Bullhouse mine-water project

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The Bullhouse mine-water project has restored the quality of 6 km of the River Don in Yorkshire, England, which was severely downgraded by the discharge of mine water from the abandoned Bullhouse mine drainage adit. The mine water contains up to 70 mg/l total iron at a pH of 5.6. The discoloration caused by the iron detracted from the amenity of the river, contrasting with the flourishing trout fishery immediately above the adit discharge. The total value of the project was £1 000 000.

Fundamentals

The Bullhouse mine water emerges from underground almost devoid of dissolved oxygen and with its iron content largely in solution in the reduced (ferrous) state. Rapid oxidation and iron removal by sedimentation as ochre (hydrated ferric oxide) require cascade aeration.

The mine water is normally net-acid. Although the raw water typically has a pH of about 5.6, the oxidation and sedimentation reactions generate acid and often lead to final pH values in the range 3.9–4.5. As the rate of chemical oxidation of ferrous iron is strongly pH-dependent, being greatly decreased in an acid medium, the reactions that occur are thus self-inhibitory. Coalfield mine water often contains bicarbonate, which reacts with the acid and prevents a decrease in pH. At Bullhouse, however, there is usually insufficient bicarbonate for this purpose. Neutralization before or after precipitation could, therefore, be required.

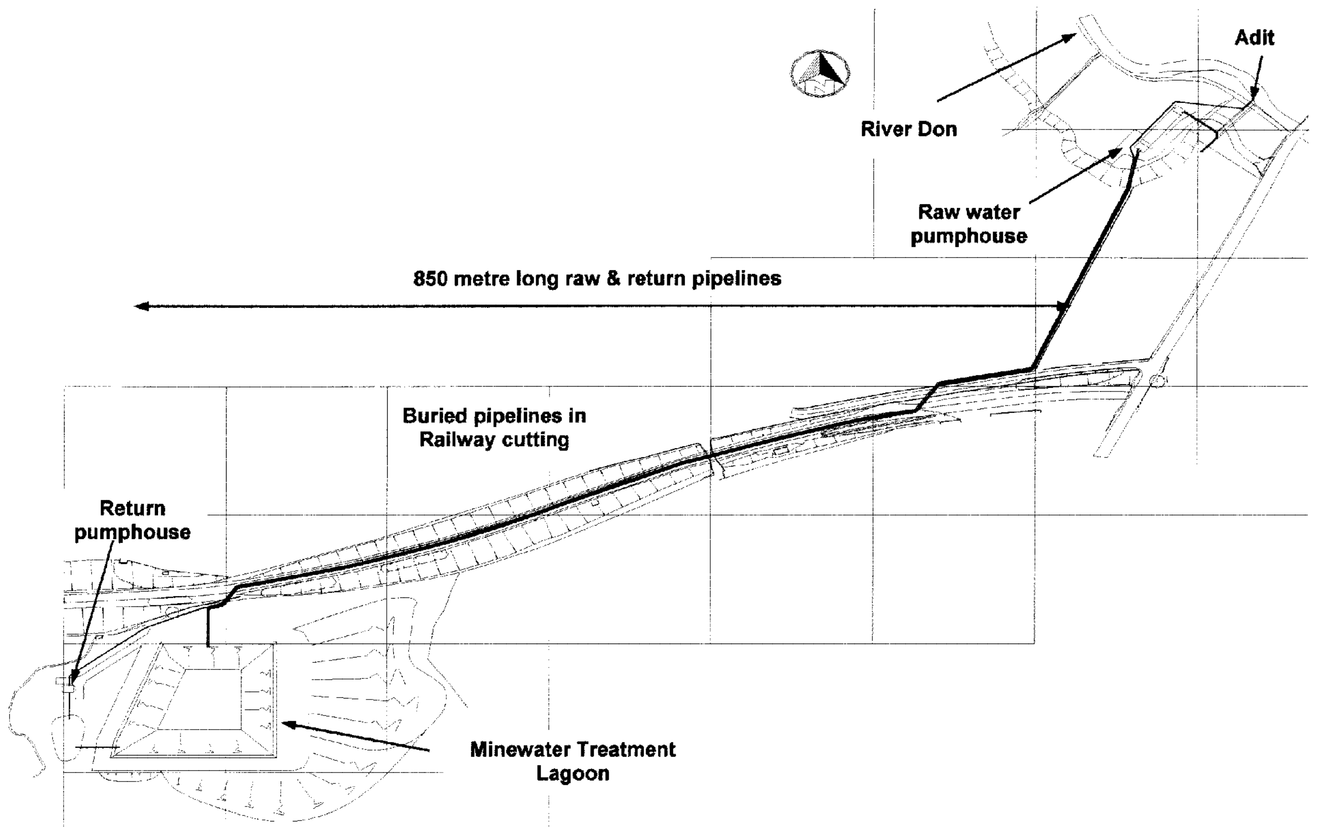

Fig. 1 Schematic layout of Bullhouse mine-water scheme

The gravity discharge from the adit is collected in an underground storage tank that acts as a flow-balancing sump. Pumps then discharge the mine water from the tank through overland pipelines 850 m in length for treatment in the Bullhouse quarry. Aeration is effected in a cascade and sedimentation of the mine water takes place in a large earth lagoon constructed in the quarry as part of the restoration of the site. The treated mine water is returned to the river at the drainage adit by a second pumping installation.

The design, construction and commissioning were integrated with a two-year research project to optimize operation and improve generic understanding of mine-water treatment.

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Notwithstanding these characteristics, it was prudent on economic grounds to design the system as if the mine water were amenable to treatment by simple aeration and toallow for chemical dosing as a flexible addition to the basic process for application if and when necessary. This plan was underpinned by the large volume available for a lagoon in the Bullhouse quarry, which provides a residence time long enough for full oxidation and sedimentation even under acidic conditions. In addition, the net alkalinity observed in the receiving river can absorb a slightly acidic discharge without significant decrease in pH below the normal value of 6.5. Thus, dosing was a contingency in case of unfavourable changes in the mineral components of the River Don or undue peak flows from the mine following heavy rain.

Construction

Design work was carried out during 1996–97 and construction works on the site commenced in spring, 1997. The scheme was formally opened in September, 1998, and full-scale monitoring was undertaken until July, 1999. An overall plan of the system that shows the pumping sump, overland pipeline, cascade, lagoon and return pumping system is given in Fig. 1.

