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Hybrid vibrating wire piezometer–packer system: design verification and underground trial at Carrapateena mine

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Abstract

Backfilling deep exploration boreholes intersecting artesian zones in underground hard rock mines is challenging because high inflow rates can wash out cementitious grout before it sets and potentially displace adjacent groundwater monitoring sensors. To address this issue, a hybrid vibrating wire piezometer–packer system (HVWPPS) was developed by combining a sacrificial inflatable borehole packer with a high-capacity vibrating wire piezometer (VWP), housed within the lower part of the packer assembly. Following laboratory trials, the HVWPPS was deployed at BHP's Carrapateena underground mine in South Australia, at a depth of 192 m below the borehole collar. The HVWPPS was installed above an artesian dyke feature and inflated to ~9,000 kPa to seal off the artesian zone while allowing water pressures to be accurately measured below the packer. The borehole above the packer was then backfilled using a customised cement-bentonite grout. VWP monitoring at 30-second intervals captured the key steps of installation, including packer inflation, grout placement, packer deflation and the subsequent water pressure response. After approximately six days of grout curing, the packer was fully deflated with no significant pressure drop observed, indicating effective sealing above the packer while groundwater pressure below the packer continued to be measured. This trial demonstrates that the HVWPPS is a practical approach for deep borehole backfilling and continuous pore pressure monitoring in the artesian zones of underground mines.

Keywords: *vibrating wire piezometer, inflatable packer, artesian groundwater, borehole backfilling, underground mining, Carrapateena mine*

1 Introduction

Groundwater pressure monitoring is an important part of hydrogeological assessment and groundwater risk management in underground mining. Discharge observations alone may not fully describe the hydraulic response of the rock mass (Gray 2024). In block cave and other deep underground mining environments, groundwater monitoring systems and piezometers are used to assess water pressures, evaluate dewatering performance and support decisions on inflow control and mine design (Morton 2022). At Carrapateena copper-gold mine in South Australia, exploration drilling has intersected deep artesian zones where groundwater discharge at the borehole collar sometimes exceeded 100 L/min. Under these conditions, the challenge was not only to control inflows during borehole closure but also to retain the ability to monitor groundwater pressures within the artesian zone. Conventional cementitious backfilling was not suitable under the inflow conditions encountered, as flowing water would wash out grout before it set. Existing borehole sealing approaches could isolate the high inflow interval but did not allow for pressure monitoring below the sealed section. These project-specific constraints highlighted the need for a single borehole installation method that could provide both hydraulic isolation and ongoing water pressure monitoring. Fully grouted vibrating wire piezometers (VWPs) have been used in mine water investigations, including deep and difficult boreholes, and can offer practical advantages in narrow or inclined holes (Yungwirth et al. 2013).

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Packer-based methods have also long been used to isolate borehole intervals for hydraulic testing and pressure measurement in rock and soil (Gray & Neels 2015). In related mining applications, continuous pressure monitoring has also been used in sealed systems, such as hydrostatic pressure monitoring behind borehole plugs (Woloshyn et al. 2011). Together, these studies show that deep pressure monitoring, interval isolation and pressure measurement in sealed systems are established practices but are generally applied separately or for different installation objectives. The present application required these functions to be combined in a single permanent borehole installation. Specifically, the artesian zone needed to be hydraulically isolated to allow borehole backfilling, while groundwater pressure below the packer had to remain measurable during and after installation. To address this requirement, a hybrid vibrating wire piezometer–packer system (HVWPPS) was developed. This paper presents the system design, laboratory verification of its pressure response, underground field deployment at Carrapateena, and interpretation of the measured pressure behaviour during and after installation.

