The abandonment of Wheal Jane, a tin mine in South West England.

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ABSTRACT

Early in 1991, Wheal Jane, a tin mine in South West England, was closed and the mine void began to fill. Generation of acidic, metal-rich drainage water was predicted and there were concerns that environmental contamination would occur unless adequate treatment was provided. Investigations and monitoring were undertaken, and predictions were made of the location, time, quantity and quality of the discharge. Predictions of location and time were accurate but those of quantity and quality were less precise.

INTRODUCTION

Early in 1991, Wheal Jane, one of the few operational tin mines remaining in England, was closed and the dewatering pumps removed. It was recognised that problems of environmental contamination would occur when the mine overflowed, unless adequate treatment was provided. A programme of investigations and monitoring was carried out to provide information on which rational management of the problem could be based. This paper describes the background to the problem, the programme of investigations and the circumstances which led to the adoption of a suitable contingency plan.

BACKGROUND

Location

Cornwall, in the South West of England, was an area of intense metal mining activity. The majority of mines were small, shallow and operated for a short time. Since the 1960's, the industry has been maintained by few, relatively deep mines, of which Wheal Jane was one. It is situated in the Carnon valley near Truro, the county seat (Figure 1).

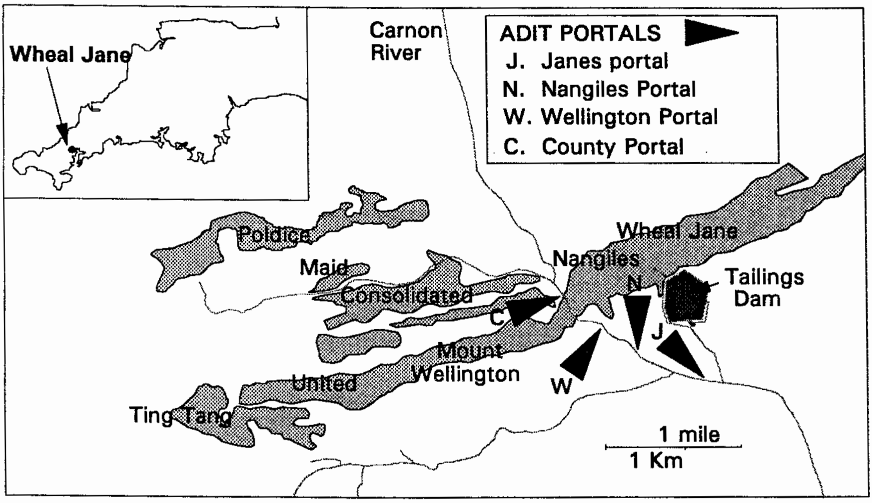


Figure 1. Map showing mining district, river, Wheal Jane & significant adits.

Geology

Wheal Jane was the last of more than 50 mines to operate in the Gwennap Mining District, an area with a rich mining history dating back to at least the 17th century. These mines were developed to exploit minerals associated with quartz porphyry dykes, intruded into the Killas mudstones during a period of regional metamorphism associated with the emplacement of the Cornish granite batholiths. The main mineral lodes exploited by Wheal Jane trend approximately SW/NE and dip at approximately 45 degrees to the north west. Typically, they include the minerals cassiterite (tin), chalcopyrite (copper), pyrite (iron), wolframite (tungsten) and arsenopyrite (arsenic). Silver, galena and a number of alteration minerals also occur in lesser amounts.

Hydrogeology

The Killas rocks in the vicinity of Wheal Jane have low primary porosity. However, fractures, faults (cross courses) and weathered zones provide storage and allow limited groundwater flow. In general, the groundwater table away from mined areas forms a subdued replica of the surface topography with locally steep hydraulic gradients. These rocks provide small yields and support a few wells, boreholes and springs which supply cottages and small farms.

In mined areas, the low permeability of the Killas rocks contrasts with the high, conduit flow permeability engineered by mine workings. The mine workings, therefore, provide a preferential flow route for groundwaters. Dewatering of Wheal Jane has occurred to 450m depth, resulting in a cone of water table depression. The precise extent of the cone has never been identified. However, the low permeability of the Killas rocks would have resulted in steep hydraulic gradients away from the dewatered mine workings, thus restricting its extent.

