Permeation Grouting of a Subsidence Impacted Watercourse in the Southern Coalfields

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Summary

Myrtle Creek has been impacted by the subsidence associated with longwall mining at Tahmoor Coking Coal Mine in Picton, NSW. Specific impacts are fracturing of the rock bed resulting in a reduction in surface flow and pool holding capacity behind the rock bars that are a characteristic of waterways in the southern coalfields.

A specific pool, Pool 23, within the impacted Myrtle Creek, was selected for remediation using permeation grouting. First, an investigation was undertaken at Pool 23 to characterise the fracture network and advise on remediation grouting design. The investigation identified the fracture and hydraulic conductivity profiles as well as local hydraulic gradients.

Second, a permeation grouting program was implemented which included drilling and permeation grouting completed by Pointe Engineering as per a grout plan and design, using a single part polyurethane grout. The layout took the form of a grout curtain, perpendicular to the creek and in longitudinal alignment with the rock bar.

Permeation grouting as a strategy for remediation of the subsidence impacted water course was demonstrated to have a positive correlation with creek surface flow and pool holding capacity to date.

1. Introduction

Myrtle Creek is a tributary to the Nepean River, in the Southern Coalfields of NSW. The creek has been incrementally impacted by the subsidence associated with longwall mining of Tahmoor Coking Coal Mine. Subsidence impacts include cracking of rock in the creek beds and apparent loss of surface water from the creek, especially at distinct pools, behind natural rock bars. Tahmoor Coking Coal Mine has undertaken works to remediate the impacts to the creek. The works included an investigation, design and construction of a low permeability grout curtain at an impacted site followed by monitoring of water flow and pool retention. This paper is a case study of the works completed and details the:

1. Subsidence impacts - late 2012 to late 2014
2. Site characterisation - late 2019
3. Permeation grouting - late 2019 to early 2020.

2. Subsidence Impacts

Subsidence from longwall coal mining can affect creek beds in several ways.

For Myrtle Creek, the most significant driving force is horizontal compression associated with the formation of the goaf, interacting with steeply dipping topography surrounding the creeks.

Horizontal compression and failure of rock below valleys can occur naturally over time as horizontal stress in the ground is redirected below the valley, concentrating at the base. The subsidence caused by longwall mining can further increase damage to the base of the valley.

As a longwall panel is mined, the overlying strata fails, caving in a downwards direction towards the mined-out panel, forming the goaf. During this caving process, the volume of the rock mass increases as void space is created by the fractures. When the subsiding rock mass is confined by solid rock on either side, dilation of the rock mass can only occur in a vertical direction. However, when topographic features such as valleys exist, the path of least resistance for the dilating rock mass is horizontal towards the side of the valley, as there is no opposing force to prevent this movement (Mills, 2014).

The horizontal movement of the ground towards the valley causes a basal shear plane to form. This basal shear plane typically forms at a horizon just below the base of the valley where the movement is restrained by solid ground. The shear plane is often a pre-existing bedding plane that has been reactivated, such as can be observed along Myrtle Creek. Sandstone basement Shear on this basal plane enables horizontal movement of the valley sides inward to generate compression of the rock strata in the base of the valley. This compression leads to low angle shear fractures forming and opening in the base of a watercourse. This process is known as valley closure. Figure 1 illustrates the mechanism (Mills, 2014).

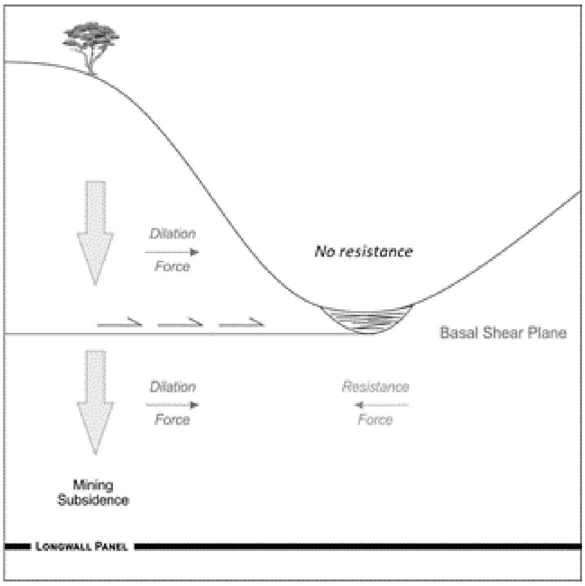

Figure 1 Sketch illustrating the mechanics of the process that causes horizontal movement of the ground concentrating at the base of a valley, known as valley closure (Mills, 2014).

