Adit hydrology in the long-term: observations from the Pb-Zn mines of northern England.

P L Younger

Department of Civil Engineering,
University of Newcastle,
Newcastle Upon Tyne NE1 7RU, UK.

ABSTRACT

Early in the life of a deep mine, an adit can serve several important purposes: exploration, ventilation, drainage, access, ore haulage etc. In the mature phase of working at depth, the adit can often be neglected, sometimes coming to represent little more than a convenient saving in pumping head for waters extracted from deeper workings accessed by shafts. In the post-closure phase, however, the adit often resumes major significance as the principal pathway for mine drainage to the environment. Detailed studies have been made of the flows and chemistry of several adit systems draining workings which were abandoned a century ago. All are in similar geological settings (carbonate-hosted Pb-Zn vein deposits of late Carboniferous age), and were all worked by similar methods. However, surprising (and environmentally important) differences between the different adits are observed in terms of both flow behaviour and hydrochemistry. While some differences can be explained by reference to detailed archival records of workings, many are less easy to account for. Taken together with some recent experiences with old adits in working and recently-abandoned tin and gold mines, these studies highlight the value of undertaking pre-closure surveys if it is desired to predict the most likely hydrological role of an adit after mine abandonment.

ADITS PAST AND PRESENT

Adits provide an artificial, highly-permeable hydraulic connection between local subsurface strata and some more distant, lower, base-level of gravity drainage. Several examples of such adits in Europe continue to under-drain mined ground many centuries after their construction. Drainage adits of several hundred metres extension have been commonly used in European orefields for millennia. Davies (1935) documents Roman drainage adits in Spain, Greece and Slovakia, some of which reached lengths as great as 2 km. In Germany, formal drainage cooperatives (*Wassergemeinschaften*) were constructing and maintaining drainage adits as early as the 11th Century (Coldewey and Semrau, 1994). With the advent of gunpowder, adits could be constructed over much greater distances. For instance, in the Ruhr coalfield (Germany) the Schlebuser Erbstollen adit was more than 12km long by the 18th Century (Coldewey and Semrau, 1994). In the tin and copper mining district of west Cornwall, a major drainage adit network known as the County Adit was initiated in 1748, and by 1880 had attained a total drivage length of some 64 km (Buckley, 1992). Most of these old adits continue to flow at high rates, and represent major, permanent modifications of the hydrology of their host catchments. The County Adit, for instance, transmits around 60% of the effective precipitation falling on the overlying surface catchment, with only 40% forming direct surface runoff (Knight Piésold, 1995).

Adit construction has, of course, continued to the present day. One very recent European example is afforded by a new gold mine in northern Spain (Río Narcea, Asturias). The gold deposit is a "skarn" (metasomatised limestone adjoining a granitic intrusion) in which extraction commenced by open-pit methods in January 1997. To avoid eventual groundwater ingress into the open pits when they reach maximum working depth, a bold scheme of dewatering was implemented, in which a 1km adit was driven below the pits, and three inclined boreholes at the forehead of the adit were used to lower the water table by gravity drainage (Figure 1); a steady drawdown of more than 50m was attained in little more than a month. Apart from its drainage function, the adit now provides useful access for exploratory drilling to delineate the reserves at depth, providing the basis for deep-mining in the future. Further auxiliary functions (for ore haulage, ventilation etc) are common to this and most other adits.

Figure 1: Pipework connecting to three inclined boreholes in the forehead of a 1 km drainage and exploration adit, Río Narcea Gold Mine, Asturias, Spain. The inclined boreholes have lowered the water table by 50m in limestones below the current open pit operation, by simple gravity drainage.

Continuation of extraction below adit level requires active pumping to dewater the deeper strata. In this stage of mine development, the original adit can often be neglected, at best functioning as a convenient saving in pumping head for waters extracted from deeper workings accessed by shafts. However, lack of regular man-access through the old adits often results in a lack of maintenance. Although roof falls very rarely result in a total loss of water-passage, they can raise the head sufficiently in the old adit that shaft inset sumps are drowned-out, and continued use of the adit becomes impractical. In such cases, renovation of the adit may be less cost-effective than re-arranging pipe ranges so that it is possible to pump directly to the shaft collar. Hence, the old adit becomes neglected, and often forgotten, until the mine is abandoned and the workings left to flood. At this stage in the mine life-cycle, the old adit can takes on a new lease of life, as the principal gravity discharge route from the mine workings.