2 Geological and hydrogeological setting of the installation zone

The trial borehole was selected by BHP and was located at Carrapateena at approximately 800 m below ground level. The borehole was drilled for exploration purposes in the direction of a proposed sublevel cave. Based on geological logging, review of the recovered drillcore and acoustic televiewer (ATV) data, the target artesian zone was interpreted as a dyke within granite at approximately 193 to 198 m below the collar. Nearby drill stem testing indicated hydraulic conductivity in the order of 10^{-12} m/s for the intact granite and 10^{-7} m/s within dyke zones. As shown in Figure 1, the HVWPPS was positioned above the interpreted dyke contact within competent rock. Core observations and ATV data indicated stable borehole conditions and no identified stress-induced borehole breakouts within the selected packer sealing interval, supporting its suitability for packer seating and sealing. Breakouts were first identified below the packer sealing interval within the interpreted dyke zone (Tetra Tech Coffey 2026).

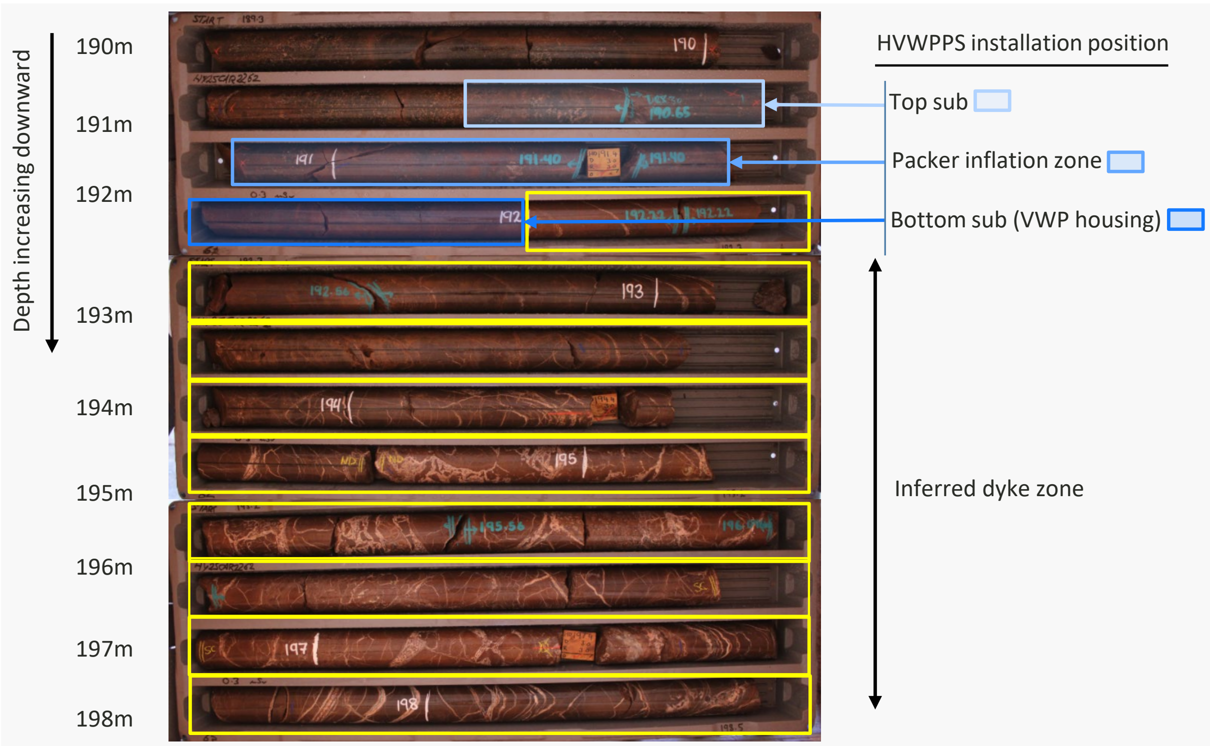
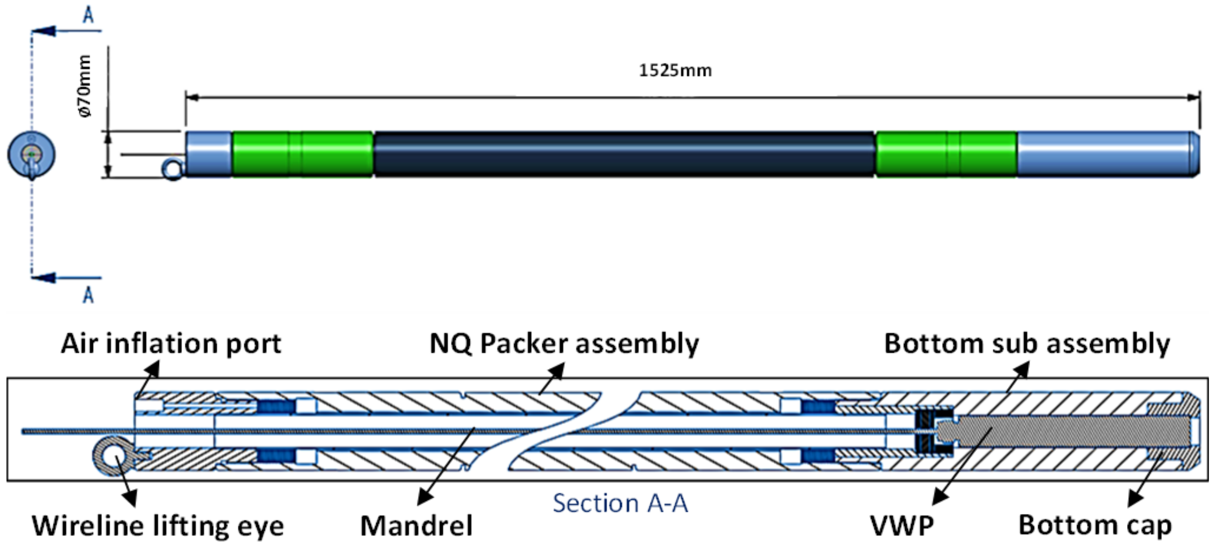