Overland pipeline

Initial works included the excavation and placement of the overland pipeline system to connect the pumphouse at Bullhouse bridge to the treatment site in Bullhouse quarry, a distance of about 850 m. The system comprises twin delivery pipelines 160 and 200 mm in diameter and a return-water pipeline 200 mm in diameter. The pipelines were placed at a nominal depth of 1200 mm to invert in a granular bed and surround. Hatch-box access points were fixed in manholes at 100-m intervals to allow access into the pipeline so that jetting of ochre accretions could be accomplished easily to maintain the full mine-water flow. The pipelaying progressed rapidly across agricultural land, but a significant delay in purchase of the former railway track resulted a four-month delay in completion of the pipeline.

Mine-water treatment lagoon

The construction of the mine-water treatment lagoon in Bullhouse quarry commenced in summer, 1997. The earth-wall lagoon created in the quarry void has a capacity of 50 000 m^3, a surface area of about 6000 m^2 and a depth of 8 m (Fig. 2(*a*)). The lagoon was constructed to standards outlined in the Mines and Quarries Act 1954 and the Mines and Quarries Tips Regulations 1971 and to the technical requirements applied by the former National Coal Board handbook on the construction of tips and lagoons.

The construction works involved a total excavation and placement of 140 000 m^3 of Coal Measure shales and superficial clay deposits that composed the backfill resulting from the former Hepworth Building Products quarry. Close selection of materials took place throughout the earthmoving contract to ensure that impermeable materials were used to form lining seals to retain water in the lagoon, whereas more permeable spoils were used either to provide drainage layers or as bulk fill. Placement of the seals in 300-mm layers was followed by compaction with a heavy vibrating roller. Permeable materials and drainage layers were placed in layers 1 m thick and less compaction was applied. The whole of the structure had been subject to a detailed geotechnical analysis to ensure that minimum required factors of safety against failure of 1.5 were achieved.

Dump trucks were loaded by excavators to transport the spoil to the placement point, where it was spread and compacted by a bulldozer towing a vibrating roller. Heavy inflows of groundwater to the excavation limited the depth of the lagoon to less than had been expected. The consequent shortfall of available material required a revised profile for restoration of the quarry, which was achieved by the inclusion of berms in the profile to reduce the amount of fill necessary.

Restoration of the site was completed by placement of 400 mm of soil materials over the restored slopes of the quarry. A full planting scheme was completed as the final step of restoration of the lagoon area (Fig. 2(*b*)). About 20 000 trees of native species have been planted on the slopes, which in future years will allow the area to present a pleasing vista to pedestrians who use the Trans-Pennine footpath skirting the northern boundary of the site, which affords a panoramic view of the treatment system.