Affected areas of Myrtle Creek show zones of fracturing from the surface, down to approximately 6m – 12m below the surface. The fractures developed as low angle conjugate open fractures creating wedges that lift the surface causing localised upward movement of the creek bed. This process is referred to as upsidence (Mills, 2007). A diagram showing the distribution of fracturing due to valley closure is shown in Figure 2.

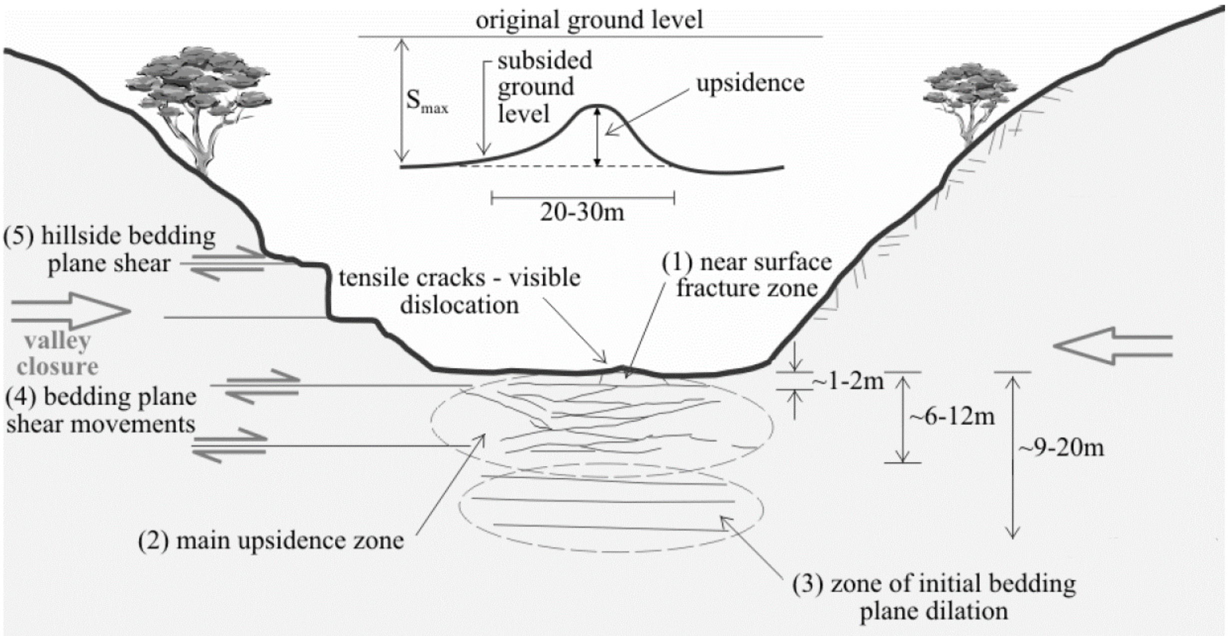

Figure 2 Typical cross section showing nature of rock fracturing observed due to valley closure in river channels in the Southern Coalfields (Mills, 2007).

The induced fracturing at the base of the creeks has led to a decrease in surface water flow and an increase in subterranean water flow at affected areas of Myrtle Creek. Figure 3 illustrates the diversion of surface flow through the fracture network of the rock bar and the return to surface flow downstream away from the area affected by mining (Mills, 2007).

