THE DESIGN, CONSTRUCTION AND COST OF AN ENGINEERED WTELAND FOR TREATMENT OF ACID DRAINAGE FROM SULPHIDE MINERAL-RICH STRATA

Peter J Norton, Christopher J Norton and Wavell Tyrrell*

Peter J Norton Associates, "Caladh", 10 St Nicholas Close,
Richmond, North Yorkshire, United Kingdom, DL10 7SP.

*Forest Enterprise, 21 King Street, Castle Douglas,
Dumfries and Galloway, Scotland, DG7 1AA.

ABSTRACT

In 1995 serious water pollution occurred downstream of a roadstone quarry excavated into sulphide-rich, low-grade metamorphic slates in an area of low-grade gold bearing rocks. The water was very acidic with pH 3.2 and contained toxic levels of Aluminium, Iron, Nickel, Zinc, Copper and Lead. En engineered wetland has been constructed in difficult mountainous terrain in Scotland which includes an experimental SAPS (Successive Alkaline Producing System) and four anaerobic wetland cells. The temptation to "over engineer" the wetlands has been avoided in this instance and the cost of the whole system of groundwater diversion, drainage and wetlands has been about £24/square metres ($39/sq.m.) of treatment area for labour and materials.

INTRODUCTION

Craigenbay Quarry is operated by Forestry Enterprise to provide a high quality roadstone for forestry roads in Scotland, The black, low-grade metamorphic slates are fissile and highly suitable as the final running course layer of the roads, The excavated rock is also sulphide-rich and in an area of minor gold-bearing strata with occasional veins of copper, lead and zinc ores which have been commercially exploited nearby.

The groundwater table in the area is high and issues permanently from the excavated faces in the quarry with the flow increasing rapidly during periods of rainfall. Analysis has shown it to be acidic with pH 3.2 and contaminated with toxic metals. In 1995 serious pollution levels were recorded about 1 kilometre downstream of the quarry in Shaws Burn which flows into Clatteringshaws Loch.

The paper describes the remedial measures taken to alleviate the pollution. This entailed diversion of surface waters and prevention of water gaining access to the sulphide-rich strata, re-designing the quarry for the next 30 years production and the construction of passive water treatment facilities in the form of anaerobic wetland cells and an experimental SAPS (Successive Alkaline Producing System).

Cost was an important factor and was kept to a minimum by not over-designing the treatment facilities as has been the case in many other recent projects.

SOURCE OF POLLUTION

The quarry lies at a height of 280m on the southern flanks of Bennan mountain about 2.5 kilometres to the north of the Cairnsmoor of Fleet granite pluton in folded and slightly metamorphosed slates of Ordovician and Silurian age (see Figure 1). Mineralization from the granite and metamorphism of the originally sulphide rich black shales has given much of the strata a high sulphur content.

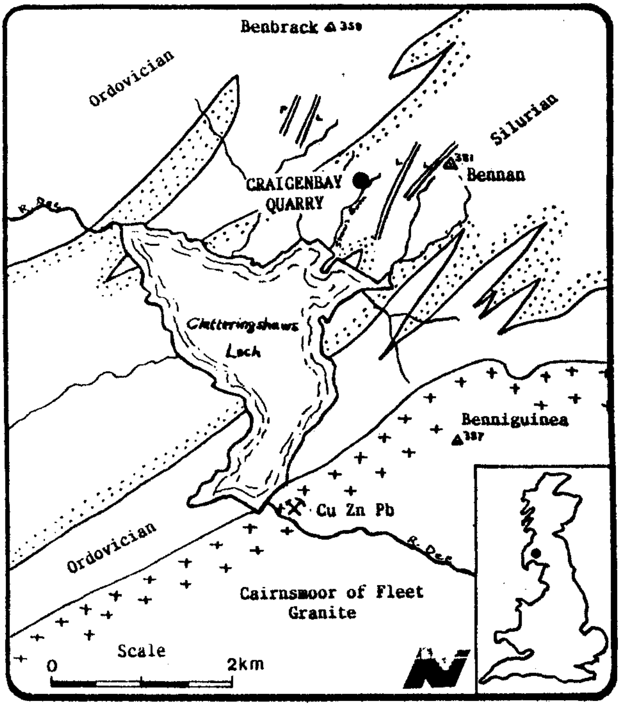

Figure 1. Location of Craigenbay Quarry Project

An assay of the strata revealed that the majority of the sulphur content is in pyrite which may be finely disseminate throughout the rock or in quartz-pyrite veins which are prevalent in the quarry. Larger veins up to 10 centimetres in width contained up to 41% S. The mineral assemblage in the samples were typical of the gold-bearing strata found in the Southern Uplands of Scotland and contained about 0.2 mg/kg Au. There were also large volumes of Fe, Al, Ti, K and Ca. Minor traces of As, Pb, Zn, Cu, Ni, Mn and Cr were also found.