Figure 1 Selected installation interval within the trial borehole showing the hybrid vibrating wire piezometer–packer system position relative to the inferred dyke zone

3 Hybrid vibrating wire piezometer–packer system development and laboratory verification

An NQ size (70 mm OD) inflatable single packer was modified with a custom housing arrangement to accommodate a 5,000 kPa-rated VWP within the lower part of the assembly, forming the HVWPPS. The system comprised a top sub, an inflatable packer section (sacrificial) and a bottom sub that housed the VWP. A custom mandrel formed part of the internal assembly and supported integration of the VWP and cable through the packer system into the bottom sub housing. Figure 2 shows the configuration of the HVWPPS and the assembled tool.



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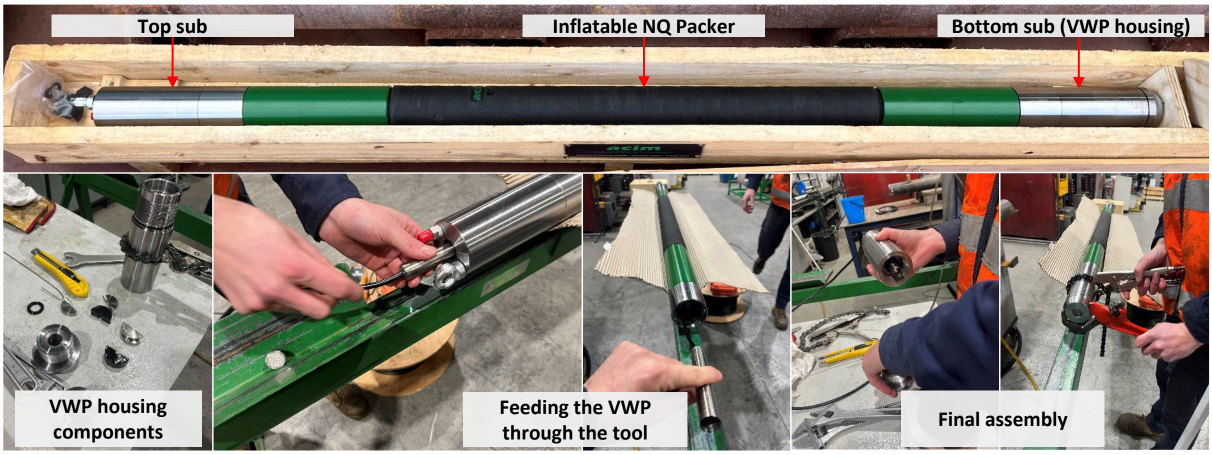