Hydrology

The majority of mine workings associated with Wheal Jane underlie and drain to the Carnon catchment. The Carnon River drains through one of the most intensively mined areas in Cornwall, discharging into Restronguet Creek and then the Carrick Roads. The majority of the Carnon Valley has been heavily disturbed by mining development, with large reaches of river channel worked on a number of occasions for alluvial metals. The flow characteristics of the Carnon River are influenced by surface drainage, recharge of mine workings and subsequent lag in mine water discharge from adits. The largest adit is the Great County Adit which discharges to the Carnon River upstream of Wheal Jane. This adit is thought to be up to 30km in total length, draining a large area of mine workings to the north west beyond the surface boundary of the catchment.

Historical River Water Quality

Prior to closure of Wheal Jane, water quality in the Carnon River was generally poor, with high concentrations of many metals, and acid conditions in the lower reaches. The County Adit is a significant source of copper, zinc and iron. The Wellington Adit also discharged to the river but contributed much smaller loads than did the County Adit. Wheal Jane discharged to the Clemows Stream, a tributary of the Carnon River. Although some treatment was provided, it was a significant source of zinc and cadmium. Other sources, particularly of arsenic, occurred further downstream.

INVESTIGATIONS

On closure of the mine in March 1991, dewatering ceased and the mine was stripped of equipment, including all pumps. The extensive mine void began to fill, and a large surface area of oxidised minerals was now exposed to groundwater leaching.

Concerns were expressed that, once the mine void was flooded, a significant discharge of poor quality water would drain from the mine and impact upon the Carnon River and tidal waters in Restronguet Creek and the Carrick Roads. It was believed that some form of treatment would be required to limit such an impact so, to facilitate suitable planning, a programme of investigations and monitoring was commissioned. This was designed to provide predictions of the location, time, quantity and quality of the discharge, and (not discussed here) of the possible impact on private groundwater supplies, river and tidal water quality. The programme included:-

Mine System and Mine Waters

- A detailed mining survey to identify all mine workings, interconnections, adits, mineral variations, underground structures etc., relevant to the future mine drainage of the flooded mine;
- A water level survey of mine shafts throughout the Wheal Jane mine system and adjacent workings to identify hydraulic connections and appropriate monitoring points;
- Measurement of rise of mine water levels in six appropriate shafts across the mine system;
- Collection of mine water samples from varying depths, (bottom, middle and top waters) in three main shafts across the mine system; and
- Continuous depth profile measurement of water quality in top waters at the three main shafts.

Groundwaters

- Survey and measurement of groundwater levels in boreholes, wells, and shafts (not interconnected with Wheal Jane), to identify the zone of groundwater depression from mine dewatering;
- Survey of private and licensed groundwater sources of supply; and
- Baseline sampling of water supplies at risk from rising mine waters. (In association with Carrick District Council's Environmental Health Department.)

Surface Waters

- Baseline water quality and flow surveys of the Carnon River and its tributaries;
- Continuous flow monitoring at selected sites; and
- Continuous water quality monitoring at selected sites.

Estuary Waters

- Baseline surveys of quality in Restronguet Creek and the Carrick Roads.

RESULTS

The information obtained from these investigations and monitoring was regularly reviewed during the period of mine flooding and the programme modified as appropriate.

Assessment of the mine water discharge location

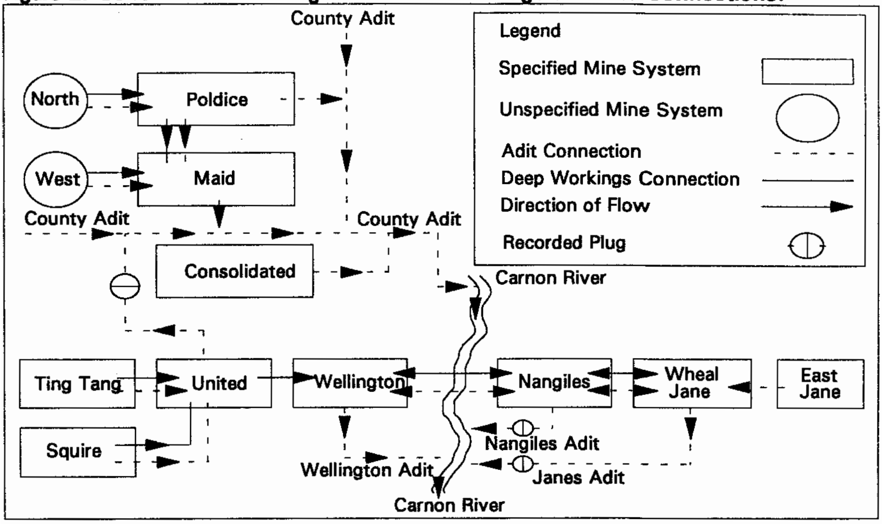
The mining survey identified a complex picture of interconnections between a number of individual workings and adit systems, Figure 2 shows a schematic diagram of the likely mine drainage connections.