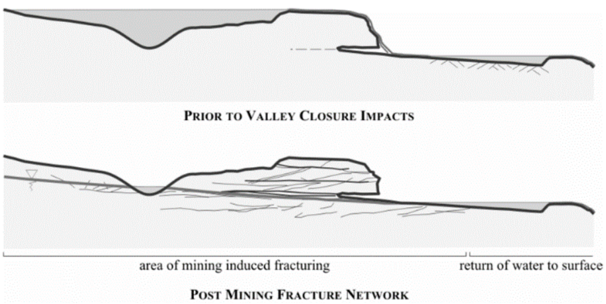

Figure 3 Longitudinal section showing diversion of surface flow through the fracture network and return flow to the surface (Mills, 2007).

Mining subsidence also disturbs the overburden strata more generally causing fracturing and increased hydraulic conductivity unrelated to the local disturbance in creek channels caused by valley closure. At Tahmoor, the widths of the longwall panels are typically less than the depth of overburden strata to the mining horizon. The panels are referred to as being of sub-critical width in subsidence engineering terms. For sub-critical width mining geometries, the effects of overburden fracturing are less significant than the surface fracturing caused by valley closure. At Tahmoor, remediation efforts are focused on remediating the near surface fracturing to reduce sub-surface flow to low levels and return a higher proportion of stream flow to the surface.

3. Site Characterisation

Pool 23 in Myrtle Creek, Picton, NSW, was chosen as the initial remediation site. The following describes the specifics regarding the site, historical monitoring of the pool and the investigation undertaken.

3.1 Site Description

Pool 23, Myrtle Creek, Picton, NSW, was observed to have been impacted by near surface fracturing due to mine subsidence. Due to its relative ease of access, Pool 23 was chosen as the first remediation site. Myrtle Creek is a tributary of the Nepean River and is a narrow creek etched into the Hawkesbury Sandstone. The creek is notable for being a series of natural pools formed behind rock bars. Pool 23 is situated upstream of Remembrance Driveway Picton, NSW. The site is a pool formed behind a rock bar with sandstone base and embankments. The Northern embankment is an exposed vertical sandstone face. The Southern embankment is a gentle slope with outcrops and a shallow layer of fill and topsoil.

The location of Pool 23 and its proximity to longwalls.is shown in Figure 4.

Longwall 28 (Figure 4) which sits beneath Pool 23, was extracted between May to June 2014 (Tahmoor Coal, 2017).

Subsidence impacts at Pool 23 have been recorded as fracturing at the base of the creek channel, reduction of water flow and reduced pool holding capacity.

No further subsidence has been observed since June 2016.

Figure 4 Longwalls Beneath Myrtle Creek Pool 23 (CMAP, 2017).

3.2 Surface Water

The depth of water in Pool 23 reduced, and remained low after longwall mining occurred beneath the pool.

A pressure transducer was installed in Pool 23 in 2010 to record pool depth. Figure 5 illustrates the pool depth over time. Monitoring started prior to longwall mining in the vicinity of the site. The pool depth remained consistently around 0.8m above the sensor, from installation in 2010 to late 2012.

The pool holding capacity had a notable reduction in late 2012 and again in mid 2014 which aligns with the timing of the longwalls being mined adjacent, and beneath the creek.

The data indicated that pool standing water levels were no longer maintained, except for a short period after significant storm runoff events (Tahmoor Coal, 2017). Rainfall data was also monitored for the area.