(*a*)

(*b*)

Fig. 2 (*a*) Quarry before construction of mine-water treatment lagoon; (*b*) completed lagoon

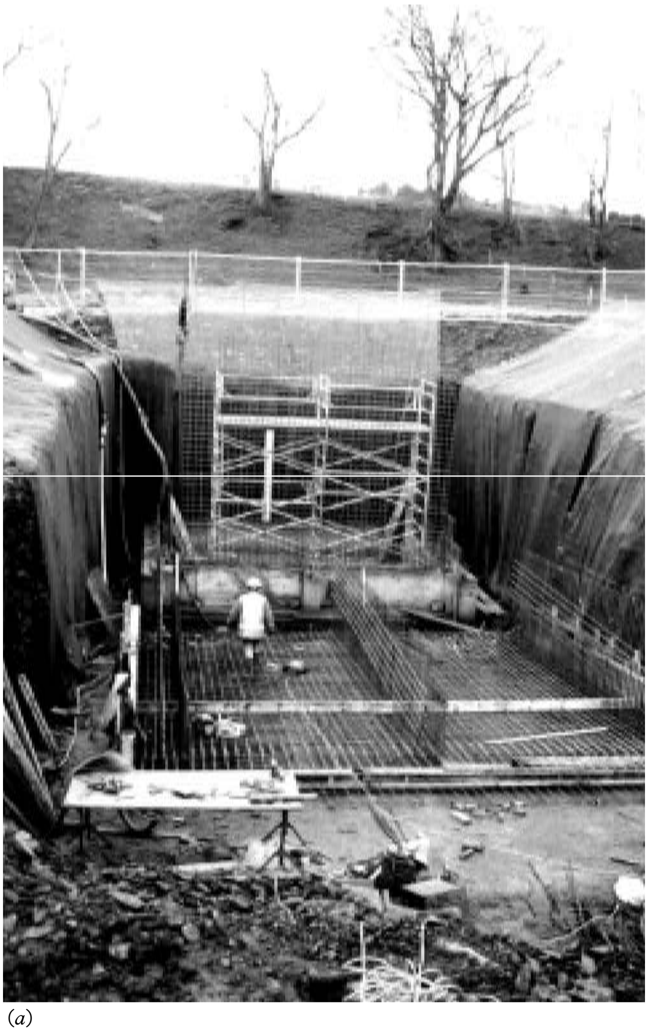
Building works

Construction of both the delivery and return-water pumphouses and the cascade aeration system commenced at Easter, 1998. The initial work was at the raw-water pumphouse, which involved excavation of a sump 6 m deep adjacent to the River Don (Fig. 3(*a*)); this proved difficult because heavy inflows of groundwater were encountered. The contractor employed a large settlement tank to control the discharge quality while the concrete blinding of the base of the excavation was completed, which significantly reduced the volume of inflow.

The underground storage tanks are in reinforced concrete and comprise twin tanks each 15 m in length and 3 m in width. The height of each tank is up to 4 m, with the top of the tanks 2 m below finished ground level. The tanks provide a storage capacity for between two and three hours' inflow of water from the adit and provide a safeguard against overflow of untreated discharges in the event of power failure. The pumping equipment is located below ground level in an adjacent dry well. Since the completion of construction and restoration only the pumping station, constructed in local stone and measuring about 5 m × 5 m, is visible above ground level (Fig. 3(*b*)).

The return-water pumping station is a simple construction that comprises a stone building housing pumps. The storage capacity for these pumps is provided in an existing earth-walled lagoon used as a balancing sump to the pumps. The return water is discharged to the point of abstraction through the return overland pipeline system.

Cascade The inlet system to the lagoon uses the level difference between the rail track and the lagoon to accommodate a



(*a*)

(*b*)

Fig. 3 (*a*) Excavation of raw-water pump sump; (*b*) completed raw-water pumphouse

cascade aeration system that oxidizes the raw mine water. The cascade comprises a 6 m high reinforced-concrete manhole constructed adjacent to the rock face that forms the northern perimeter of the quarry. By alternating the position of internal access hatches on landing stages a simple means of aeration of the mine water is achieved. Consideration also had to be given to the ingress of air into the manhole system, security against unauthorized access and the provision of a means to jet away ochre deposits at regular intervals. The water from the cascade is distributed into the lagoon by twin-wall plastic pipework arranged to spread the flow over the full area of the lagoon. Intermediate manholes allow the research contractor access to measure the water flow and quality or introduce chemical treatment should this be desired.

