Abandoned Coal Mine Mitigation in Artesian Conditions

Joshua Zimmermann

Brierley Associates, Cottage Grove, MN, USA, jzimmermann@brierleyassociates.com

Abstract

For years, a neighbourhood in Glenrock, Wyoming, suffered from various odd damages, including the sudden appearance of artificial springs, flooded basements/crawlspaces, and shifting foundations. The source of this damage was the underlying Glenrock No. 1 and No. 2 Mines, where years of collected groundwater in the underground workings had resulted in high-pressure artesian conditions within the mined interval, hydraulically fracturing the overlying rock. Surficial depressions from mine subsidence were also commonplace throughout the town, damaging roads, homes, and other infrastructure. This paper covers the innovative program that used high mobility grouting to mitigate the risks associated with these conditions and lessons learned that could be used to treat similar situations in the future.

Keywords: Geohazards, artesian, mining, subsidence, grouting, foundations, underground coal mines

Introduction

Glenrock, WY is a town of 2,400 people in central Wyoming, approximately 25 miles (40 km) east of Casper, WY. The Deer Creek Coal Company began regular underground coal mining operations at the Glenrock No. 1 Mine on October 1, 1888 (Day, 1890). By the end of 1891 the main stope had been driven down dip for 1600 ft (500 m) with the coal seam averaging 6.5 ft (2 m) thick (Johnson, 1892). By the end of 1907, the main stope of the No. 1 Mine extended for 3000 ft (900 m) down dip while the No. 2 mine extended for 1200 ft (365 m) nearly on strike of the coal seam, with both mines being operated essentially as one (Shaw 1907). The No. 1 Mine extended north almost as far as the Platte River, and being approximately 200 ft (60 m) lower than the river at this point, it required continuous pumping for dewatering. Owing to a poor roof, large amounts of water in the mine, and the inability to utilize the coal as fuel for the local railroad, the mine(s) were permanently closed in late 1909. A mine map for the Glenrock No. 1 and No. 2 Mines is shown in Fig. 1.

Almost immediately after the closure of the mine, numerous mine related subsidence events were reported across the area. These events were typically isolated in nature and were dealt with by the local government or property owners through surficial backfilling of the depressions. It wasn't until the passing of the Surface Mining Control and Reclamation Act (SMCRA) of 1977 that federal funding and resources became available for large scale abandoned mine reclamation programs. In Wyoming, this was handled through the Department of Environmental Quality (DEQ) Abandoned Mine Land (AML) Division. The Wyoming DEQ funded two separate investigation and mitigation programs in Glenrock from 1983 to 1987 and from 1993 to 1998. These programs were primarily focused on reducing risks from subsidence across the larger Glenrock area and used low mobility grout and concrete mixes, as well as sand slurry (a mixture of sand and water) injected into the collapsed mine workings to create columns which would stabilize the weakened roof of the mine.

After additional subsidence events were noted in the Spring of 2015, a third program was initiated from 2015–2023 to investigate and mitigate any remaining risks from the underground mines in the Glenrock area. During a geotechnical investigation performed as part of this program in 2018, artesian conditions were found within the mined interval in the northern half of the Glenrock No. 1 and No. 2 Mines. Due to the depths of the mine workings in this

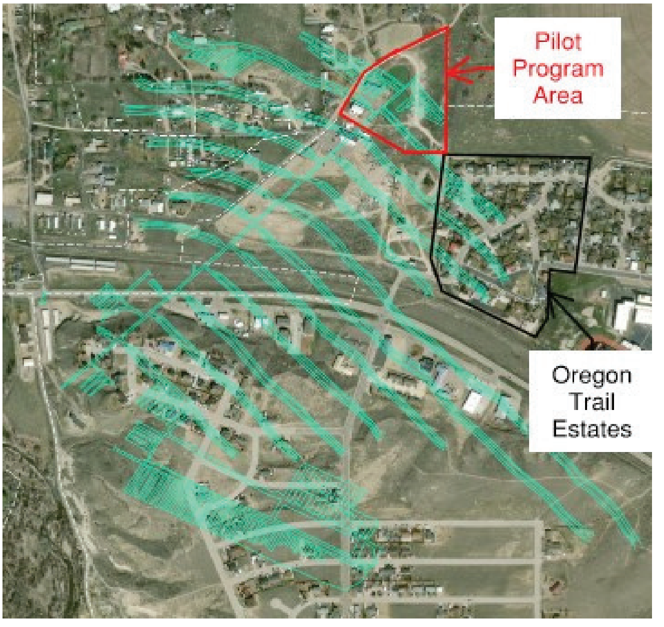

__Figure 1__ Mine Map of Glenrock No. 1 and No. 2 Mines

area (100 to 200 ft or 30 to 60 m below the ground surface), minimal exploratory or mitigation work has been previously performed due to the perceived lower level of risk under prior investigatory programs. Up to 10 ft (3 m) of artesian head pressure was encountered at the surface when drilling encountered the mine workings under the Oregon Trail Estates Neighbourhood in the northeastern most extent of the mine. Through additional geotechnical/chemical analysis and interviews with property owners in the area, previously unreported issues of sudden instances of flooding crawlspaces/basements, artificial springs, and additional damages, such as subsidence, were present in the community. Over one dozen separate properties were determined to have suffered negative effects from the underground mine workings present in the area.