ADITS IN ABANDONED MINES

Adit performance during abandonment

Where an old adit has remained an integral part of a mine drainage system even after workings proceeded to greater depth, maintenance will have been maintained and few surprises should be in store after the mine is abandoned and left to flood. However, where the adit has been ignored, the condition of the adit will often be a considerable source of uncertainty in mine abandonment planning. Question which arise include:

- Is the adit sufficiently open that it will drain freely once the head of water in the workings exceeds the adit invert elevation?
- Does the adit contain accumulations of easily erodible sediments / secondary mineral precipitates, which might dissolve and lead to water pollution when the adit begins to flow again?

One example will suffice to illustrate the potential problems implicit in these two questions. Piles of roof-fall debris within an adit can impound water until the driving head is sufficient to cause erosion (probably initially by "piping") of the debris. Catastrophic failure of the debris pile can then lead to a sudden outrush of water from the adit, entraining large masses of suspended solids. This appears to have been the case at Nangiles Adit, Cornwall, on 13th January 1992, when up to 50 Ml of water (previously impounded in the abandoned Wheal Jane Mine) rushed out into the Carnon River in less than 24 hours, entraining an enormous quantity of ochre from the mine walls and floor as it flowed. This led to the infamous propagation of a dramatic red plume in the Fal Estuary, drawing public attention to the Wheal Jane incident (Banks *et al*, 1997), which is widely regarded as the most extreme minewater pollution incident yet experienced in Europe (although this title must now be in question, following the Aznalcóllar Tailings Dam failure in Spain in April 1998). It is interesting to note that the cause of the Nangiles Adit outburst was long held to have been failure of a man-made plug in the portal of the adit. Recent exploration (undertaken by South Crofty plc on behalf of the UK Environment Agency) has revealed no trace of any plug in the portal, but strong evidence for the impoundment of the water behind roof-fall debris (Gatley *et al*, 1998a).

Adit performance in the long-term

There are some adits which retain a major dewatering function throughout the mining history of a given region. This is particularly true of long, deep adits which extend into deep workings by commencing at a distant, low base-level of drainage. For instance the County Adit retained a high flow even when the Wheal Jane and Mount Wellington Mines worked to many hundreds of metres below it. (After closure of Wheal Jane, a modest increase in the flow of the County Adit was observed; a typical analysis of County Adit water is given in Table 1).

Two other UK examples of note include the Blackett Level in Allendale, Northumberland, and the Nent Force Level, Cumbria, both of which drain Pb-Zn mines of the North Pennine Orefield. This orefield has been one of the world's most prolific sources of lead, which occurs in multiple sub-vertical hydrothermal veins, hosted in Carboniferous clastic and carbonate sedimentary rocks (Dunham, 1990). Lesser amounts of zinc, barite and fluorite have also been worked (with 2 remaining mines working the latter two minerals). The Blackett Level portal (Figure 2) lies at an elevation of around 220m above sea-level, and is 7 km from the furthest of the group of lead mines at Allenheads which it dewaters. As the ground surface at the Allenheads mines is around 400m above sea level, the drawdown achieved by the Blackett Level amounts to around 180m. This permanent lowering of the water table essentially removed dewatering expenses from the revenue costs of the mines, ensuring that the Allenheads Mines retained economic potential long after most other mines in the region had closed. Flow and hydrochemical data for the Blackett Level are given in Table 1, from which it may be seen that the Level produces a large flow (around 0.2 $m^3.s^{-1}$) of very good quality water, the discharge of which is beneficial to the receiving watercourse.

Table 1: Average flow ($Ml.d^{-1}$) and chemistry data (all "total in mg/l" except for pH and conductivity (μS/cm)) for selected major adits draining abandoned UK mines.