Frequent folding, faulting and intrusive dykes of diorite, lamprophyre and porphyrite all occurring in a predominantly north-east, south-west direction appear to control the local groundwater flow. The strata above the quarry is covered by a deep peat bog which acts as a reservoir of surface water (see Figure 2). Otherwise the strata is close to the surface and the high annual rainfall of about 1900 mm runs straight off the mountainside in rapidly flowing burns (streams). The monitored groundwater table in the excavated faces of the quarry rises and falls between 262m in periods of drought and 278m in prolonged periods of rainfall in winter.

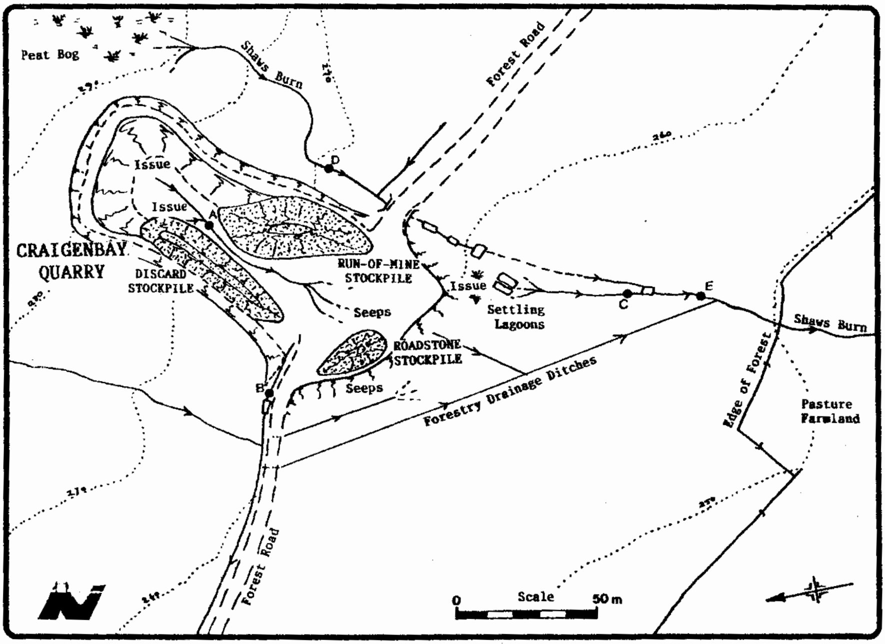

Figure 2. Situation prior to quarry re-design and treatment

Groundwater was also issuing from immediately below the quarry from close to the base of the stockpile of roadstone which was found to be a further source of pollution as the black slates in the stockpile has more opportunity to weather, oxidise and provide a source of AMD.

The groundwater issues and streams were gauged with V-notch weirs and the observed polluted groundwater flow from the quarry and the immediate area was estimated to be between zero and 50 gallons per minute (gpm) or 0.18 litres/second. As the groundwater volumes were relatively low it was therefore decided to allow for treatment of a volume of 50 gpm.

WATER QUALITY AND QUANTITY

Water Quality

Regular sampling of the water in the streams below the quarry and groundwater issuing from strata exposed by the excavations have been taken since September 1995 by Forestry Enterprise and the local office of the Scottish Environmental Protection Agency (SEPA). The locations of the sampling points are shown in Figure 2 and the average results to date are shown in Table 1 below :

LOCATION (See Figure 2)	pH	Fe	Al	Mn	Pb	Zn	Cu	Ni
GROUNDWATER :								
A. Quarry Face	3.81	2.4	6.5	1.1	<0.01	0.02	<0.01	0.27
B. All Quarry	3.37	13.4	21.1	1.6	<0.01	0.03	<0.01	0.51
C. Settling Lagoon	3.25	24.0	88.9	18.4	<0.04	0.80	0.8	1.9
SURFACE WATER :								
D. Shaws Burn	5.95	0.1	0.8	0.01	0.01	<0.01	0.8	<0.01
E. Shaws Burn	3.88	4.4	12.9	3.2	0.01	0.01	0.22	0.35
PRESCRIBED LIMIT	5.0	2.0	0.2	0.05	0.05	0.50	3.0	0.05

TABLE 1. Water analysis results (in parts per million)

As can be seen, the groundwater after passing through the sulphide-rich strata, issues as very acid (down to pH 3.2 on occasions) and polluted with several "List 2" heavy metals and also with Al and Fe. The Al content is surprising and can only be attributed to the sedimentary nature of the original euinic black shales prior to metamorphism.