This investigatory program determined that the presence of Glenrock Mines 1 and 2 had likely altered the localized historic groundwater regimes by creating preferred flow paths for water to flow from the shallow to deeper parts of the mine. This new groundwater gradient resulted in pressurized water within the mine interval, which hydraulically fractured the overburden under the neighbourhood, resulting in cross-communication and contamination of the deeper aquifer to the shallow alluvial aquifer. This would periodically result in sudden flooding events that were damaging multiple homes within the area through rapid and sudden water infiltration into crawlspaces and basements, formation of intermittent artificial springs along roads, and damaged foundations due to the underlying groundwater pressure and rapid change in groundwater levels. Subsidence events were also commonplace within the area as the mine workings slowly weakened and became more fractured over time.

While similar conditions exist in numerous abandoned underground mine locations across the US, mitigation methods are mainly focused on treating the mine water through pumping to a treatment system or allowing it to flow to the surface to relieve the groundwater pressure. These systems need to essentially run in perpetuity to prevent damages to the surrounding community. However, continuous treatment system was not readily feasible in such a populated area, and the DEQ desired a one-time, permanent solution to the problem.

Methods

To test potential solutions for the affected area, a pilot program was initiated in the summer of 2019 to determine if pressurized, upstage void fill grouting would be a feasible option for mitigation of such a problem. This type of grouting (using a high mobility grout mixture) had proven highly successful in mitigating subsidence risk across the rest of the Glenrock area. By starting grouting operations within the mine interval, using high mobility grout mixtures, and raising the depth of injection as pressures increased, the entire mine interval and any rubble-filled or compromised overburden would also be infilled and stabilized.

The goal of the pilot program was to determine the feasibility of using this method to not only fill in the void space of the mine, but also fill any fractures, joints, or otherwise compromised rock above the mine roof that were creating pathways for groundwater communication to the surficial aquifer with impermeable grout. Additionally, lessons learned from the pilot program would help create the methodology/design approach to alleviate potential risks from the mitigation program to the overlying sub-division. The potential risks associated with the injection of pressurized high-mobility grout included displacement of groundwater into building foundations, inducing the structural collapse of the mine, infrastructure sub-grade failure through over-saturation, environmental considerations, ground surface movement, and the stability of the grout mixture in the artesian conditions.

The pilot program was conducted just northwest of the Oregon Trail Estates (as shown in Fig. 1), which was an area subject to similar hydrogeologic, geochemical, and geotechnical conditions. This undeveloped property was generally flat, containing minimal topographic relief. Because of the existing water-filled gravel pit (pond), this was an ideal location to conduct this pilot study to allow mine water discharge and provided ample space to allow for any adverse variability in water control issues. The area of the pond measured 43,000 ft^2 (4,000 m^2) and is shown in Fig. 2. With 2 ft (60 cm) of available freeboard, this provided roughly 630,000 gallons (2.4×10^6 L) of available storage for groundwater discharge within the mine interval, not including evapotranspiration rates.

For continuous groundwater monitoring throughout the pilot program, nine (9) Geokon 4500H pressure transducers were installed in monitoring wells around the site within the mined interval, the overriding Lance Formation, and the shallow alluvial aquifer. An additional five (5) piezometers were also installed in the adjacent Oregon

Figure 2 Pond Adjacent to the Pilot Program Site for Discharging Mine Water

Trail Estates Neighbourhood. Each well was equipped with a GeoNet Wireless Network datalogger with satellite uplink for continuous groundwater monitoring data feeds. All cloud based services were provided by Sensemetrics. Transducer data value outputs included; pressure, temperature, and depth to ground elevation. Datalogger nodes were programmed by Brierley to take readings in one hour intervals; however, recorded intervals would be adjusted dependent on proximity of grouting or the area of hydraulic interest. All transducers were closely observed throughout the program.