Monitoring of water levels across the mine system showed that Wheal Jane, Wellington and United workings were hydraulically well connected, flooding at the same rate. The lowest decant point was identified as the Wheal Jane adit, estimated at a level of 14 to 15m Above Ordnance Datum (AOD). However, the main mineral lode had been worked to within a few metres of the bed of the Carnon River at an elevation of about 15m AOD and there remained a potential for direct discharge to the river by diffuse seepage. The next decant point at Nangiles Mine was believed to be at 16 to 17m AOD elevation.

Assessment of the mine water discharge time

A graph of the mine water rise at one of the main shafts monitored is presented at Figure 3. Early recovery was rapid, but soon slowed and became irregular, presumably due to the varied filling time for voids at different levels. The flooding rate was considered to be related to the volume of workings and recharge from groundwaters. As the mine flooded the groundwater gradient into the mine reduced and, therefore, the rate of recharge from groundwater was expected to decrease. Also, it was known that at Wheal Jane, the volume of interconnected workings increased higher in the mine due to the number of extensive shallow old mines.

Figure 2. Schematic Flow Diagram of Mine Drainage and Interconnections.



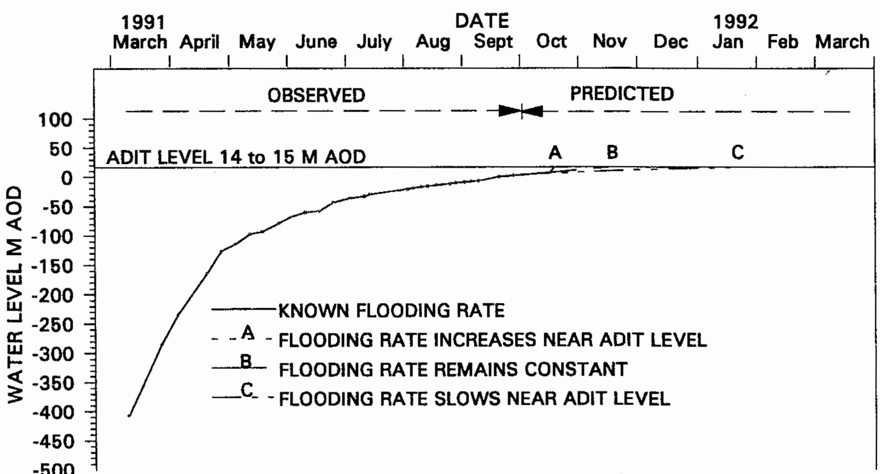


Figure 3. Recovery At Wheal Jane Number 2 Shaft.

M AOD = Metres above Ordnance Datum

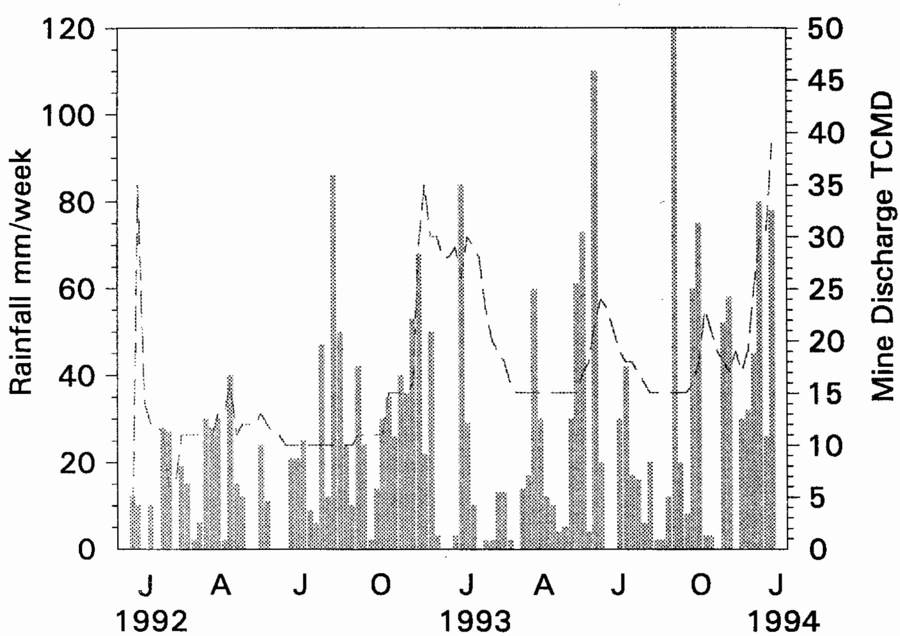
Towards the end of mine flooding the recovery was slow. In early October 1991, it was predicted that if the flooding rate remained constant, discharge would be within six to seven weeks. Discharge occurred on the 17th November 1991 from the Wheal Jane adit into the Carnon River. The monitoring and survey work had successfully identified the discharge location and approximate time.

