Recharge-driven Underground Dewatering and Post-Closure Groundwater Recovery

Simon Sholl[1], Stephen Wheston[2], Geoff Beale[1]

[1]*Piteau Associates, Canon Court West, Abbey Lawn, Shrewsbury SY5 8AN, United Kingdom, ssholl@piteau.com, gbeale@piteau.com*

[2]*Tembusu Ltd, 1 Killastafford Cross, Cashel, Co Tipperary, Ireland, stephenwheston@gmail.com*

Abstract

Lisheen Mine, located in Tipperary, Ireland, was operational between 1999 and 2015. Through most of mine life, dewatering rates were typically within a seasonal range of 60 to 90 MLD (60,000 to 90,000 m^3/d) , and rapidly changed with precipitation, which reflected the low storage of the limestone bedrock. After closure, groundwater levels in the mine workings rose over 120 m in the first three months, further demonstrating the low storage of the bedrock. Full recovery of the workings was confirmed in early 2018, 2 years after closure, when the natural seasonal variation in groundwater levels had re-established.

Keywords: IMWA2021, Ireland, Limestone, Recharge, Underground, Porosity, Storage, Closure

Introduction

Lisheen Mine, located in Tipperary, Ireland, produced around 6,000 tonnes per day of zinc and lead ore between 1999 and 2015. The mine exploited a 'Mississippi valley'-type ore deposit hosted in the Waulsortian (reef) Formation, Carboniferous limestone.

Ore was extracted from four underground mining zones: Main Zone, Derryville, Bog Zone and Derryville Island (Figure 1). During operations, groundwater inflows to the mine typically varied from less than 60 MLD (60,000 m^3/d) during prolonged periods of dry weather to over 90 MLD (90,000 m^3/d) following wet periods. Initially, the groundwater inflow was predominantly derived from local groundwater storage in the weathered Waulsortian limestone and was less sensitive to rainfall patterns.

As mining ended, the underground workings were cleared of all potentially hazardous material and the mine was allowed to flood by stopping all dewatering pumps on 31st December 2015. Bulkheads and three low pressure barricades were built underground to provide a restriction to groundwater flow within the workings post-closure. The objective was to limit the potential for equilibration of heads across the mined out area. Ventilation shafts were backfilled with coarse inert rock, concrete and capped with a reinforced concrete lintel. On commencement of rewatering, the groundwater levels in the mine workings rose over 120 m within the first three months, and full recovery confirmed within 2 years.

Geology

The bedrock throughout the entire Lisheen district consists of Early Mississippian, Carboniferous limestone. Waulsortian Formation limestone is the most dominant unit locally and the unit in which virtually all the production mining occurred. Typically, the Waulsortian in the area of Lisheen has a zone of epikarst extending to about 30 to 50 m below ground level. This zone usually includes more weathered, fractured and cavernous rock. Under natural conditions, most groundwater flow occurs in this upper epikarst zone. The intensity of fracturing below 50 m is observed to decrease significantly. This is typical of Irish limestones where, generally, a more permeable and productive zone extends to a depth of around 30 m, below which isolated faults and fissures form the only permeability to a depth of 150 or 200 m Drew (2018).