(b)

Figure 2 Hybrid vibrating wire piezometer–packer system developed for the Carrapateena trial: (a) Schematic and section view of the system configuration; (b) Assembled tool and key assembly stages

Prior to field deployment, the assembled HVWPPS was tested in a laboratory pressure chamber to assess its response during packer inflation and under controlled water pressure applied through the hydraulic pressure inlet at the base of the pressure chamber, below the HVWPPS. The purpose of the test was to confirm that packer inflation did not cause mechanical interference on the housed VWP while also verifying its response to hydraulic pressure applied below the packer. The laboratory verification setup is shown in Figure 3.

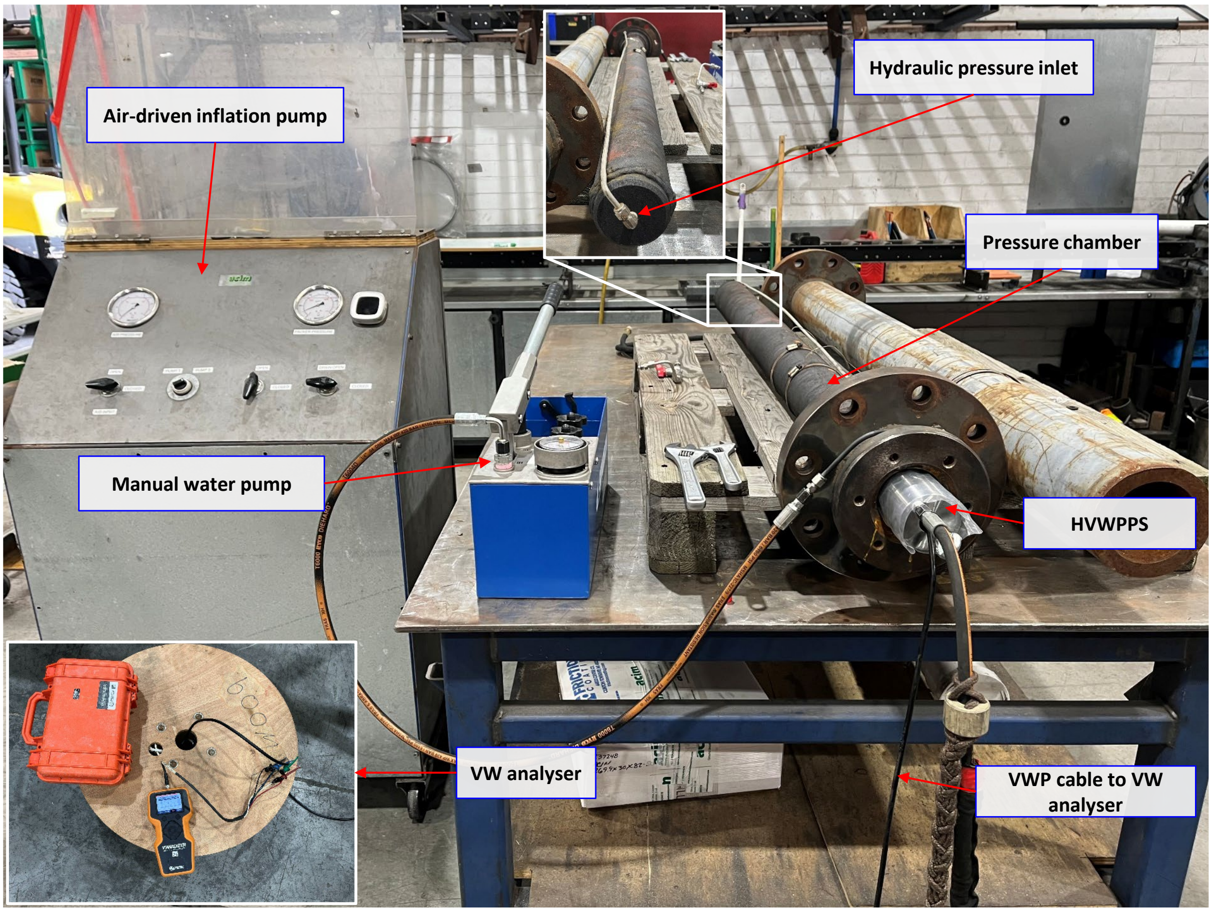


Figure 3 Laboratory verification setup for the hybrid vibrating wire piezometer–packer system

The verification results are summarised in Table 1. After the packer was inflated to a pressure of 10,342 kPa and the chamber was prepared for pressure testing, staged water pressure loading was applied at 1,379, 2,069 and 3,448 kPa through the hydraulic pressure inlet below the HVWPPS. During packer inflation, the VWP recorded only a nominal response (approximately 3 kPa), indicating that packer inflation did not significantly load the sensor. Under hydraulic loading, the sensor-derived pressures for the three stages were 1,292, 2,005 and 3,421 kPa, corresponding to deviations of 87 kPa (6.31%), 64 kPa (3.09%) and 27 kPa (0.78%), respectively, showing close agreement with the applied pressures. Given the manufacturer's stated