Pumping borehole for saline mine water in Whitburn, North East England: Problems and novel resolution

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Abstract

Pumping of saline mine water at Whitburn is required to prevent pollution of a drinking water aquifer. Initially pumping was from a monitoring borehole drilled in 2010, however, due to its construction it started to fail and needed replacing. During construction of a new replacement abstraction borehole, several problems were experienced, some related to the geology encountered, though the main issue was poor connectivity to the target mine workings. Project constraints prevented a full re-siting of the borehole. Therefore, options to achieve the required connectivity to workings and thereby performance, from the drilled borehole were explored and implemented.

Keywords: Saline, pumping, borehole, problems, water-jetting

Introduction

Whitburn lies within the Westoe-Wearmouth mine water block, which includes several connected collieries and workings within at least 16 coal seams. The mine water block includes workings that are onshore (approximately 93 km2) and offshore (approximately 85km2). The Permian drinking water aquifer overlies approximately 63% of the mine water blocks onshore extent, and Permian strata overlies all of its offshore extent. Following the cessation of mining and pumping in 1993 the workings flooded.

To improve the understanding of rising mine water in the block, a monitoring borehole was drilled at the former Whitburn Colliery site. The data from which would inform assessment of mine water management requirement and options. A pumping test at Westoe Shaft in 2011, established a likely future pumping need of between 10 and 20L/s, with highly saline mine water (up to 96000µS/cm at 25°C). Following the identification of this need it was determined that the Whitburn monitoring borehole was sufficient for pumping, which started in 2015.

Whitburn first borehole (BH1)

The borehole at Whitburn was constructed in 2010 and targeted an underground roadway (125 m from the No.2 shaft) in the Yard (regional index G) Seam (fig. 1). The borehole was originally designed to be a monitoring borehole, rather than specifically for abstraction. A summary of key construction details for BH1 is as follows (all depth are metres below surface):

a) Final internal diameter of 201mm to 147m, and 140mm to 183m
b) Deviation of 7m to the west, at the full depth of 190m
c) Solid steel casing (324mm ID) from surface to 18m, outer annulus grouted from base to surface
d) Solid steel casing (lining) (201mm ID) from surface to 149m, outer annulus grouted from base to 17m
e) Solid steel (water well) (140mm ID) casing from 147m to 183m (there is a reduction in internal diameter in the borehole), outer annulus grouted from base to 147m
f) Open hole from 183m to 190m. Gravel packs or well screen are not typically included for Coal Authority pumping borehole – these are to underground roadways, and well screens typically become clogged
g) Mine water level at time of construction was 111m
h) Base of quarry backfill at 16 m, and base of Permian (limestone aquifer) at 107m

Due to issues relating to borehole construction (material, diameter and deviation), and its use for pumping (pump install, pump material) the borehole started to develop issues. Interactions between the casing and pump, compounded by the saline water and dissimilar metals present caused the pump-to-riser connection to corrode and fail. The pump dropped down the borehole and therefore required recovery and replacement. In addition, the innermost set of casing had started to deteriorate. The causes of damage are likely to have included, removal and install of pump and associated infrastructure, and galvanic corrosion between the mild steel casing and dissimilar metals in the pump. The failing borehole exhibited reduced yield and repeated pump outages. Attempts to remedy yield issues were made, but had limited success. Based on ongoing issue with pumping and the stability of the borehole itself, it was decided to replace the borehole with one purpose-built for pumping.

Whitburn replacement borehole (BH2) specification

The replacement borehole needed to take in to account issues experienced with BH1. The replacement borehole needed to meet to the following key specifications:

a) Minimum final internal diameter of 305mm to allow pump install without damaging the borehole, and also to provide a yield of up to 30L/s
b) Verticality with a maximum deviation of 1 m from vertical at the base of the borehole, to allow improved pump install, and intersect the underground target
c) Expected depth of 194m to a roadway in the Yard Seam at Whitburn
d) Innermost casing to withstand the highly saline mine water present within the borehole (tab. 1)
e) Casing and grout at different horizons to prevent any interaction between the mine water and surrounding environment, including the Permian drinking water aquifer
f) Design life of at least 20 years
g) Restricted locations in the current site compound, due to site head works and underground target locations (fig. 1)

In addition to the drilling specifications for the Project, there were other concerns relating to control of mine water at Whitburn and the mine water block. Whitburn has a pumping water level control band based on risks to the overlying Permian aquifer. Across much of the mine water block, the groundwater and mine water levels are unknown, whilst available measurements show continuing rise of the mine water. To manage the risk of pollution to the overlying Permian aquifer, the control band at Whitburn is based on the highest known water level in the block (Boldon) and the lowest Permian water level (one of the drinking water abstraction wells), with a 10 m conservative protection buffer allowing for uncertainties.