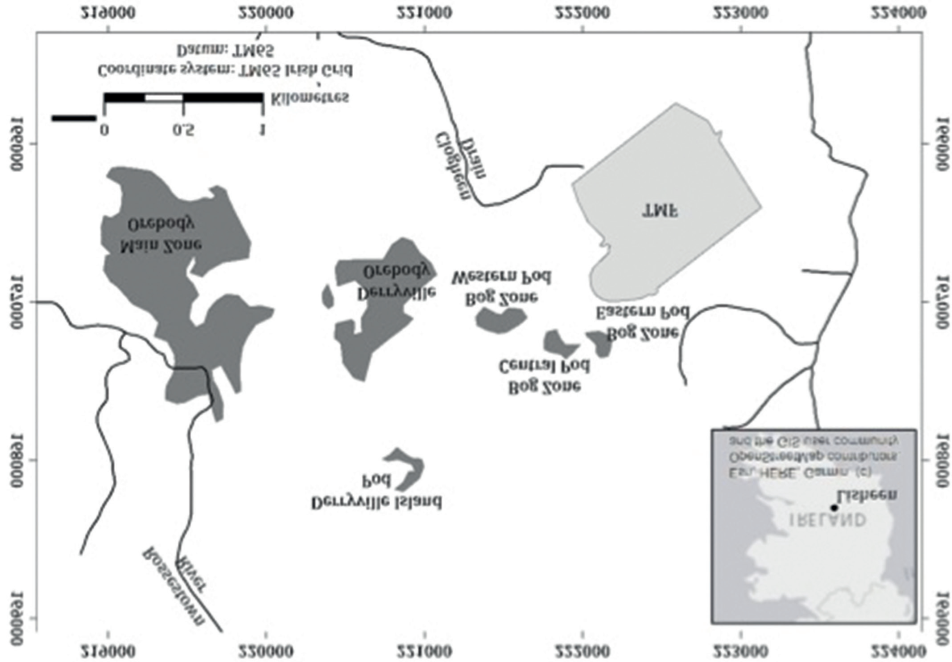

***Figure 1** Plan of Lisheen infrastructure, orebodies and mineral lenses.*

Argillaceous Bioclastic Limestone (ABL) dominates the areas to the northwest and northeast of Lisheen. The ABL is a massive limestone and is generally unfractured. Typically, it does not yield any groundwater and forms a flow barrier between the overlying Waulsortian and the interbedded Lisduff Oolite Member (oolite). The main decline was driven through the ABL.

Locally, little is known about the hydrogeology of the oolite which occurs stratigraphically within the ABL. It is evident from the available data at Lisheen that it provided the main conduit for the inflows to the F2/F3 zone in the decline. F2/F3 defines two major fault zones intercepted during decline development. The oolite is known to be fractured and to yield groundwater in the vicinity of the main geological structures. However, away from the main structures, the degree of fracturing and its potential to transmit groundwater in the area south of Lisheen is uncertain. In the most southerly production areas, mining into the oolite encountered no major groundwater inflows.

In general, the regional geology strikes in a northeast-southwest direction along the axis of the Rathdowney Trend. The two dominant structural orientations are as follows.

- **North northwest-south southeast** structural set forms the dominant local structural trend. The F2/F3 feature, together with most of the main faulting in the vicinity of the orebodies, is aligned along this trend.
- **East northeast-west southwest** structural set associated with the regional Rathdowney Trend is evident in the immediate mine area.

Early mine life

The decline was constructed in ABL to allow advanced dewatering of the orebody (in more permeable Waulsortian) while the decline was being advanced. A major groundwater inflow was encountered as the decline was driven through the NNW-SSE trending F2 and F3 fault zones. The water was derived from the oolite, which had a contact with the ABL, 5 to 12 m below the floor of the

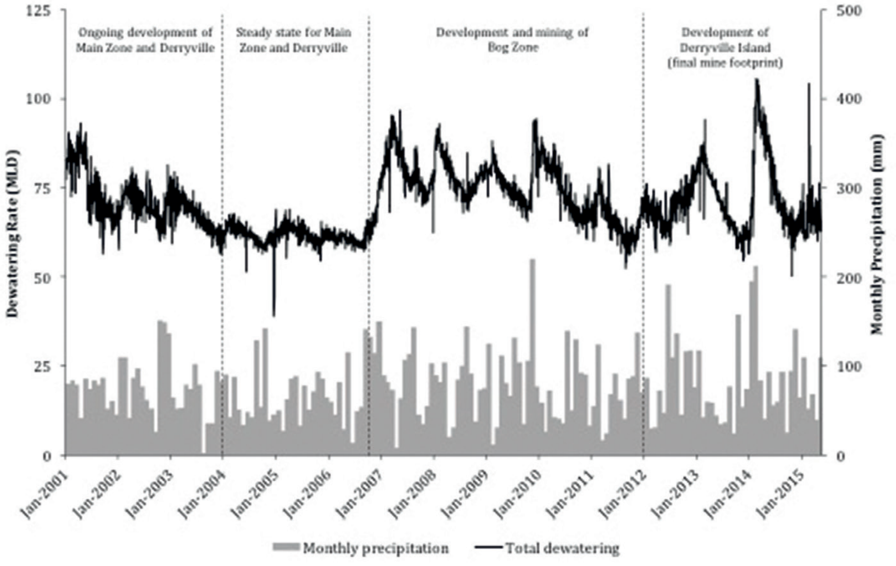

***Figure 2** Dewatering rates from 2001 to 2015.*

decline. The fault-controlled upthrown block of led to sustained inflow from the F2/F3 feature throughout the entire period of mine operations. All other inflows to the mine were from the Waulsortian Formation.

Since the decline was designed to enter the orebody at about 170 m depth, advanced dewatering of the Waulsortian was required (using surface wells) during the time the decline was being advanced. Surface drilling was difficult because of the cavernous nature of the formation (particularly above the Main Zone ore) but sufficient drawdown was achieved to allow depressurization of the initial production workings. Once underground mining was established, sub-horizontal dewatering holes were installed from the workings so the surface wellfield became under-drained and redundant.