Adit	County	Flow	Cond	pH	Fe	Zn	Cu	SO_4	HCO_3	Cl
County Adit	Cornwall	34	- -	4.0	8	4.5	1.2	- -	0.0	- -
Blackett Level	Northumberland	10	425	7.6	0.03	0.08	0.015	50	200	28
NentForce Level	Cumbria	2	600	7.5	0.12	3.1	0.002	181	220	12
Eagle Level	North Yorkshire	5	400	7.6	0.09	0.09	--	12.7	193	22
Dolcoath Deep Adit	Cornwall	7	- -	7.0	0.5	0.9	0.1	87	- -	48

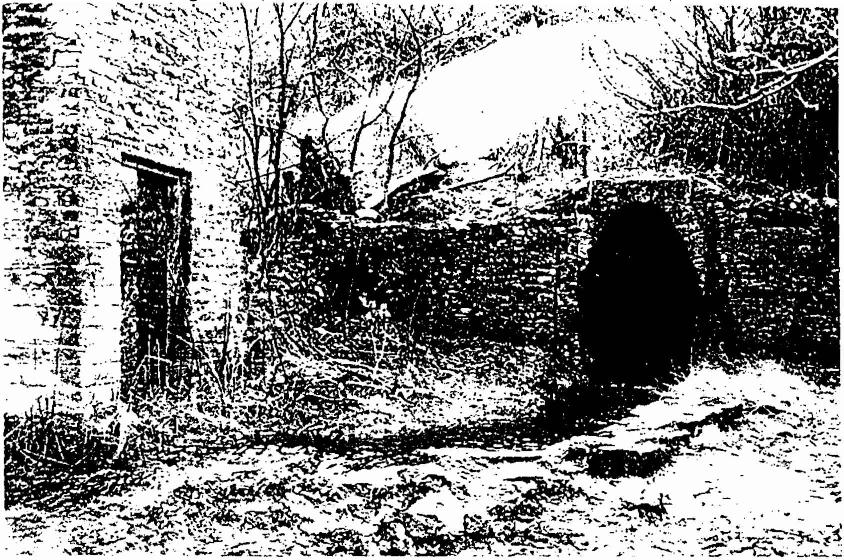

Figure 2: The portal of the Blackett Level, Allendale, Northumberland UK, in 1997. Driven between 1854 and 1896, the level still flows at up to 20 $Ml.d^{-1}$, permanently dewatering mines up to 7 km away.

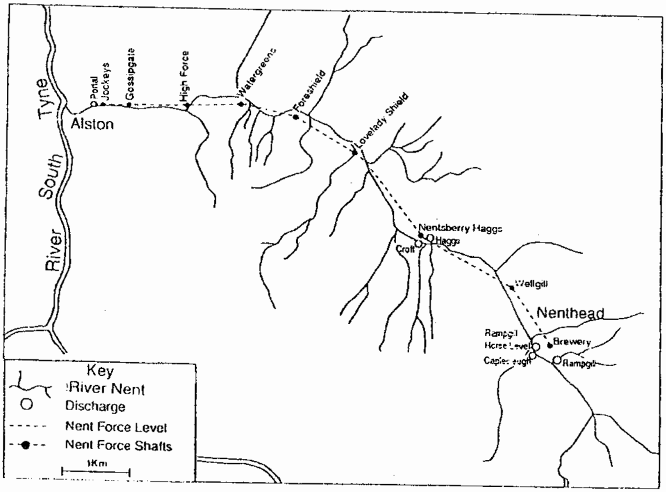

Figure 3: Map of the Nent Valley, Cumbria, UK, showing the surface trace of the Nent Force Level below the valley axis, the locations of air-shafts and access shafts along the Nent Force Level (black circles) and the positions of major adit portal other discharges (open circles) from perched groundwater systems in mine-workings lying above the level of the Nent Force adit.

The Nent Force Level, Cumbria, is almost the same length as the Blackett Level (which it predates by almost 50 years), and it achieves around 200m of permanent drawdown in the Nenthead mines around its forehead (Figure 3). The portal lies at around 300m above sea level near the town of Alston. Table 1 summarises the flow and hydrochemistry of the Nent Force Level, which is in some respects comparable to the Blackett Level, save for the elevated concentrations of zinc in the water. In this respect the Nent Force Level resembles discharges from other mine adits in the catchment (Table 2), the portals of which are marked on Figure 3. (These discharges relate to vadose zone drainage and perched groundwater above the strata dewatered by the Nent Force Level). Though little deep mining has taken place in the Nenthead Mines since 1914 (save for some Witherite extraction at Nentsberry Haggs, which ended in 1952). The zinc yielded by these long-abandoned adits results in serious degradation of the River Nent throughout its length (Nuttall and Younger, 1998).