Prior to construction of Whitburn BH2, a liaison group was set up between the Coal Authority, the Environment Agency (regulator) and Northumbria Water Limited (municipal drinking water supplier). The group worked together to propose a temporary revised control band, to allow some mine water rise during construction of the new borehole. At the same time as the planned mine water drilling works, one of the Permian groundwater supply wells was scheduled for maintenance. This aided the relaxation of the mine water pumping control band. With the revised pumping control band, the drilling works could be undertaken

Table 1 *Summary of pumped mine water laboratory chemistry at Whitburn BH1, mean values 2015 to 2022*

	Electrical conductivity (µS/cm at 25°C)	Chloride (mg/L)	Sulphate (mg/L)	Total Iron (mg/L)	Alkalinity (mg/L as $CaCO_3$)
Mean	85417	31297	3237	95.4	300
Minimum	32700	19700	2790	67.2	131
Maximum	102000	52800	3850	156	416

Note: based *on 221 samples, taken by the Coal Authority operational contractors*

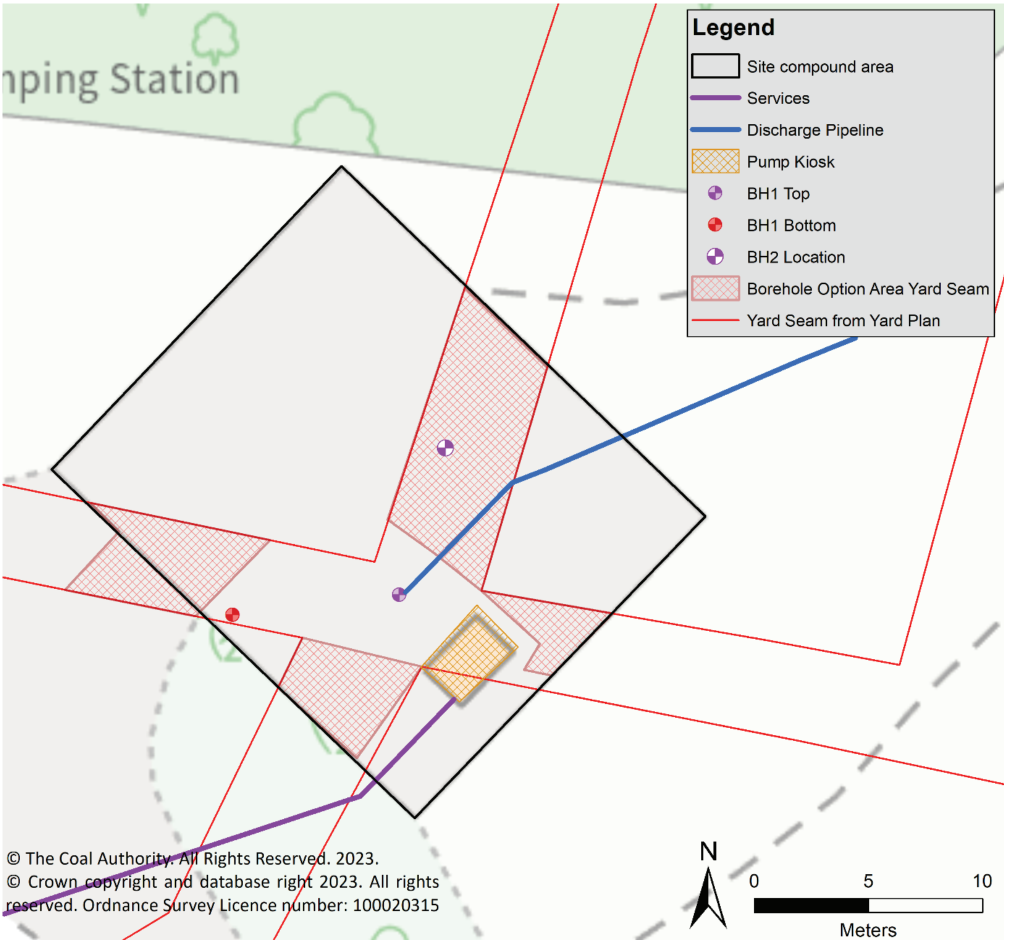

Figure 1 Whitburn site compound with expected underground mine workings in the Yard Seam

with abstraction from BH1 (which is in close proximity to BH2) temporarily halted. BH1 was retained on standby throughout the works such that pumping could quickly be started if required.