Two discharge wells were also installed for the pilot program (as shown in Fig. 3). Each discharge well consisted of a 5 in (12.7 cm) diameter PVC pipe drilled into the void of the mined interval so that artesian water would flow to the surface. No pumping equipment was needed nor installed on either discharge well. Sealing within the annular spacing of the PVC pipe consisted of K-Packers and bentonite chips to the surface. A pressure-sealed adaptor was installed 1.5 ft (0.5 m) below grade and fitted with a control flow valve to divert water through a perpendicular 12.7 cm PVC to the storage pond. Diversion casing was also set below grade at 1.5 ft (0.5 m). Artesian water flow rates remained consistent throughout the project through the discharge wells, with a maximum rate of up to 400 gpm (1.5m^3/min). A diaphragm pressure gauge (maximum measuring capacity of 100 PSI or 700 KPa) was added as a secondary monitoring source for quick pressure observation in the field.

To determine if foundation settlement or heave would be a risk during potential subsidence mitigation in Oregon Trail Estates, ground movement load testing was conducted in the center of the pilot area to simulate bearing load conditions similar to that of a single-family foundation footing while injecting grout immediately below. To replicate these conditions, two 1.2 × 1.2 × 1.8 m boxes and three 1.2 × 1.2 × 1.2 m boxes were carefully crafted. Boxes were filled with grout where weights were estimated at roughly 11,400 lb (5,170 kg) and 7,700 lb (3,500 kg), respectively, corresponding to bearing pressure of 700 PSI (4,800 KPa)

Figure 3 Discharge Well Setup for the Pilot Mitigation Program. The Valve Seen in the Figure Allowed for the Controlled Release of Artesian Groundwater at Various Rates

and 500 PSI (3,450 KPa), respectively. Each box was placed into pre-dug pits with the underlying unconsolidated silty sand with clay (alluvium) moderately compacted using the back of a backhoe bucket across the bottom of the pit area. Each corner of each settlement box was surveyed regularly throughout the project to determine if ground movement occurred.

During the summer of 2019, a total of 74 boreholes were drilled across the pilot project site, through which a combination of 3,800 m^3 of low, medium, and high mobility grout mixes was injected under various depths, pressures, and conditions.

Conclusions

At the end of the pilot program, it was determined that the most critical aspect to safely grouting in artesian conditions was controlling the groundwater pressures within the mined interval. Grouting near the settlement boxes with any grout mix or depth near the mine interval at the pilot location did not appear to influence their movement. The total differential movement of any settlement boxes did not appear to exceed 0.25 in (6 mm) at any location, with many boxes indicating 0 in (0 mm) of net movement. Also, confirmation coring conducted at the project's end uncovered many samples of cured grout found penetrating fractures and joints within and well above the mined interval. This effectively eliminated groundwater communication pathways and lowered the groundwater table locally while reducing subsidence risk.

However, in multiple instances where the discharge wells were deliberately left partially open or closed, releases of groundwater at the surface at random locations were noted to occur. This includes one instance of discharged mine water to the surface which happened on the 3rd day of the pilot program, where groundwater began leaking through the asphalt approximately 900 ft (270 m) to the southeast of the injection location within the Oregon Trail Estates Neighbourhood. When this occurred, there was a small, 4 in (10 cm) increase in the groundwater level in the nearest monitoring well screened in the mine interval, but an increase in groundwater pressure of nearly 2 ft (0.6 m) within the mine void itself.

This phenomenon confirmed there is a strong level of groundwater transmissivity within the mine interval and through joints/ fractures to the overlying Lance formation and alluvial aquifers with little resistance to the flow (even if it is up dip). It also showed that the groundwater influence that this connection allows between formations can be isolated in nature, with only limited areas displaying notable effects from this connection. Therefore, nearby monitoring wells not screened within the mine interval may be unable to indicate significant changes in groundwater pressure as they would be outside of the zone of influence of the hydraulic connection between formations.

Therefore, the pilot program indicated that it was feasible to utilize grout in artesian conditions provided proper groundwater monitoring was implemented and discharge wells were properly located and utilized. Lessons learned from this program were directly implemented in the subsequent mitigation within Oregon Trail Estates area in 2021. Before the project's initiation, 16 more wells with remote sensing capabilities were installed throughout the project area to provide better monitoring of the shallow and deep aquifer groundwater pressure. A series of 6 discharge wells were also installed around along the northern and western edges of the project boundary to provide multiple avenues for relieving groundwater pressure. Each discharge well was connected via an underground pipe network to a central manifold where groundwater samples could be collected throughout the project, flow rates monitored, and all discharged water