Assessment of the mine water discharge quantity

Wheal Jane is connected to a large number of unsurveyed 18th century workings and it was not possible to predict accurately the discharge flow from rate of rise and workings volume calculations. Therefore, a preliminary water balance was undertaken, projecting the known workings to surface to define a recharge catchment.

Water balance calculations using long term average recharge data predicted a mine water discharge of between 5,000m³/d and 20,000m³/d. The actual discharge since flooding has been recorded between 5,000m³/d and 40,000m³/d. Figure 4 shows a graph of total mine water discharge between January 1992 and January 1994, compared with rainfall. The flow is closely related to rainfall events although a lag exists of up to one month between rainfall event and peak flow.

Figure 4. Mine Water Discharge and Rainfall.



Assessment of the mine water discharge quality

Surface samples collected regularly from the rising mine waters in six shafts across the mine system identified widely fluctuating levels of acidity and dissolved metal concentrations. These were considered to be as a result of variations in mineral deposits and exposure, and complex patterns of mine water flow.

To provide a better understanding of the variation in mine water quality, regular depth sampling and depth profile monitoring was also undertaken. Samples were taken using a flow through bailer to a depth of up to 180m below water level at three main shafts across the mine system. The results for pH and selected metals at Wheal Jane number 2 shaft are shown in Table 1. In general, water quality was found to deteriorate with depth within Wheal Jane, with samples from depth being very acidic with high concentrations of dissolved metals. Better water quality was observed close to surface and waters sampled in United Mines were of much better quality. A multi-probe water quality meter, modified to allow monitoring to depths of up to 10m, was also used to identify water quality variations near surface. Results are in Table 2. No consistent pattern emerged. On some occasions there were declines with depth in dissolved oxygen saturation, pH and conductivity but on others, quality was consistent throughout.

Table 1 Variations in Water Quality With Depth During Recovery at Wheal Jane

1991		pH	Cu mg/l	Zn mg/l	Fe mg/l	Cd mg/l	Hg μg/l
5 July	Top	3.7	4.5	98	94	0.1	0.06
	Middle	2.6	40.0	1379	1846	2.6	0.52
	Bottom	2.5	44.0	1541	2162	4.8	0.01
9 July	Top	-	17.5	550	878	0.8	0.23
	Middle	-	47.8	1457	2050	2.5	0.18
	Bottom	-	47.0	1510	2160	2.4	0.25
16 July	Top	3.5	8.4	220	292	0.4	0.001
	Middle	2.6	43.5	1460	2030	2.9	0.002
	Bottom	2.6	38.2	1480	2070	2.9	0.002
23 July	Top	5.0	0.8	43	4.5	0.1	0.29
	Middle	3.2	24.5	1080	1350	2.0	0.69
	Bottom	2.5	36.3	1600	2010	3.0	<0.05
30 July	Top	5.0	0.7	50	10	0.1	0.25
	Middle	2.4	32.6	1880	2270	3.1	0.14
	Bottom	-	3.0	190	156	0.3	<0.05
10 Sept.	Top	2.9	5.8	2000	2400	3.4	0.03
	Middle	2.9	6.8	2000	2400	3.4	0.09
	Bottom	2.9	5.7	2000	2450	3.4	0.05
16 Oct.	Top	3.6	1.4	600	590	0.9	3.94
	Middle	3.0	3.5	1800	2170	2.8	3.29
24 Oct.	Top	3.3	2.6	1075	4170	1.7	<0.02
	Middle	3.2	3.9	2430	2370	3.0	0.03
5 Nov.	Top	6.0	0.8	65	1.9	0.1	<0.02
	Middle	3.7	5.8	44	2240	2.6	<0.02

Table 2. Variations in quality in surface layers during recovery at Wheal Jane.