accuracy of less than 0.5% full-scale (HMA Group 2022), equivalent to approximately ±25 kPa for the 5,000 kPa sensor used in this study, the difference at the highest loading stage was considered consistent with the specified instrument accuracy. This trend suggests improved agreement at higher applied pressures within the tested range. The weaker agreement at the lowest loading stage was not considered critical for the present application as the 5,000 kPa sensor was selected based on an expected borehole pressure of about 3,000 kPa. Overall, the laboratory verification showed that packer inflation did not significantly affect the housed VWP, and that the sensor, despite being installed within the housing, remained capable of measuring pressure applied below the packer.

Table 1 Summary of laboratory verification results for the hybrid vibrating wire piezometer–packer system

Stage	Description	Applied pressure (kPa)	Sensor-derived pressure (kPa)	Deviation (kPa)	Difference (%)
1	Reference reading (unloaded)	0	0	0	0
2	Packer inflation	10,342	3	–	–
3	Water pressure from below – Step 1	1,379	1,292	87	6.31
4	Water pressure from below – Step 2	2,069	2,005	64	3.09
5	Water pressure from below – Step 3	3,448	3,421	27	0.78

4 Field installation and pressure response

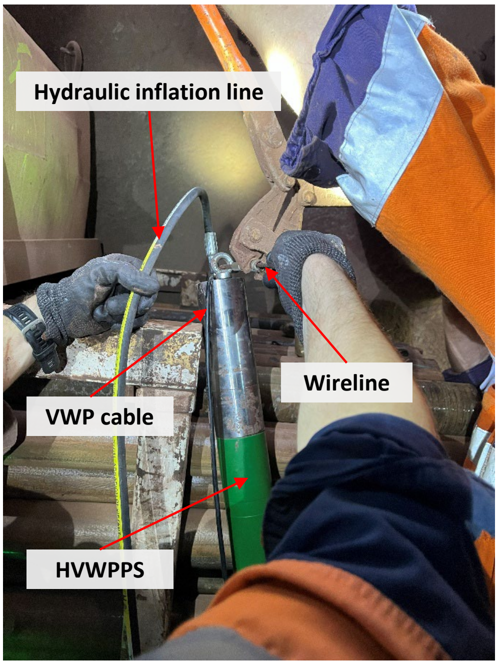
The HVWPPS was installed in the trial borehole and inflated at the target depth before backfilling of the borehole above the packer. The following sections describe the installation procedure, grout backfilling above the packer, and the recorded pressure response during and after installation.

