were strategically placed along excavation sides and parallel to the railway to ensure sufficient drawdown at the center where wells couldn't be placed (Figure 4).

5 CALCULATION OF GROUND SETTLEMENT

The Alluvium contained low-strength, highly compressible clays, silts, and peats which were at risk of settlement during the dewatering. This posed a significant risk to the existing railway line. OGI modeled the groundwater system to predict the likely groundwater levels beneath the active railway line during dewatering, then calculated ground settlement using a ground model with a range of soil stiffness parameters and groundwater drawdown levels below historic groundwater levels.

Ground settlement was calculated to range between 28mm (for the upper bound soil stiffness) and 6mm (for lower bound soil stiffness), see Figure 7. The contractor implemented a track monitoring plan with a traffic light system to halt dewatering if settlement exceeded trigger levels.

6 ENVIRONMENTAL PERMITTING

Groundwater abstraction for temporary dewatering became a licensable activity in England in 2018. Construction sites that plan to abstract more than 20m³/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 must also be in place.

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 allow dewatering to be implemented on the project. OGI liaised with the EA throughout the project on behalf of the principal contractor.

This responsibility involved submitting a pre-application advice request at the beginning of the project, followed by preparation of the abstraction licence and discharge permit applications.

7 IMPLEMENTATION OF THE DEWATERING SYSTEM

In the four weeks before the blockade, wells were drilled and installed. A phased approach was implemented to minimize differential settlement, with southern wells activated first, followed by northern wells after an hour of monitoring.

The groundwater level was reduced to 1.0m below excavation level within 2-3 days (Figure 6). A maximum railway embankment settlement of 7mm was monitored (Figure 7). The settlement levels were below the track monitoring trigger levels. A trial pit confirmed dry conditions prior to the main excavation works commencing. This demonstrated the effectiveness of the installed dewatering system. During the blockade, the system maintained dry, stable conditions, allowing construction to proceed on schedule. The box culvert was installed, the ground backfilled, and the railway returned to operation at the end of the four-day period.

Photos of the construction works are shown in Figure 8.

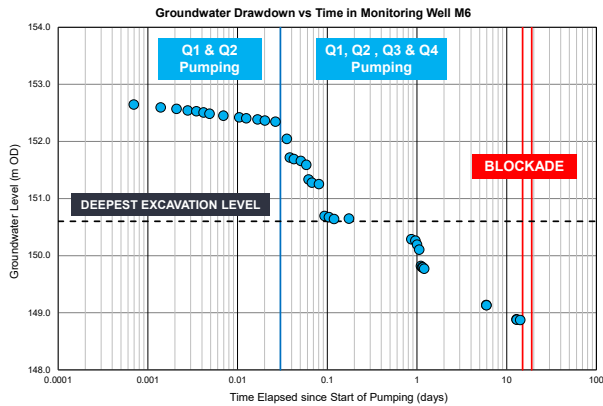


Figure 6. Reduction in groundwater level monitored in advance of the railway blockade during the commissioning of the dewatering system.

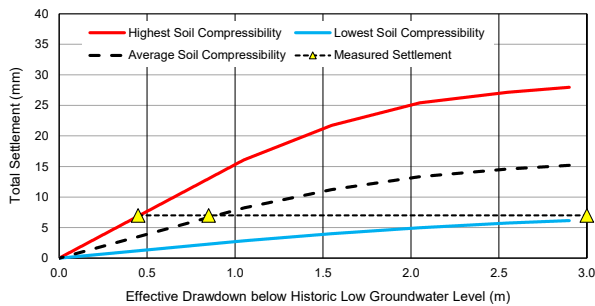


Figure 7. Calculated total settlement vs effective drawdown below historic groundwater level.



Figure 8. Photos of the construction works from left to right: (a) excavation in dry ground, (b) laying the culvert foundation.



Figure 9. Photos of the box culvert after the dewatering system was turned off.

Two weeks after the blockade, when the dewatering system was deactivated, following which the groundwater level rebounded back to pre-dewatering levels within 24 hours (Figure 9),

demonstrating the system's critical importance to the success of project.

8 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, ground excavated, culvert installed, and the railway line reinstated within a four-day period. Following the site investigation works, the impact of groundwater on the temporary works was identified as a clear geohazard. Groundwater flooding and saturated soil destabilisation were identified as 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 the groundwater management led to the implementation of a groundwater control dewatering system, with the construction of the box culvert successfully completed during the 4-day railway blockade.

9 ACKNOWLEDGEMENTS

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