The lead mines of the Greenhow Hill Orefield, North Yorkshire exploit veins in a similar geological setting to that of the Allenheads and Nenthead mines (Everett, 1997). Six major adits still drain the Greenhow mines more than a century after they were last worked in earnest. With the exception of modest concentrations of ironin the waters of one of the adits ($\leq$ 0.8 $mg.l^{-1}$ Fe in Perseverance Level), these adit waters are all of high quality, being essentially intercepted karst drainage (Everett, 1997). Indeed, until very recently, the adit with the greatest flow (Eagle Level) has been used as a source of public water supply, requiring little more than contact chlorination before the water is put into distribution. (Banks *et al* (1996) describe similar use of lead mine adit drainage in Derbyshire for public supply).

As part of an assessment of the source protection requirements for the Eagle Level, a two-year study of the hydrological behaviour of a number of old adits in the Greenhow mining field has recently been completed (Everett, 1997). Figure 4 shows the rainfall and corresponding adit flow rates over the period of study. It is immediately striking that the Cockhill and Gillfield Adits show a "flashy" response to rainfall, whereas the Eagle Level (and to a lesser degree the Perseverance Level) show fairly constant flow rates, indicating that they are sourced from a large stored volume of groundwater. This difference in response is simply explained by the depth below ground surface of these different adits: All of the adits underdrain Greenhow Hill, the summit of which is around 410m above sea level. The portals of Cockhill and Gillfield Adits lie at 298m and 289m above sea level respectively, whereas the portals of Eagle Level and Perseverance Level lie at 189m and 187m above sea level respectively. Nearly all of the water entering the two deeper adits (Eagle and Perseverance Levels) must first pass through saturated zone storage in the limestone country rock; by contrast, surface runoff which enters karst dolines and mining-induced crown-holes and fractures can flow rapidly into and through the two shallower adits (Cockhill and Gillfield).

Where the unsaturated zone contains sulphide minerals which are prone to oxidation, it is possible for seasonal flushing by rapidly infiltrating rainfall to cause an increase in contaminant loadings. For instance, returning to the example of the Nent Valley (Figure 3, Table 2), it is clear that some of the shallower adit systems (Haggs, Caplecleugh and Rampgill Horse Level) have higher zinc concentrations than the deeper systems (eg Nent Force Level). It has also been observed that zinc concentrations are higher when adits flows are highest (in response to winter rains and snowmelt), indicating a "vadose zone flushing" response (ie removal of sphalerite