Whitburn BH2 construction – summary of problems

The drilling works were planned to start in June 2021 and finish in November 2021, however, due to problems with drilling, the works were completed in December 2021. The main issues effecting drilling works were:

1) Quarry backfill material to a depth of 26m, approximately 10m deeper than expected, based on BH1 (7m away) drilling records. Difference between expected and actual depth of quarry backfill is considered to be due to BH2 being on lower bench than BH1.
2) Casing not installed through full extent of quarry backfill resulting in flush loss and additional grouting requirement.
3) Highly fractured Permian limestone resulted in losses of water and poor flush returns, delays due to additional grouting and water needs.

Although these points delayed the project, unexpected geology is not unusual during drilling works, and can often be mitigated against and / or resolved during drilling works.

Whitburn BH2 – the big problem

In the Coal Measures strata, drilling progressed well and as expected. However, the borehole did not intercept the target underground roadway, instead solid intact coal was encountered. The borehole was progressed to 197m, approximately 4m below the base of the coal seam (at 190 to 193m). No loss of flush was observed, during drilling of the coal or surrounding strata, flush loss is typical when drilling into mine workings and fractured strata.

Without a connection to the mine workings, there is essentially no yield of mine water, and the borehole will not be useful for pumping mine water. Standard borehole development works, and air-lifting were undertaken in an attempt to create a connection to the mine workings. A falling-head test in BH2, showed a yield of <0.01L/s, compared to the desired minimum yield of 30L/s.

The failure to intercept workings prompted a review of the original target location and depth. Was the borehole in the correct place? Did the borehole go to the correct depth? The target area of the mine was worked in the 1940s with the abandonment plan dated to the 1960s. The plan is considered unlikely to have significant errors. Confidence in referencing to surface is considered high given the target location 125m east along a roadway from mine shafts with known surface locations. The geological information and drilling observations were reviewed with chippings and later geophysical surveys confirming coal present and intact between 190 and 193 m. The geophysical survey also confirmed the bottom of the borehole had deviated by <0.25m and therefore should have contacted the underground roadway (width of 2 to 4m). The information review concluded that the mine plan and roadway position must be incorrect though the source and specifics of the error remain unknown. As a result, it was not known if the recorded roadway would lie to the east or west of the drilled borehole. Further review of Yard Seam workings shown on other seam plans, indicated it to be probable that the borehole was to the west of the roadway, and likely within 1 m.

Whitburn BH2 – initial options

Given the spatial limits of the borehole compound, the presence of the two existing boreholes (and associated infrastructure) and the limited targets in underground workings, a further borehole in the site compound was not feasible. Therefore, should an alternative borehole location be considered it would need a new site area and pumping infrastructure, this would likely result in a significant delay to the replacement of the failing BH1.

Options had to be devised and considered that could be effective and be delivered within a short time scale. Collaboration between the Coal Authority and existing and potential partners generated four initial options for appraisal in January 2022 (tab. 2)

Following initial assessment of options, plans of actions and more detailed assessments of risks were developed for: a combination of water-jetting with or without controlled explosives. In March 2022, the assessment of the options selected the use of water jetting without explosives. The use of explosives within the borehole was considered too great a risk to the plastic casing.

Whitburn BH2 – the final solution

Throughout April and May a method was developed to undertake the works safely and successfully. In the meantime, options for resuming temporary pumping from BH1, and options for a third borehole were being

Table 2 *Summary of pumped mine water chemistry at Whitburn BH1*

Option	Description	Positives	Negatives
Managed explosives	Attempt to control the direction / area of blast to create fractures	Create fractures in multiple directions over a wide area	Innermost plastic casing could fail
Uncontrolled explosives	Uncontrolled blast to create fractures	Create fractures in all directions	Innermost plastic casing could fail
Widening the base of the borehole	Use a narrow drill bit to scour out the base of the borehole	Multiple directions over a large area	Unlikely to have a wide penetration area
Directional pressurised water-jetting	Direct pressurised water to create a slice into the coal	Considered likely to cut the required penetration thickness Unlikely to damage the borehole and casing	Limited direction and depth

progressed. The final method needed satisfy the following requirements:

a) allow resumed pumping from BH1 to prevent rising mine water and aquifer pollution
b) protect BH1 during the water-jetting works – at the time BH1 was the only available borehole to pump from
c) prevent collapse of BH2
d) control any solids in the water during the works, and treat the water produced during the works to meet our discharge consents
e) demonstrate that the required yield improvements in BH2 had been achieved.