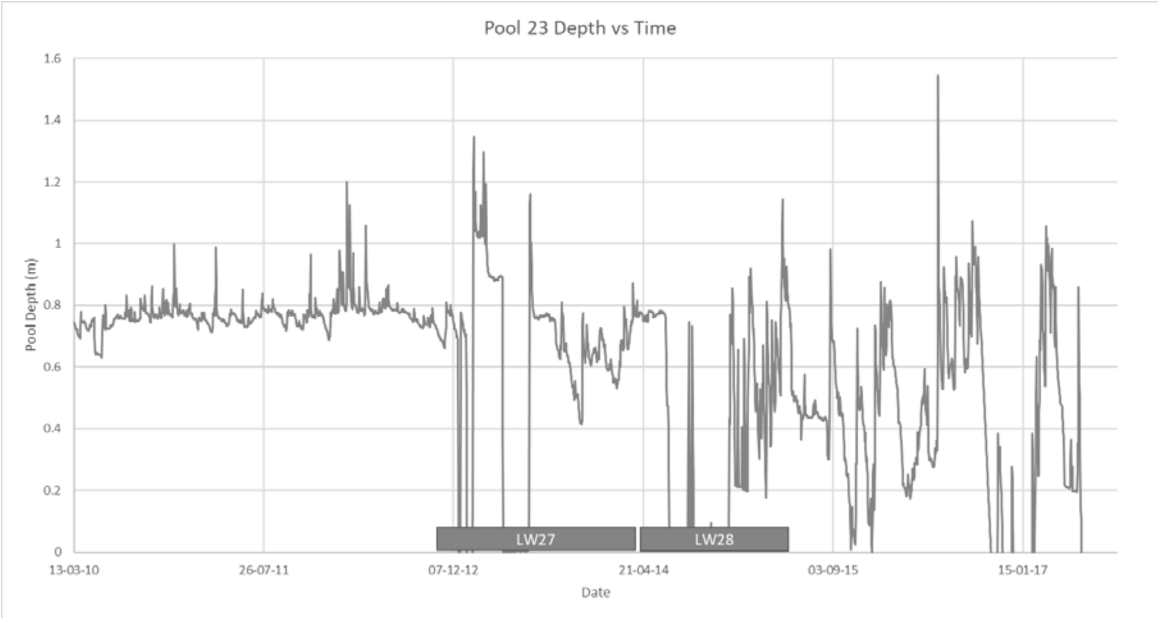

Figure 5 Myrtle Creek Pool 23 surface water logger prior to remediation.

3.3 Investigation

The geotechnical investigation was conducted in 2019 with the aim to characterise the fracture network and advise on remediation grouting design.

The investigation included drilling 10 bores equidistant across the alignment of the curtain, in-situ permeability testing and caliper survey.

The boreholes were diamond cored to a diameter of 76mm. Loss of drilling fluids occurred on each borehole within a few meters of drilling.

Two boreholes were tested for hydraulic conductivity and suitability for grouting using a constant pressure step injection test. This test is also referred to as a Lugeon Test. The results illustrated in Figure 6 (shown in orange and green bars) show a reduction in hydraulic conductivity with depth. The tests undertaken in the centre of the creek and near to surface gave very high hydraulic conductivity values. Specific values could not be calculated as the they were above the working range of the test. The testing showed that all sections tested were economically groutable with Lugeon values greater than 1 uL (Houlsby, 1976).

The caliper survey was conducted in all boreholes across the creek. Testing results are presented in Figure 6. The distribution of large fractures reducing with depth, as described in Section 2 above, was also confirmed from testing. The caliper survey identified the reduction in fracture apertures with distance horizontally from the centre of the creek.

The characterisation of fractures within the core identified the target fractures for grouting. The sub horizontal bedding planes of between 0° and 15° from horizontal characteristically had some large apertures varying from 5mm to 100mm with no infill. The sub vertical fracture set were generally closed.