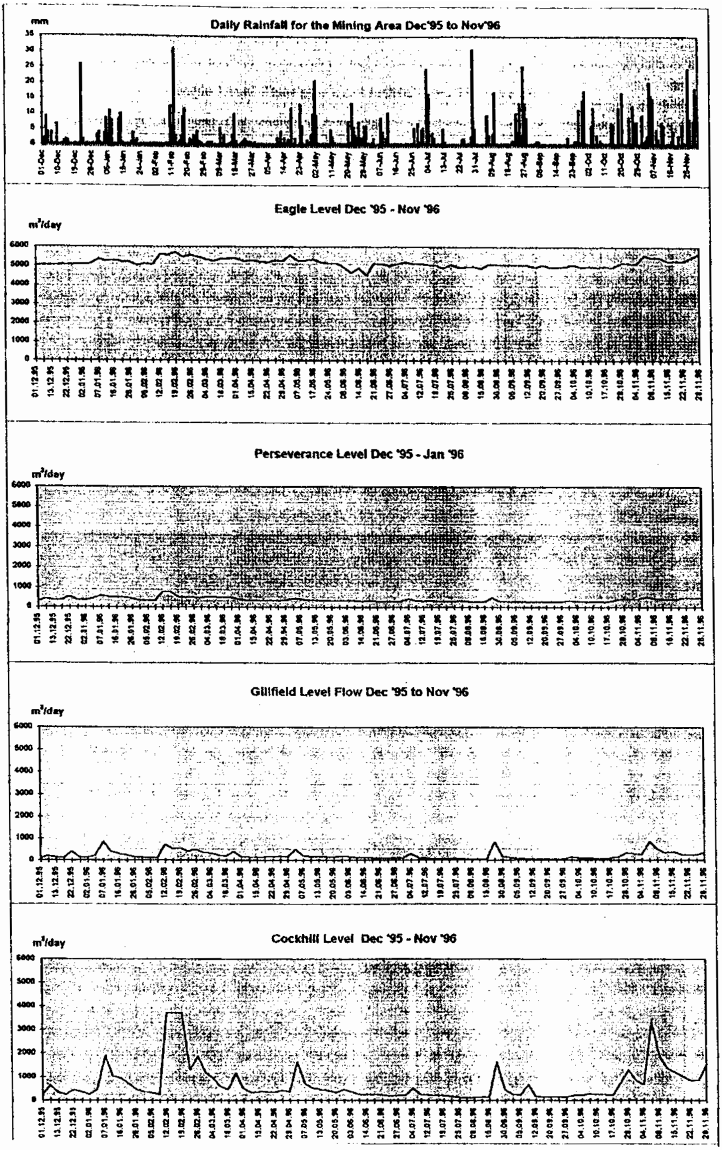

Figure 4: Rainfall and adit discharge records for the Greenhow mining area, North Yorkshire (after Everett, 1997). (The flattened peaks on the Cockhill record represent times when the flow depth exceeded the range of the depth logger).

Table 2: Summary of Flows and Selected Hydrochemical Parameters for Adit Discharges in the Nent Valley, Cumbria.

Adit Name	Nent Force	Haggs	Croft	Rampgill Horse Level	Caplecleugh Horse Level
Flow (l/min)	1650	230	380	350	1000
pH	7.1	7.5	7.4	7.5	7.5
Hardness (mg/l as $CaCO_3$)	335	395	242	299	302
Fe (μg/l)	121	181	136	1796	206
Zn (μg/l)	3063	7783	1307	7090	6868
Pb (μg/l)	5.4	4.1	4.0	190	47
HCO_3 (mg/l)	220	217	218	146	180
SO_4^{2-} (mg/l)	181	250	71	163	163

oxidation products by infiltrating water) rather than the dilution effect that might otherwise have been expected (Nuttall and Younger, 1998).

There is one further aspect of the transience of adit discharge quality which is worthy of note here: This is the tendency for adits carrying ferruginous waters to periodically release a large slug of suspended ochre (ferric hydroxide / oxyhydroxide). These events are sometimes termed "ochre outbursts" in the Pennines. They arise as follows: Over a period of many years, ochre precipitating in the adit can accumulate to such depths that it begins to impound the water in the adit. When the mass of impounded water eventually exceeds the retaining strength of the ochre mass, spontaneous failure can occur, allowing a temporary surge of water from the adit as the storage is depleted. This surge of water carries fragments of ochre from the former impoundment out of the portal into the receiving watercourse. UK adits known to periodically give rise to ochre outbursts include the following: Dowgang Colliery (Nent Valley, Cumbria), Old Meadows Colliery (Lancashire; D Laine, personal communication), Black Clough Colliery (Lancashire; M Thewsey, personal communication), Garth Tonmawr Colliery (South Wales; P Edwards, personal communication). No doubt many more examples exist.

IMPLICATIONS FOR ABANDONMENT PLANNING

When planning the abandonment of deep mines, old adits in the shallowest parts of the workings resume an inordinate importance in terms of the long-term control of minewater discharge. As the examples in this paper show, the long-term functioning of adits can be beneficial (eg Blackett Level and Eagle Level), innocuous (eg Gillfield and Cockhill Adits) or environmentally damaging (eg Nent Valley adits, County Adit etc). When explaining your mine closure plans to regulatory authorities, it is of immense value to be able to state categorically which of these three roles the adit connected to *your* workings will have. For this reason alone, it may be worthwhile retaining limited access to old adits throughout the period of active working, so that all uncertainties can be removed before the mine is finally allowed to close. As a final example, during the preparations for closure of South Crofty tin mine, Cornwall (which finally occurred in April 1998) access to the Dolcoath Deep Adit (Gatley *et al*, 1998b) proved to be indispensable to the following tasks:

(i) developing a clear understanding of the pathways deep mine waters will eventually follow to the surface after rebound is complete
(ii) ascertaining that the shallowest workings do not contain soluble, acid-generating salts waiting to be dissolved when the deep mine waters enter them
(iii) proving that shallow minewater quality is good, and
(iv) allowing precautionary adit-clearing works to ensure that there are no dangerous build-ups of water behind piles of debris when the rebounding waters reach adit level.