The worst pollution source has consistently been from the area around the settling lagoons and it was considered that the stockpiles of weathered roadstone and run-of-mine shales were the origin. Also the made-up ground of similar discard material down-slope of the quarry was considered to contribute to the problem. It was decided to remove them prior to construction of the wetlands to prevent further pollution.

Prior to the discovery and treatment of the problem the polluted water found its was to Shaws Burn which eventually drains into Clatteringshaws Lock after passing through pasture farmland with grazing upland cattle and sheep which used the Burn for watering. Clearly water treatment facilities were needed. It was decided to opt for passive wetland treatment as the cheapest, most environmentally acceptable method of improving the quality of the water rather than relying on the more expensive and environmentally unacceptable methods using chemical treatment such as with lime.

Water Volumes

Ascertaining the flow of groundwater has been difficult as the rainfall and surface flow in the area is so variable and unpredictable. V-notch weirs were placed strategically in the quarry issues and below the settling lagoon sources of polluted water and also in Shaws Burn upstream and downstream of the pollution event. In this way a crude value of ground water flow was calculated to be in the order of 50 gallons per minute on average throughout the year.

WETLAND DESIGN

Assuming that there would be some dilution of the pH with neutral surface waters then it was expected that the water entering the wetlands would be, at worst, pH 4. Using the standard design formula devised by the United States Bureau of Mines (USBoM); if the pH is 4 then the wetland area required is equivalent to the Fe load in grams per day divided by 55 it was calculated that about 1500m^2 to 2000 m^2 of anaerobic wetland area would be needed for treatment. The greater area made allowance for extra treatment of the Al and heavy metals.

As the water was still so acid and estimated to contain on average 60 ppm Al it was also decided to build a Successive Alkaline Producing System (SAPS), again pioneered by USBoM, to raise the pH and to hopefully remove some of the Al prior to the water entering the wetland cells.

The most difficult problem in the construction was the steep and very variable terrain. It was difficult to find 10 m^2 of flat land let alone 2000 m^2. Although there were areas of flat boggy land about 500m away from the quarry it was felt that it would be best to treat the water as close to the source as possible to avoid creating any further pollution with any further excavation elsewhere in similar sulphur-rich strata.

The final design is shown in Figure 3 below and incorporates an SAPS system and four wetland cells. The siting of the individual wetlands was complicated by the terrain hence the length of connecting channels.

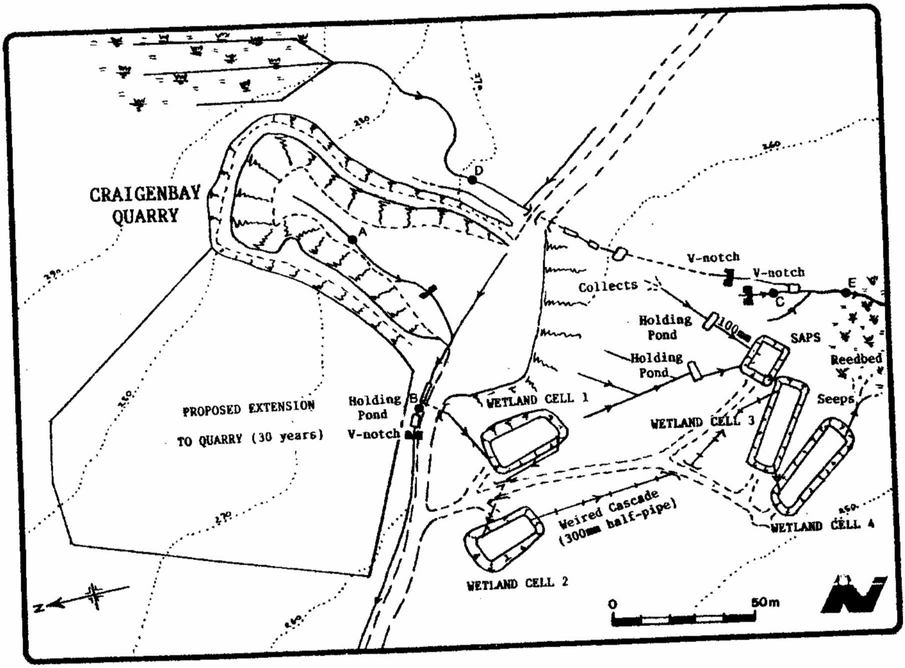

Figure 3. Final design wetland

Work on construction was commenced in late summer of 1997. Fortunately, a variable quantity of impermeable clay was found underlying some of the area designated for the wetland and this was taken to line the base of each cell. The ground was very uneven and, due to the thinness of the soil and peat, it was occasionally necessary to excavate into rock to maintain a gradient of 3% for the base of the cells.