Early in mine life, total dewatering reached a peak of 93 MLD in the April 2001 (Figure 2) reducing to around 60 MLD by mid-2006 when it was considered that the hydrogeological system was almost in steady state for the mine workings developed at that time. Virtually all of the groundwater storage removal had taken place, and the dewatering rate was sustained by regional groundwater recharge over the area of drawdown. Water levels in the footprint area of the mine were drawn down to close to the top of the workings.

Operational dewatering

Initially, mining was limited to two primary ore bodies Main Zone and Derryville (Figure 1). It was a number of years before the full footprint of these working areas was developed. Therefore, during the early years of mining, Lisheen was not just managing recharge water but also continued to intercept stored water as new mining areas were developed. It was not until around 2004 that the full extent to the two main orebodies were developed and the mine entered a relatively steady state for a few years until new ore bodies were developed.

From 2007 onwards, the additional mining areas were opened up (Bog Zone and Derryville Island, Figure 1). These mining zones added inflows from groundwater storage during their development as well as increasing the overall area of drawdown around the mine. This led to an increased inflow from recharge.

Over the life of the mine there were periods of high winter rainfall together with a number of very dry summers. These factors caused a both seasonal and inter-annual fluctuations in the mine inflow rate. From late 2008 to the end of mine life (December 2015), groundwater storage removal was a minor contributor to dewatering, with almost all inflow due to groundwater recharge over the area of drawdown. This was demonstrated in the winter of 2013/14. The mine pumping rate in November 2013 was at an all-time low of 55 MLD (Figure 2) as a result of the very dry summer and autumn. Between 28th December and 19th February, the rate increased from 56 MLD to an all-time high of 106 MLD following exceptionally high rainfall in January and February 2014.

The rapid recharge to the underground workings is, in part, due to the low storage of the limestone bedrock. At its maximum extent, the estimated area of drawdown (in the Waulsortian) was between 90 and 95 km². This area represents a 'zone of capture' for recharge to the mine workings, with a (strongly seasonal) recharge rate typically between 200 and 350 mm/yr, around 15 to 30% of the mean annual precipitation.

Throughout the period of mine dewatering, the near-surface glacial deposits that overlie the Waulsortian showed no measurable drawdown in shallow piezometers. The near-surface water balance was not materially affected by dewatering of the underlying limestone bedrock. Strong vertical hydraulic gradients developed throughout the area of dewatering influence.

Mine closure

Prior to closure, a predictive numerical groundwater model was used to produce an envelope of likely groundwater rebound curves (Figure 3). The model distinguished between the shallow epikarst (typically 30 m thick in the model) and deeper competent bedrock. The epikarst was assumed to have a specific yield of 3% and the deep bedrock 1%. Literature values of porosity for limestones tend to be in the range of 1 to 20% and specific yields between 0.5 and 15%, (Misstear *et al*. 2006).

Volumetrically, by the end of mining, the volume of groundwater removed from storage was estimated to be around 10 million m³ from the epikarst and around 4 million m³ from the competent bedrock. A further 1 million m³ of void space also remained within the mine workings, a small proportion of the total mined volume because most of the workings were backfilled with cemented paste.

Dewatering ended at Lisheen when the dewatering pumps were switched off on 31st December 2015. Groundwater levels in the mine workings rose over 120 m in the first three months. In one monitoring well, water levels rose from -63.8 mOD on 22nd December 2015 to 66.3 mOD on 23rd March 2016. This is an increase of 130.1 m in 92 days; an average of 1.4 m/d.

This initial response to dewatering was faster than predicted (Figure 3), so the rebound prediction was revisited and calibrated to the first three months of monitoring data. The analysis showed that, to calibrate the recovery curve, only the mine workings void space was required. The groundwater storage component of the competent bedrock, therefore, had to be close to zero. Regardless of the actual porosity of the bedrock, this suggests that the specific yield of the competent Waulsortian is significantly lower than 0.5%. The discrepancy between literature and 'calibrated' bedrock specific yield was a key learning from the closure programme. When water levels rebounded, most of the void space being replenished (re-watered) was within the workings themselves. The surrounding Waulsortian bedrock required little additional water to achieve full recovery.

Following the calibration, the monitored groundwater levels remained within the predicted recovery envelope (Figure 3), fluctuating seasonally between being above the 'base case' to below it. The seasonal variation in recovery rates further demonstrates the dominant control that recharge, over storage, has on the groundwater system.

Influence of larger epikarst dewatered volume can be seen once groundwater levels reach around 40 to 50 m below ground level (Figure 3). The rate of recovery reduces significantly from around 1.3 m/d in the deep, low porosity bedrock, to around 0.09 m/d – a 15-fold reduction in rate. However, not all of the reduction can be attributed to specific yield, reduced hydraulic gradients and seasonal recharge variations are also key controls.