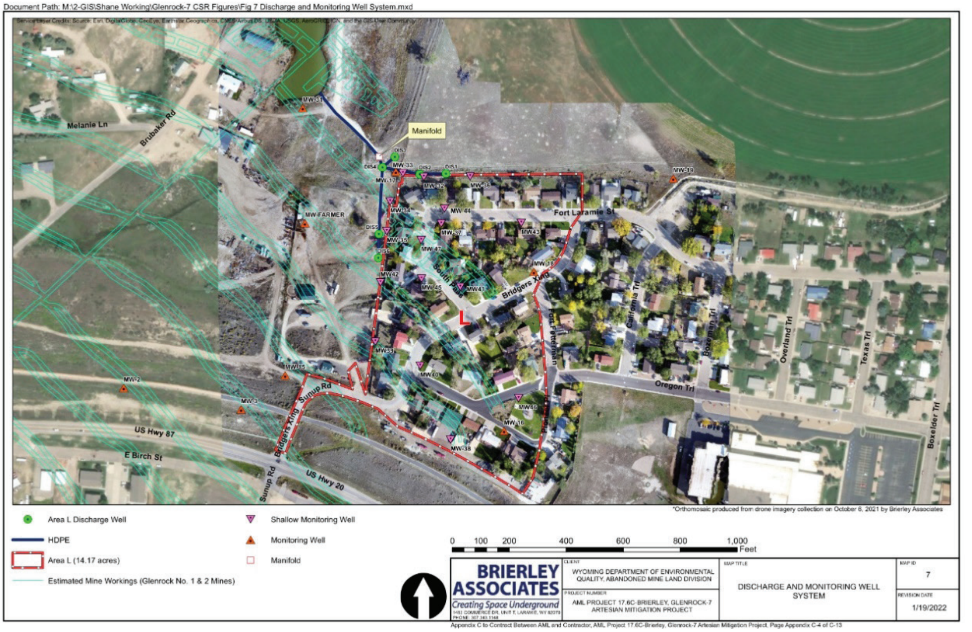

***Figure 4** Monitoring and Discharge Well Setup for the Mitigation of the Oregon Trail Estates Neighbourhood*

could be conveyed to a single retention pond. A map showing the location and outline of this monitoring well and discharge network can be seen in Fig. 4.

The project within Oregon Trail Estates was conducted from May to November of 2021. Grouting activities were driven from the southern end of the project site to the north to "push" the groundwater towards the discharge wells and minimize the chances for isolated pockets of pressurized groundwater to form. Groundwater levels in all locations were constantly monitored by an engineer during the project for anomalies, with pumping rates, the locations of grout injection, and the rate of groundwater release from each discharge well carefully coordinated between the engineer and the contractor. Daily and weekly testing of the discharged water for pH, TDS, TSS, and other factors (per DEQ policy) occurred throughout the project. No notable changes in groundwater chemistry were noted until the end of the project, when grouting activities began to influence the discharge wells. Once this occurred, each well was subsequently taken offline and abandoned until only one discharge well remained after the project.

A total of 24,537 yd³ (18,760 m³) of grout was injected during the project, with a cumulative total of 27,990 yd³ (21,400 m³) of water released through the discharge wells. The difference between the amount of grout injected compared to the amount of discharged groundwater is due to the continual recharges of the aquifer during the project. No instances of inadvertent groundwater release, ground movement, or other damages were noted to have occurred within the area at any time during the project. Additionally, head pressure within the mine interval was noted to have dropped by 3-ft (1 m) during the project, which persisted after completion. This corresponded with groundwater levels within the surficial aquifer dropping in some locations by up to 14 ft (4.25 m). This indicated that the connections from the pressurized deep aquifer to the surface had been infilled with grout, reducing or eliminating the influences on the shallow groundwater levels. Subsequent verification coring in the area confirmed a high degree of infilling of voids, joints, and fractures both within and above the mined interval, as can be seen in Fig. 5

Several properties that reported consistent flooding issues in the past noted that conditions dramatically improved during the project, a condition which has persisted as of the date of this paper. Combined with the results of the continuous groundwater monitoring and verification coring per-

__Figure 4__ Core Sample Covered from Verification Drilling. Note that the Grout Material has Flowed Around and Completely Infilled the Space Surrounding a Wooden Support from the Mine

formed in the project area, this indicates that the negativity influences from the artesian conditions have been notably reduced. This indicates that with careful planning, coordination, and monitoring that mitigating artesian conditions from underground coal mines via grouting is a viable method to reduce risk to infrastructure in a populated area.

Acknowledgments

The author thank the Wyoming Department of Environmental Quality's Abandoned Mine Land Division for funding the design and construction of all work discussed in this paper.

References

Day, David T. (1890) Mineral Resources of the United States, Calendar Year 1888. United States Geological Survey, Washington Government Printing Office. p 652

Johnson, A.A. (1892) Annual Report of the Wyoming Agricultural College for the Year 1891. University of Wyoming, Laramie, Albany County, Wyoming, p 248

Shaw, E.W. (1907) The Glenrock coal field, Wyoming, Investigations of the Coal Fields of Wyoming by the United States Geological Survey in 1907, Advance chapter from U.S. Geological Survey Bulletin No. 341, Contributions to Economic Geology, Part II, Coal and Lignite, p 151-164, Washington Government Printing office, 1909.