4.1 Installation and deployment

The field installation was carried out underground in the trial borehole as part of the Carrapateena field trial. The borehole had a total depth of 198.5 m, an inclination of 60° and a diameter of 96 mm. The installation string comprised the HVWPPS tool, a sacrificial wireline, the VWP cable, a tremie line and a hydraulic inflation line. These components were secured to the wireline at approximately 1 to 3 m intervals before the string was lowered in a controlled manner using the drill rig winch, with a swivel on the wireline to reduce the risk of tangling.

Before lowering, the VWP and its housing assembly were saturated in a water bath and an initial zero reading was taken. The sensor assembly was then reassembled into the HVWPPS prior to installation. The final installation depth was confirmed at 192 m using metre markings on the VWP cable and cross-checked by filling the borehole with water to the collar such that the sensor reading corresponded to the full water head, confirming the sensor depth before packer inflation.

Once the target depth had been confirmed, the wireline was secured at the collar and the packer was inflated. The expected groundwater pressure at the installation depth was approximately 3,000 kPa, and an additional pressure margin of about 6,000 kPa was adopted to promote isolation of the target zone. On this basis, the packer was inflated to approximately 9,000 kPa before backfilling the borehole above the packer (Tetra Tech Coffey 2026).



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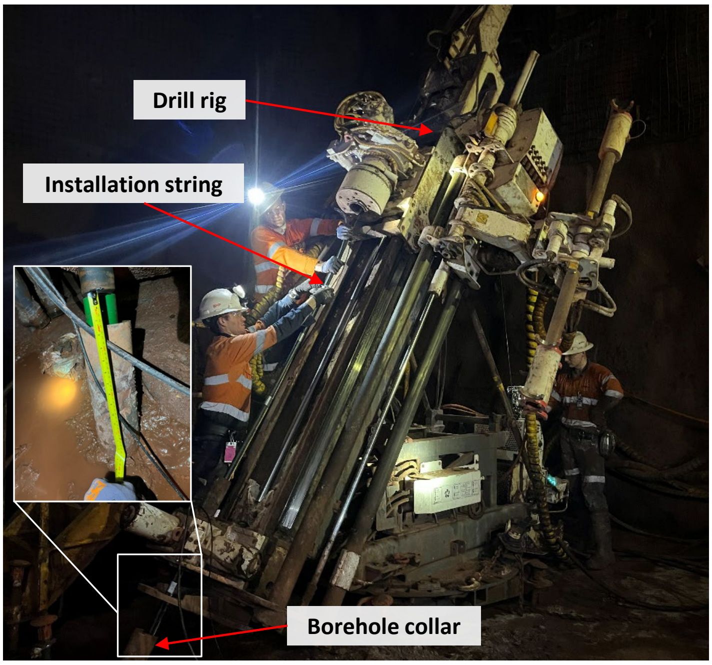

(b)

Figure 4 Underground installation of the hybrid vibrating wire piezometer–packer system (HVWPPS) at borehole HY25CAR2262: (a) Prepared HVWPPS before lowering; (b) Deployment at the borehole collar

4.2 Borehole backfilling and grouting

Backfilling above the packer was undertaken using a modified cement-bentonite grout delivered by the tremie line. In this application, the grout functioned primarily as borehole backfill above the packer because the VWP was housed within the HVWPPS below the packer and was not in direct contact with the grout. The grout mix was derived from the grout development study (Ghelichzadeh et al. 2026) and was modified onsite to suit the field installation and pumping conditions.

The initial field grout mix comprised cement, water, pre-hydrated bentonite and a retardant. The bentonite was pre-hydrated for approximately 18 hours prior to mixing. During site mixing, the first batch was found to be too viscous for pumping and tremie placement, so it was discarded. The field mix was then modified by adding a superplasticiser, and the revised mix proportions were adopted for installation. The final grout mix used during installation is summarised in Table 2.