The mine achieved full recovery by the summer of 2017, when water levels reached typical summer (seasonal low)

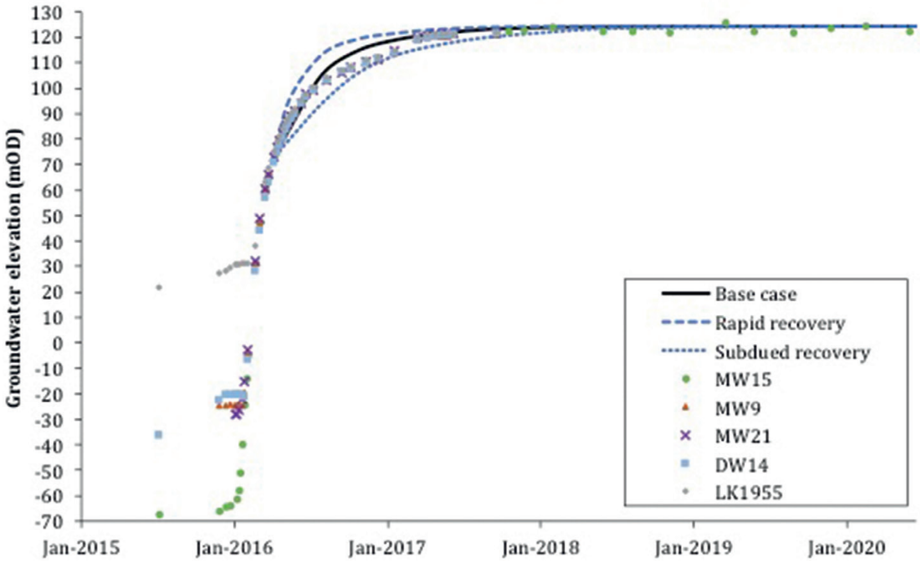

Figure 3 *Groundwater recovery predictions and monitoring data.*

elevations. Full recovery of the workings was confirmed in early 2018 (2 years after closure) when the groundwater level reached between 123.6 and 125.3 mOD, compared with a pre-mining elevation of about 125 mOD. Following that time, a slight seasonal reduction in groundwater levels was observed, indicating that the natural seasonal variation in groundwater levels had become re-established.

Conclusion

Mining at Lisheen required complete lowering of the bedrock groundwater table to the level of the underground workings because of the vertically interconnected nature of the Waulsortian limestone in the immediate area above the orebody. Initial dewatering was carried out using surface wells that were installed concurrently with driving the access decline in low permeability (tight) ABL. The goal of the surface wells was to achieve advanced depressurization of the initial ore zones prior to the decline reaching the Waulsortian. As soon as underground mining in the Waulsortian was established, all dewatering was carried out using underground wells and drill holes, and the surface wellfield became under-drained and redundant.

Groundwater storage removal at Lisheen was primarily associated with the dewatering of the shallow, relatively high storage, higher permeability epikarst. Successive expansions at Lisheen led to short-term increases in storage pumping but also step-change increases in recharge pumping as the area of drawdown progressively increased with each expansion. Once all expansions were complete, the area of drawdown remained relatively constant and so changes in dewatering rate reflected the seasonal and inter-annual variations in recharge only.

For much of the mine life, dewatering rates at Lisheen were typically within a seasonal range of 60 to 90 MLD, but strongly influenced by season and periods of wet weather. This reflects the rapid infiltration rates and limited groundwater storage to 'buffer' recharge before entering the mine workings.

Mine closure provided further evidence of the very low storage conditions at depth. While literature estimates suggest limestone specific yield are within the range 0.5 to 15%, the groundwater rebound analysis at Lisheen suggests that the actual value is significantly lower than 0.5%.

While the specific yield typically describes laboratory-defined drainable portion of a core sample, for 'real-world' dewatering and closure predictions, the specific yield must be defined by both the drainable portion and the ability for it to be drained at the scale of the mine. The presence or absence of regional permeability, or permeable structures, connecting the country rock to the mine workings has a very significant impact.

This work demonstrates the importance of understanding both the bedrock storage and the seasonal variation in recharge when planning underground dewatering operations and predicting groundwater rebound.

Acknowledgements

The authors would like to thank Vedanta Zinc International for allowing access to information used to generate this paper.

References

Drew D (2018). Karst of Ireland: Landscape Hydrogeology Methods. Geological Survey Ireland, Dublin.

Misstear B, Banks D and Clark L (2006.) Water Wells and Boreholes. Wiley & Sons Ltd.