A sequential plan to meet all the criteria above, as follows was developed:

1) Clean out the borehole of debris and confirm the pre-works borehole yield
2) Fix the water jetting tool to the drill rods, the drill rods were also used to track the orientation of the water-jetting tool
3) Water jet at the target depth in the likely direction of the roadway. Pressurised water at 2000 to 3000 bar injected laterally from the base of the drill string. Nozzle moved steadily upwards to slice the coal seam, forming a vertical slot in the coal seam wall of BH2.
4) Clean out any debris from the water-jetting and perform yield tests and assess the results
5) Repeat the water-jetting at the same depth and orientation to improve any pathway
6) Clean out any debris from the water-jetting and perform yield tests and assess the results
7) Make BH2 operational for pumping, as per the pre-determined pumping plan to mitigate risks of the borehole and not breach discharge consents

Results

After each set of water-jetting and air-lifting, a falling-head test was undertaken. The first test was undertaken on the 14th June 2022 and showed a yield of >5 L/s with a well loss of 0.2 m, the flow rate was limited during the test. The second falling-head test showed a yield of >30 L/s with a 5 m well loss. For comparison the original borehole BH1 abstracted approximately to 10 to 15 L/s with a well loss of approximately 2 m.

Based on the post jetting tests, it was estimated that the works created a slot in the coal seam, approximately 120 to 150 mm wide and 300 mm high, in the east side of the borehole. The slot dimensions are considered to be similar to the open-hole section in the roadway of the original BH1.

The dimensions of the slot may increase with time, due to ongoing pumping and scouring of the flow pathway between the pump and mine workings.

The water-jetting has been successful and increased the yield of the borehole from <0.01 L/s to >30L/s, this is likely because the jetting created a pathway through the coal to the roadway. Acoustic images and geophysical surveys were taken post water-jetting, the data shows possible fracturing and / or collapses that appeared following the water-jetting works. The precise extent and dimensions of the fractures etc. are unknown. It is also uncertain if the pathway is direct result of the water-jetting, or a secondary result from collapse above the water-jetting zone. Collapses of the borehole between the roadway and base of casing would likely deposit material in the sump at the bottom of the borehole (approximately 8m below the roadway) and at the time of the works, the borehole was seen as effectively not fit for purpose of pumping mine water.

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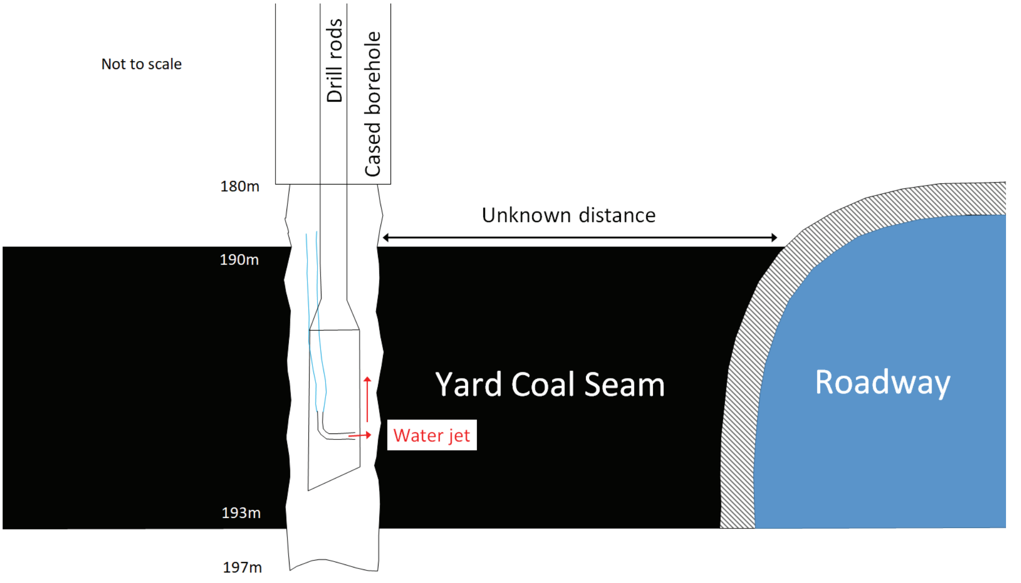

***Figure 2** Conceptual diagram of water-jetting*

***Figure 3** Water jet test at surface (left), and borehole CCTV image post-water jetting (right). Photograph from Integrated Water Services and European Geophysical Services*