Mechanical and electrical works

Six identical, 40 l/s centrifugal pumps were purchased to provide an economical and reliable flow from the raw- and return-water pumphouses. Under normal flows (about 2000 t/day) one pump in each direction should be sufficient. Five pumps are installed and available for operation and the sixth pump is maintained as a spare. Flexibility is thus available to switch pumps in unforeseen circumstances and to limit the potential downtime in case of any failure.

The raw-water pumphouse contains two pumps to pass the water into the overland pipelines. A third pump recirculates water in the raw-water storage tanks through submerged jets that create agitation to maintain ochre solids in suspension. This minimizes the build-up of solids in the sump and assists pumping overland to the quarry for settlement. A further advantage of this system is that the turbulence caused also assists in oxidation of the raw mine water and helps to minimize the accretion of solids inside the pipeline.

The return-water pumphouse contains two pumps—one duty and standby—both of which are connected to a single, overland return-water pipeline. The adjacent polishing pond is elevated above the pumphouse and provides a positive flow into the pump suction as well as a flow-balancing element for the return water clarified in the main lagoon. The operation of the systems in both pumphouses is monitored by a PC with data acquisition by radio link. A failure alarm to the maintenance contractor is initiated automatically.

The normal operation of the pumps is to maintain a minimum level of water in the sumps at both pumphouses. This maximizes the available flow-balancing and provides the maximum time to overflow of contaminated water directly into the river in the event of short power failures. Monitoring of the water level in the sumps is linked to the operation of the pumps by an electronic control, which gives the ability to vary the speed of operation and maintain an essentially constant water level.

Operation

Routine monitoring of the system indicated that the Bullhouse system functioned satisfactorily, without a need for chemical dosing, for most of the first year of essentially continuous operation. The River Don rapidly became clean and trout were observed immediately below the discharge. The low pH of the treated mine water was counteracted satisfactorily by the net alkalinity of the River Don. Environment Agency requirements on iron (<1 mg/l) and pH (>6.5) were met consistently downstream of a 200-m mixing zone. The general appearance of the site from the air and local vantage points (in particular, the Trans-Pennine trail) is now in keeping with the general surroundings. The season's growth of planted and naturally propagated vegetation has been successful and wildlife is abundant around the system. The cost of maintaining the 'standalone' operation is, as anticipated, about £50 000/year.

Testwork was carried out to determine the optimal operating conditions. The system could be prevented from overload under adverse conditions by the simple addition of one or two 25-kg bags of caustic soda per day (£10–£20/day) at the pumping sump. Such conditions resulted occasionally from high flow rates after heavy rain—in particular, in October, 1998, and during the following spring, when the ground was saturated. Owing to the design of the pumping system no advantage was to be gained from research-based control of the pumping schedules. Because of the large volume of the lagoon and the success of the inlet injection system the lagoon usually behaves as a fully reacted system. Intensive dosing with caustic soda or hydrogen peroxide at the pumping sump (to prevent accretion in the pipeline) was technically successful, but was expensive and did not offer a clear advantage over conventional pipe-cleaning. Magnesium hydroxide dosing at the polishing pond provided a simple and inexpensive means (if required) of raising the pH before discharge.

The rate of accretion in the pipework was estimated by means of a saddle attachment to the 160-mm pipe at 2–4 mm/month. This rate was modified by partial dewatering, reshaping and hardening (but insignificant structural change) of the deposits during ageing. When the pipework was jetted out after nine months the annular ochre layer was about 2.5 cm thick. Although hydrogen peroxide pre-dosing prevented new accretions in the pipework (thus substantiating theories of direct surface reaction with ferrous iron), the process led to surface hardening of the pre-formed deposit. Detailed modelling of the accretion was precluded by numerous, uncoordinated changes in the flow rate through the pipe.

The accumulation of sediments in the lagoon was studied by depth sampling, mainly within a trench excavated along the northern edge of the lagoon floor. Owing primarily to silt contamination from runoff from slopes adjacent to the lagoon the thickness and quality of the recovered ochre did not give a close match to the theoretical predictions. However, it was clear from deposits obtained from the cascade that the Bullhouse lagoon ochre will eventually be of high enough grade for recovery as a potential source of iron salts, such as ferric sulphate, which might be applied as a water-treatment coagulant.

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