Table 2 Final grout mix adopted for backfilling above the hybrid vibrating wire piezometer–packer system

Component	Ratio by weight of cement (kg)
General purpose cement	1.0000
Fresh water	0.9700
GEL X 13A sodium bentonite (pre-hydrated)	0.0350
MasterRoc HCA-20 (retardant)	0.0073
CEMENT FR (superplasticiser)	0.012

The key aspects of grout placement and quality control are summarised as follows:

- Pre-hydrated bentonite was used at a bentonite to water ratio of 1:16 to improve grout stability under the project-specific borehole conditions, including an elevated temperature of up to 55°C at about 200 m depth and highly saline groundwater, with total dissolved solids of about 281,000 mg/L (Tetra Tech Coffey 2025).
- A retardant was included to provide a longer working time during placement, particularly because the limited working space underground and the limited pump capacity increased the risk of premature setting of the grout during pumping and tremie placement. This resulted in a final setting time of about 60 hours and full packer deflation was undertaken only after approximately 6 days.
- A friction reducing superplasticiser was used to control viscosity, improve pumpability through the tremie line and reduce pumping resistance during placement.
- Fresh grout quality control included density, Marsh funnel viscosity, bleeding, and initial and final setting times. The mean density was 1.42 t/m^3, Marsh funnel viscosity was about 50 to 55 s, and bleeding was 1.0% after 1 hour and 1.5% after 2 hours, indicating a stable mix during placement.
- Samples of the grout during placement returned a mean 28-day compressive strength of about 3.0 MPa, based on two cube specimens.

4.3 Pressure response during and after installation

Pressure was recorded at 30 s intervals from the time the HVWPPS assembly was lowered into the borehole. Monitoring continued through packer inflation, grout placement, the 6-day inflation hold period and subsequent full packer deflation. The resulting pressure response over time is shown in Figure 5.

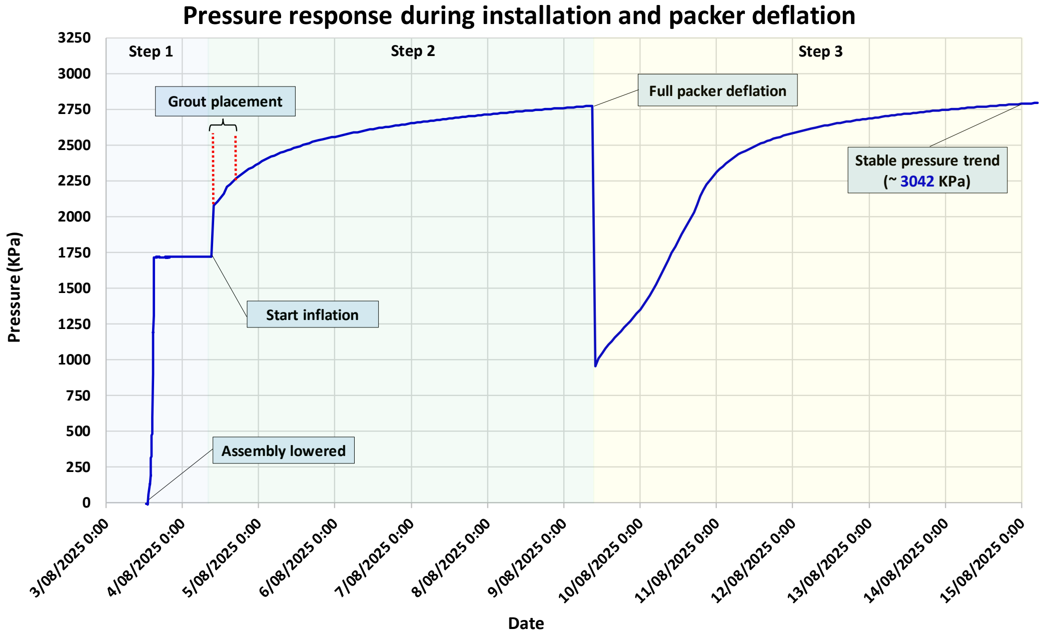

Figure 5 Pressure response of the housed vibrating wire piezometer during installation and subsequent monitoring

The recorded pressure response is interpreted in three main steps:

- Step 1: initial installation response
  - On 3 August 2025 installation commenced and the HVWPPS assembly was lowered into the borehole. During this step the recorded pressure increased from near zero to about 1,719 kPa within approximately 3 hours, likely because the system partially restricted the water pathway

as it was positioned in the borehole. The pressure then remained broadly stable until packer inflation began.