Date	Depth (m)	DO (%)	T (°C)	pH	Cond. (μS/cm)
10 September 1991	0.0	17.5	18.5	2.87	8710
	0.5	11.9	18.4	2.86	8470
	1.0	10.0	18.5	2.85	8320
	1.5	9.0	18.6	2.84	8270
	2.0	8.0	18.6	2.83	8190
	2.5	6.6	18.6	2.84	8160
	3.0	5.7	18.5	2.83	8150
	3.5	5.1	18.6	2.84	8120
	4.0	4.7	18.7	2.83	8090
	4.5	5.8	18.7	2.84	8080
	5.0	7.3	18.5	2.85	8080
	7.5	7.9	18.6	2.83	8150
	10.0	8.3	18.5	2.84	8190
1 October 1991	0.0	47.0	12.9	4.10	4710
	0.5	48.0	12.9	4.10	4720
	1.0	45.0	12.8	4.10	4620
	1.5	8.5	16.0	3.13	5480
	2.0	5.9	16.3	3.07	5490
	2.5	6.7	17.9	2.82	6550
	3.0	3.5	18.3	2.80	6690
	3.5	3.0	18.4	2.78	6680
	4.0	2.7	18.5	2.77	6660
	4.5	2.6	18.5	2.78	6690
	5.0	2.2	18.6	2.77	6730
	7.5	2.7	18.5	2.78	6830
	10.0	4.4	20.5	2.77	6960
23 October 1991	0.0	3.1	10.8	3.04	1326
	0.5	1.6	10.9	3.03	1342
	1.0	1.4	10.9	3.03	1299
	1.5	2.3	10.9	3.03	1312
	2.0	2.7	10.9	3.03	1303
	2.5	2.0	10.9	3.03	1295
	3.0	1.5	10.9	3.03	1322
	3.5	1.2	11.0	3.02	1309
	4.0	1.2	11.0	3.02	1309
	4.5	1.0	11.0	3.02	1303
	5.0	0.8	11.0	3.01	1297
	7.5	0.9	11.0	3.02	1304
	10.0	0.9	11.0	3.02	1319
13 November 1991	0.0	80.0	10.0	6.15	650
	0.5	74.6	10.1	6.68	710
	1.0	74.2	10.2	6.67	800
	1.5	74.2	10.2	6.22	700
	2.0	78.7	10.3	5.85	1070
	2.5	75.8	10.3	5.90	1320
	3.0	69.3	10.4	5.36	1380
	3.5	68.0	10.4	5.04	1810
	4.0	66.0	10.5	4.90	1800
	4.5	63.0	10.5	4.85	1780
	5.0	63.0	10.5	4.90	1800
	7.5	70.0	10.5	4.84	1580
	10.0	72.0	10.5	4.89	1570

Mine water circulation was considered to be complex, possibly controlled by a combination of recharge, temperature gradient, density variation, and hydraulic mechanisms. Accurate prediction of the discharge water quality was not possible, although a likely range was identified. The actual quality of the discharge was better than the worst water quality monitored but still was very acidic and high in metals.

DISCUSSION

There were three main difficulties associated with this early stage of the work at Wheal Jane - operational, technical and organisational. Information was limited and it proved difficult to obtain sufficient data to allow the use of sophisticated predictive models. Underground access was denied, quite rightly, on health and safety grounds, which meant that further surveys of decant levels, connections and the poorly recorded voids were impossible. Frequent loss of sampling apparatus due to entanglement with debris in the main shaft curtailed the programme of assessing water quality changes as the water approached the surface.

As a consequence, our understanding of the changes in flow and chemistry during filling was limited. Simple conceptual models were created and, as additional data became available, were modified appropriately or rejected. However, the predictions of discharge quantity and quality were imprecise. In the design and costing of a suitable treatment plant, both these factors are essential. It was fortunate that the initial discharge was relatively small and of reasonable quality. The crude treatment system which had been devised was adequate to deal with the problem in the short term.

Overlying these problems was the major difficulty of the principal players being unsure of the framework in which they were operating. The National Rivers Authority (NRA) is a regulatory body, not set up to deal with or to fund an enormously costly operation, the responsibility for which was unclear. The mining company believed that its responsibility was negligible but wished to take what steps it could to assist the NRA. The protection of the environment was paramount and, in the short term, this was achieved by successful negotiation between all the parties concerned.

CONCLUSIONS

The problem at Wheal Jane is huge and complex, and had in the early stages a number of operational, technical and organisational difficulties. Nevertheless, with the programme of investigations described here, it was possible to predict with reasonable accuracy some of the effects of mine abandonment, which allowed suitable contingency measures to be introduced.