With a clear perspective of the possible long-term behaviour of the adit systems, rational planning of mine closure is relieved of a major source of uncertainty.

ACKNOWLEDGEMENTS

I would like to think Charlotte Nuttall and Shirley Everett for their hard work, which yielded much of the Nent and Greenhow respectively, and also for drawing Figures 3 and 4 respectively. Charlotte's work is funded by the UK Engineering and Physical Sciences Research Council and the Environment Agency, and Shirley's by Yorkshire Water Ltd. The photo reproduced as Figure 2 was taken by Aidan Doyle, and Figure 1 was taken by the author whilst a guest on the property of Río Narcea Gold Mines S.A.. I am grateful to Prof Fernando Pendás of the School of Mines, Oviedo, for arranging that visit. For the data relating to Wheal Jane, the County Adit and South Crofty Mine I am indebted to the Environment Agency, to whom I acted as an External Technical Review Consultant on their Cornish minewater projects from 1994 - 1998. I would like also to record my gratitude to, and admiration for, Steve Gatley, Mark Owen and Chris Rogers, who took the trouble to reveal the splendours of Dolcoath Deep Adit to me at a time of great stress and sadness during the closure of Cornwall's last tin mine. Finally, I am eternally grateful to Adam Jarvis for not losing his head in Mayne's Shaft.

REFERENCES

Banks, D., Younger, P.L., and Dumpleton, S., 1996, The historical use of mine-drainage and pyrite-oxidation waters in central and eastern England, United Kingdom. Hydrogeology Journal, 4, (4), pp. 55 - 68.

Buckley, J.A., 1992, The Cornish Mining Industry - A Brief History. Tor Mark Press, Penryn. 48pp.

Coldewey, W.G., and Semrau, L., 1994. Mine water in the Ruhr area (Federal Republic of Germany). In: Proceedings of the 5th International Mine Water Congress, Nottingham, UK, 18 - 23rd September 1994. Volume 2: 613 - 629.

Davies, O., 1935, Roman Mines in Europe. Clarendon, Oxford. (Reprinted 1979 by Arno Press, New York). 291pp.

Dunham, K.C., 1990, Geology of the Northern Pennine Orefield, Volume 1 Tyne to Stainmore (2nd Edition). *Economic Memoir of the British Geological Survey*, sheets 19 and 25, and parts of 13, 24, 26, 31, 32 (England and Wales). HMSO, London. 299pp.

Everett, S.A., 1997, The Hydrogeology of the Greenhow Mining Area and its Relationship with the Eagle Level Water Supply. Unpublished M.Phil. Thesis, Department of Civil Engineering, University of Newcastle, UK. 188pp.

Gatley, S.T., and Owen, M., and Rogers, C., 1998a, Nangiles Adit Inspection. Unpublished Report by South Crofty plc to the Environment Agency, Exeter. 7pp plus appendices and plans.

Gatley, S.T., Owen, M., Rogers, C., and Boon, R., 1998b, Dolcoath Deep Adit. Report on its condition and the South Crofty Mine decant location. Unpublished report of South Crofty plc, Pool, Cornwall. 18pp plus appendices and plans.

Knight Piésold and Partners, 1995, Wheal Jane Minewater Study. Environmental Appraisal and Treatment Strategy. Report to the National Rivers Authority South Western Region, Exeter.

Nuttall, C.A., and Younger, P.L., 1998, Reconnaissance Hydrogeochemical Evaluation of an Abandoned Pb-Zn Orefield, Nent Valley, Cumbria, UK. Proceedings of the Yorkshire Geological Society (*in review*).