- Step 2: packer inflation, grout placement and hold period
  - On 4 August 2025 packer inflation commenced at approximately 09:00. The near vertical pressure increase observed at the start of Step 2, from approximately 1,719 kPa to 2,082 kPa, occurred in less than one hour. Grout placement then took place during the same step. Over the following 6 days, while the packer remained inflated, the pressure continued to increase gradually and reached about 2,776 kPa immediately before full packer deflation. This trend is consistent with continued pressure development below the packer while the grout hardened above it.
- Step 3: full packer deflation and subsequent pressure stabilisation
  - On 9 August 2025, full packer deflation commenced at approximately 09:00, and the recorded pressure dropped sharply from about 2,776 kPa to 958 kPa in less than one hour. The pressure then increased again and followed a stable rising trend toward about 3,042 kPa. This indicates that sealing above the packer had already been established before deflation and that sufficient grout hardening had occurred by the time the packer was released.

5 Discussion

The field trial indicated that the HVWPPS can seal a deep artesian zone while continuing to measure groundwater pressure below the packer. As noted, with conventional backfilling of artesian boreholes, grout can be washed out before setting, and sensors near the artesian zone may be displaced or damaged. With the HVWPPS installation, the sacrificial packer provides the main hydraulic seal during grout placement, while the housed VWP remained below the packer and continued to record pressure during installation and the post-installation period.

The laboratory verification and field observations of packer/sensor interaction were consistent. In the pressure chamber in the laboratory, packer inflation had only a negligible effect on the housed VWP response. In the field trial, grout placement did not cause a clear extra change in pressure, and the pressure continued to rise along the same trend that had already started after packer inflation. Together, these results suggest that the housed VWP was responding to hydraulic conditions below the packer rather than to direct mechanical effects from packer inflation.

The recorded pressure history showed a clear sequence of pressure change. During initial installation, the pressure increased from near zero to about 1,719 kPa. Following packer inflation and grout placement, it continued to rise and reached about 2,776 kPa during the 6-day hold period. After full packer deflation, the pressure dropped sharply to about 958 kPa, then increased again and followed a stable rising trend toward about 3,042 kPa.

In this trial, the grout acted mainly as a backfill and sealing medium. Because the housed VWP was positioned below the packer, the relevance of the grout mix detailed in this paper is principally its constructability and sealing performance.

This was a single field trial, and the results should be interpreted accordingly. The pressure response presented here is specific to a single borehole, installation geometry and set of field conditions. Notwithstanding this, the trial demonstrates a practical approach for artesian boreholes where both borehole closure and continued pressure monitoring are required, particularly where conventional grout only installations are difficult to execute under high inflow conditions.

6 Conclusion

A hybrid vibrating wire piezometer–packer system (HVWPPS) was developed and trialled for installation in an underground artesian borehole at Carrapateena mine. Based on the laboratory verification and field trial, the following is noted:

- Laboratory verification showed that packer inflation did not significantly affect the housed VWP and that the sensor remained capable of measuring pressure applied below the packer.
- Field installation confirmed the system could be deployed underground, inflated at the target depth and the borehole backfilled above the packer using grout delivered by tremie line (subject to suitable grout trials).
- The field pressure record showed no clear additional pressure response during grout placement. After full packer deflation, a marked pressure drop was observed, followed by a renewed increase in pressure.
- The post-installation pressure response is consistent with sealing having been established above the packer, while groundwater pressure below the packer remained measurable after full packer deflation and then rose toward a stable trend.
- This trial demonstrates that the HVWPPS is a practical approach for sealing and monitoring deep artesian boreholes in underground mines.

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