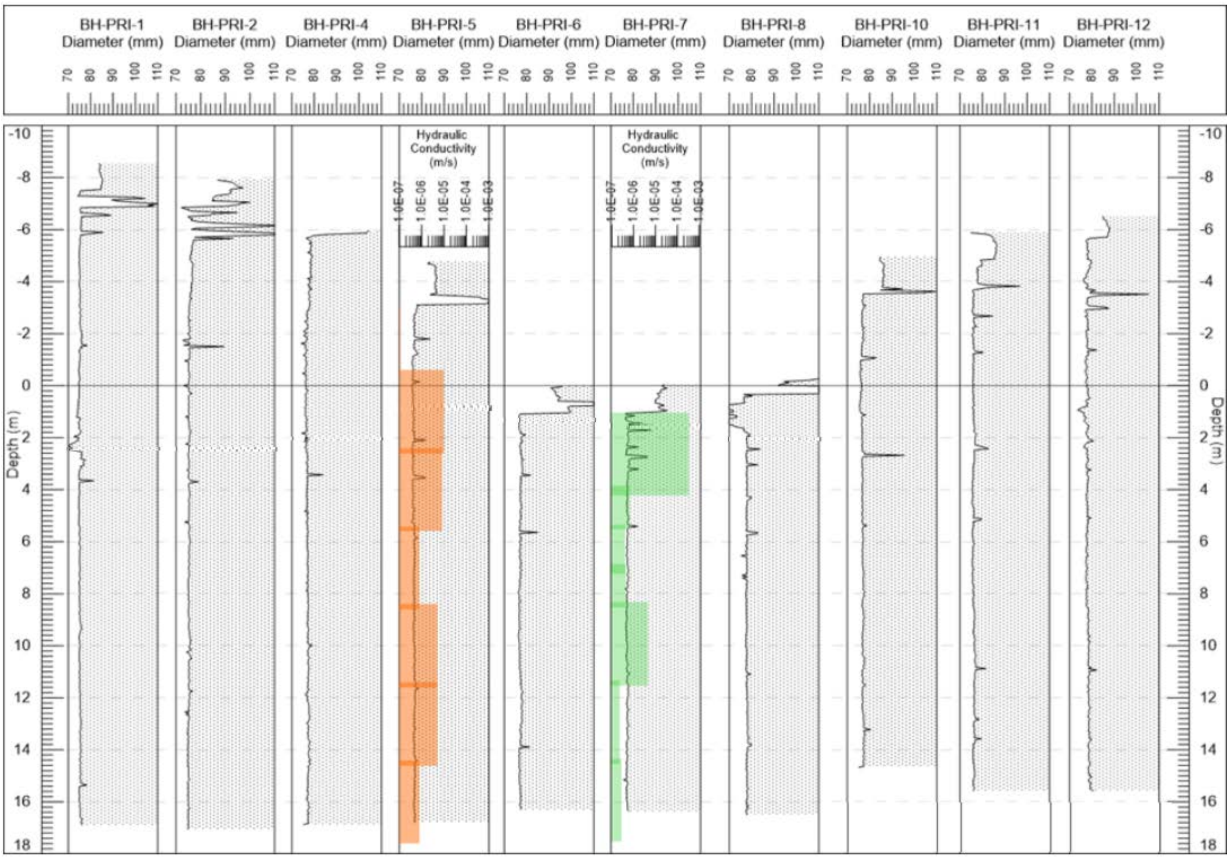

Figure 6 Myrtle Creek Pool 23 caliper survey and Lugeon testing (Strata Control Technology).

The standing water levels were measured approximately 1 day post drilling. The water levels were also measured during a dry period. The levels indicated a local hydraulic gradient towards the northern embankment, just off-centre to the creek. A high gradient on the northern side and a relatively shallow gradient from the south. The standing groundwater level was measured at approximately 1.2m below the rock bar at the time of the investigation.

4. Permeation Grouting

Permeation grouting was undertaken at Pool 23 to return the surface water flow and pool holding capacity.

Permeation grouting is the process by which open geological features are sealed to control water. This is completed by drilling and then injecting a suspension of solids in water (e.g. cement grout) or a pure chemical solution (e.g. polyurethane) (Weaver, 1991). For Pool 23 remediation grouting, a pure chemical solution (approved by the relevant government agencies) was injected.

The layout of drilling used enabled the grout to form a low permeability subsurface feature. At Pool 23, the layout suiting the conditions and purpose was a grout curtain. A grout curtain involves a row (or multiple adjacent rows) of drill holes injected with grout as presented in Figure 7 and Figure 8.

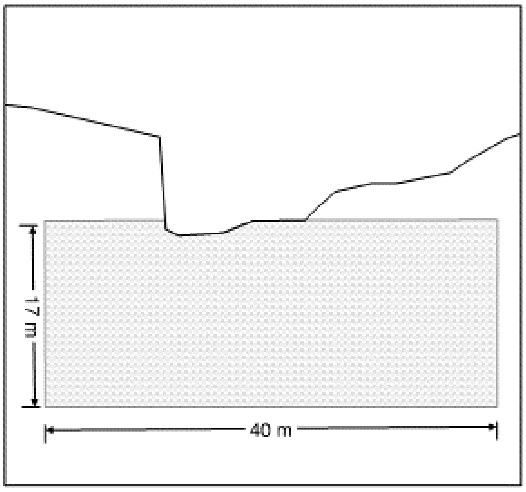

Figure 7 Sketch illustrating the cross section of the grout curtain.