A layer of 95% pure limestone (-40 mm size) was the spread to a depth of 15 cm over the base to aid initial raising of the pH. This was followed with a minimum of 1.0 m of a mixture of soil and peat to provide the organic material for growth of the bulrushes (typha latifolia) which were planted at 0.5m spacing. Thus a typical anaerobic wetland environment was constructed and flooded with surface water and rainfall so that the bulrushes had an opportunity to grow to maturity by summer 1998 (see Figure 4).

In early summer 1998 the remaining earthworks and construction of channels, wires and pipes were completed. The total cost of the project has been £ 33,200 ($55,000) for 1371 m^2 of active treatment area or about £24 / m^2 ($39 /$m^{2)}$

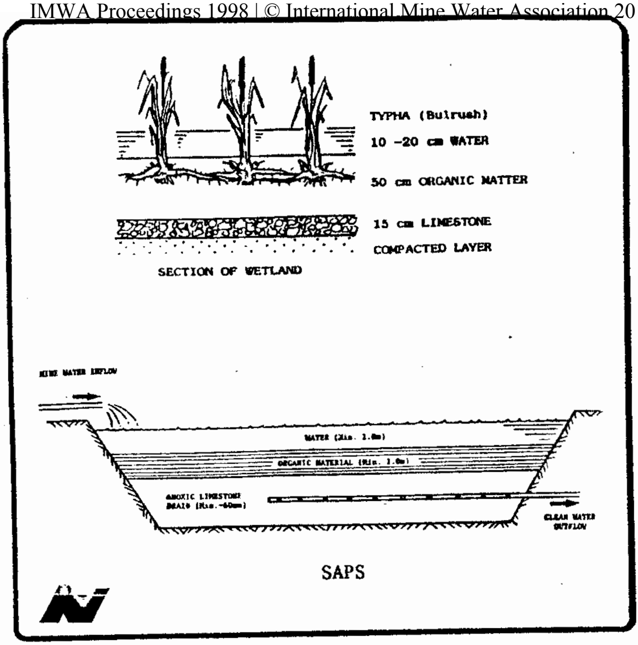

Figure 4. Design of wetland construction and Successive Alkaline Producing Systems (SAPS)

As can be seen from Figure 3 wherever possible holding lagoons above the wetlands and the SAPS were constructed to settle any solids and also to retain water for periods of drought. Four cascades about 400 mm in height were included in the long channel between wetland cells 2 and 3 to aid oxidation and promote precipitation of Fe and Al.

The water from the settling lagoon area had to be dealt with in a special manner. Firstly, the lagoons were filled in with impermeable material and drainage ditches dug to collect water from the vicinity. This was lead into the experimental SAPS system via a 100 mm pipe to control the volume, with the buried outlet pipe from the system passing into the base of wetland cell 3 controlled by a valve in order to monitor performance.

The final outlet from Wetland 4 is lead into a naturally occurring reed bed for final "polishing" before the treated water eventually enters the downstream watercourse. In the meantime alternative pure water supplies have been found for the farms below the quarry.

In order to reduce the source of groundwater flowing into the quarry it was also decided to drain the reservoir of water contained in the peat bog uphill of the excavation. A series of drainage ditches as shown in Figure 3 were dug to achieve this.

The polluted water from the quarry and the old settling lagoon area will be gradually allowed to flow into the wetland during the summer of 1998 and the situation regarding quantity and quality of water closely monitored.

CONCLUSION

The cost of £24/m^2 for the project is considered to be good value for money, allowing for the acidity of the water and compared to similar projects elsewhere which, in the authors opinion, have been increasingly over-engineered in recent years.

The essence of wetland technology is that it is a cheap, aesthetically pleasing and environmentally acceptable passive method of treating acid mine drainage when compared to expensive and environmentally unacceptable methods using chemical treatment. The situation of Craigenbay has potential application elsewhere in base metal mining, especially in gold and copper bearing strata, where many operators require quick, reliable and inexpensive solutions to their acid drainage problems.

ACKNOWLEDGEMENTS

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