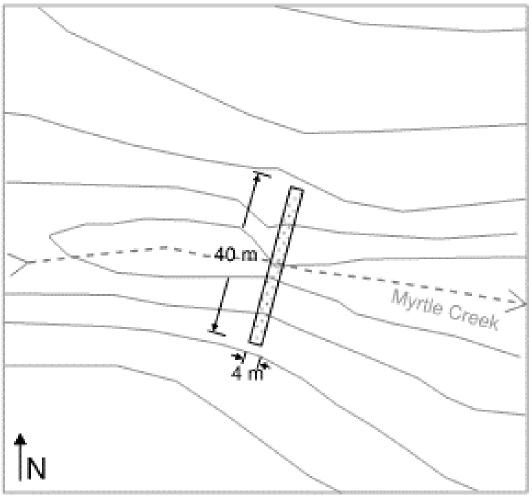

Figure 8 Sketch illustrating the plan view of grout curtain alignment.

4.1 Drilling

The drilling process at Pool 23 involved a series of boreholes perpendicular to the flow of the creek and in alignment with the controlling rock bar. Boreholes were drilled with a purpose-built man portable drill rig. The row of boreholes extended 20m from the centre of the creek up both embankments as represented on Figure 7 and Figure 8 below. The boreholes were drilled to 17m below the existing ground/creek level following the review of the ground characterisation data.

A contemporary North American dam grouting drilling and grouting sequence (Bruce, 2013) was established for efficiency and to provide validation by use of grout takes. A single row curtain was used based on the low head requirements as opposed to standard dam grouting practice where high heads are experienced.

4.2 Grouting

The boreholes were injected with grout to create a grout curtain or low permeability barrier. The grout used was a medium viscosity, non-toxic hydrophobic polyurethane grout approved for use in drinking water catchment areas. The hydrophobic polyurethane grout used was a single part polyurethane that requires the addition of a catalyst. Once mixed the grout remains physically unchanged until it comes into contact with water. An induction period begins as soon as the polyurethane is exposed to water. The period duration is a function of the ratio of catalyst used and the grout temperature. At the completion of the induction period the polyurethane begins to chemically react. The ratio of catalyst to polyurethane is used to control the induction time, at given temperature, and therefore determines the theoretical grout spread (Andersson, 1998).

Once reacted, the polyurethane begins to foam creating interlocked pockets of carbon dioxide. The foaming action increases the grout viscosity. At Pool 23, this characteristic was used to limit the spread of grout to the design intent. The polyurethane foams between 5 and 20 times its volume adding economic value when comparing to traditional grouts. The single part polyurethane formed a low permeability rigid foam that filled fractures in the formation, thereby reducing the formation's conductivity.

Grouting was monitored for both pressure and flow and digitally recorded. An experienced engineer on site determined completion based on set criteria and monitored the live data. Drilling, testing and injection data were logged into a database.

5. Results

Pool 23 has been holding water and has been overflowing since completion of the works in early 2020.

The pressure transducer installed in Pool 23 in 2010 showed the depth of water had reduced and remained low after longwall mining occurred. The grout curtain was completed in January 2020 and Figure 9 shows a graph illustrating the pool depth prior to and post construction. No monitoring data was recorded between mid 2017 and when grout remediation works began.

The pair of dashed vertical lines in Figure 9 indicate the construction period of the grout curtain. The pool depth has consistently remained 0.8m above the sensor. From visual observations the pool filled during a rain event in February 2020 and has remained full and over-flowing to the date of writing this paper. Figure 10 and Figure 11 show the pool before and after remediation respectively.

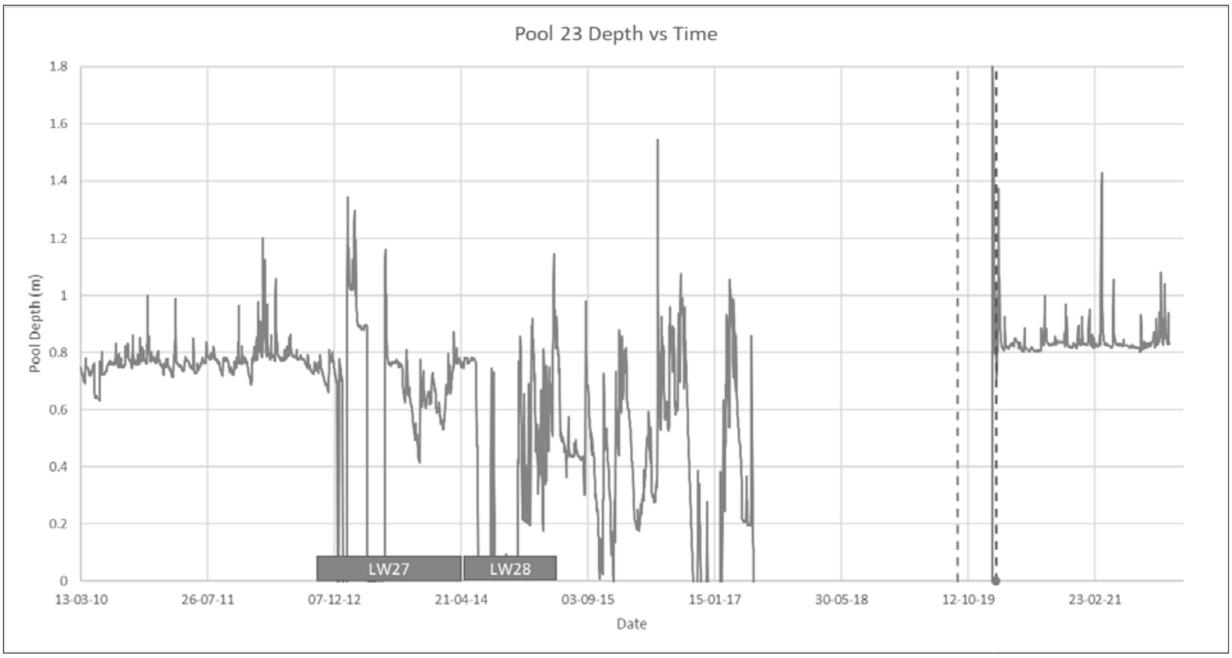

Figure 9 Myrtle Creek Pool 23 surface water logger prior to and post construction.

Figure 10 Pool 23 prior to remediation in September 2019.

Figure 11 Pool 23 post remediation in February 2022.

The use of man portable construction equipment led to cost effective drilling and minimal environmental impact.

The single part polyurethane grout suited the environmental requirements with:

- high degree of control over mixing prior to injection ensured unmixed polyurethane was not injected.
- high degree of control over reaction time, and therefore spread, ensured grout was only placed were it was intended for.
- Sealing of large water filled fractures where traditional grouts could potentially get diluted and washed downstream.

Although minimal, the impacted areas from the construction works were rehabilitated with coir logs, jute mesh and planting of native species.

Remediation grouting at Pool 23 in Myrtle Creek has successfully improved surface flow and pool holding capacity.

6. Conclusion

Whilst the longwall mining of the area beneath Myrtle Creek has caused reduction in surface flow and pool holding capacity of creeks, it can be concluded that innovative approaches, drawing technology from other industries (e.g. dams and tunnelling) have the potential to remediate mining impacted streams.

The site chosen for the remediation grouting was a rock bar controlled pool with a high level of fracturing/hydraulic conductivity in the centre of the creek. The bedrock conductivity reduced with distance horizontally and vertically. The site had a standing water level approximately 1.2m below the base of the rock bar and a hydraulic gradient dipping just off-centre of the creek prior to remediation grouting.

A permeation grouting program, designed from a detailed investigation, has demonstrated to be positively correlated to the pool holding capacity and surface water flow within the monitoring period. The re-establishment of the pools in Myrtle Creek and other watercourses is very valuable from an environmental and social responsibility point of view. The method used in this project led to an economically viable, technically sound and low environmental impact solution.

7. Acknowledgements

The success of this project was made possible with the support from Tahmoor Coal and technical assistance from SCT Operations Pty Ltd (SCT).

8. References

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