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Remediation schemes to mitigate the impacts of abandoned mines

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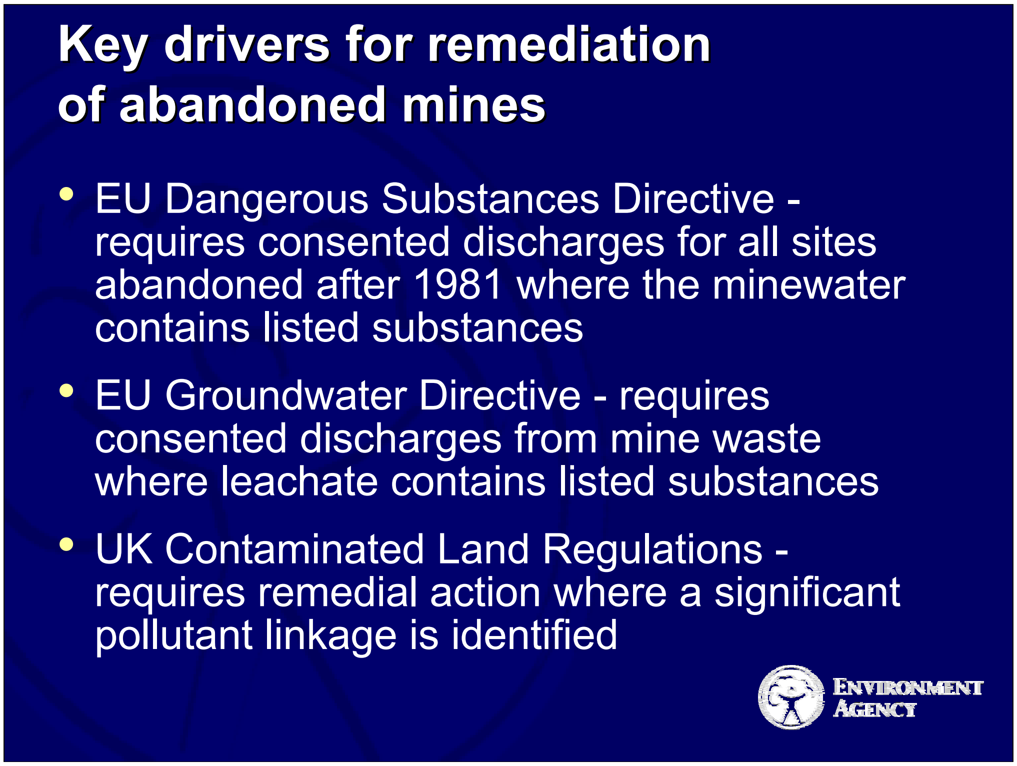
The UK has a long history of mining, from copper mining in the Bronze Age through to a peak in the 19th Century and general decline over the last 100 years.

The main environmental problem associated with abandoned mines in the UK is derogation of water quality by minewater released from underground workings and mine waste & spoil.

Presentation aims & content

- "To illustrate the approach to remediation in England & Wales through 3 case studies"
- Remediation drivers
- Remedial strategy case studies:
  - active treatment of minewater
  - passive treatment of minewater
  - stabilisation of tailings
- Conclusions

This presentation will discuss the key drivers for remediation in England and Wales and illustrate the development of remedial strategies through three case studies.



Brief description of the current legislative drivers in the UK - 2 European and one national.

Future drivers

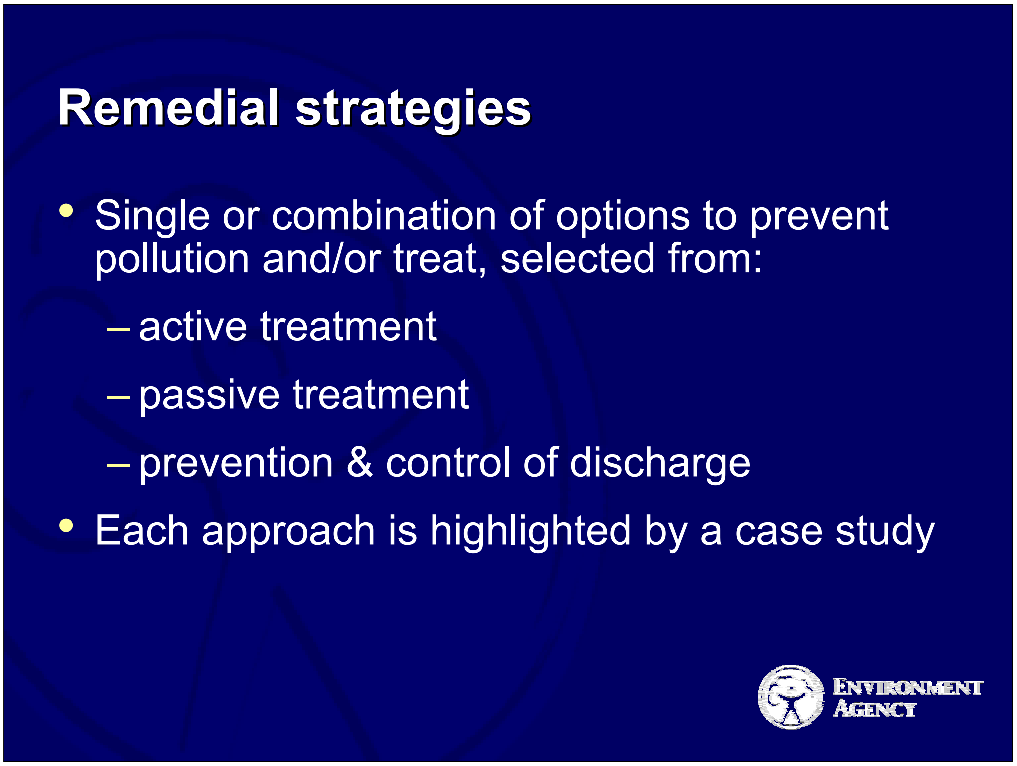
- EU Water Framework Directive - consolidates a number of directives, including the dangerous Substances and Groundwater Directives. Environmental objectives will need to be set for ALL water bodies in terms of chemical and ecological quality.
- Future EU Mining Wastes Directive - will require exchange of technical information on best available techniques with a view to developing methods to identify and remedy "closed waste facilities"

Water quality in many formerly mined catchments is dominated by minewater discharges from groundwater, and spoil leaching

Areas impacted by non-ferrous metal mines include Cornwall, mid-Wales, Anglesey (north Wales), south Shropshire and the north Pennines.

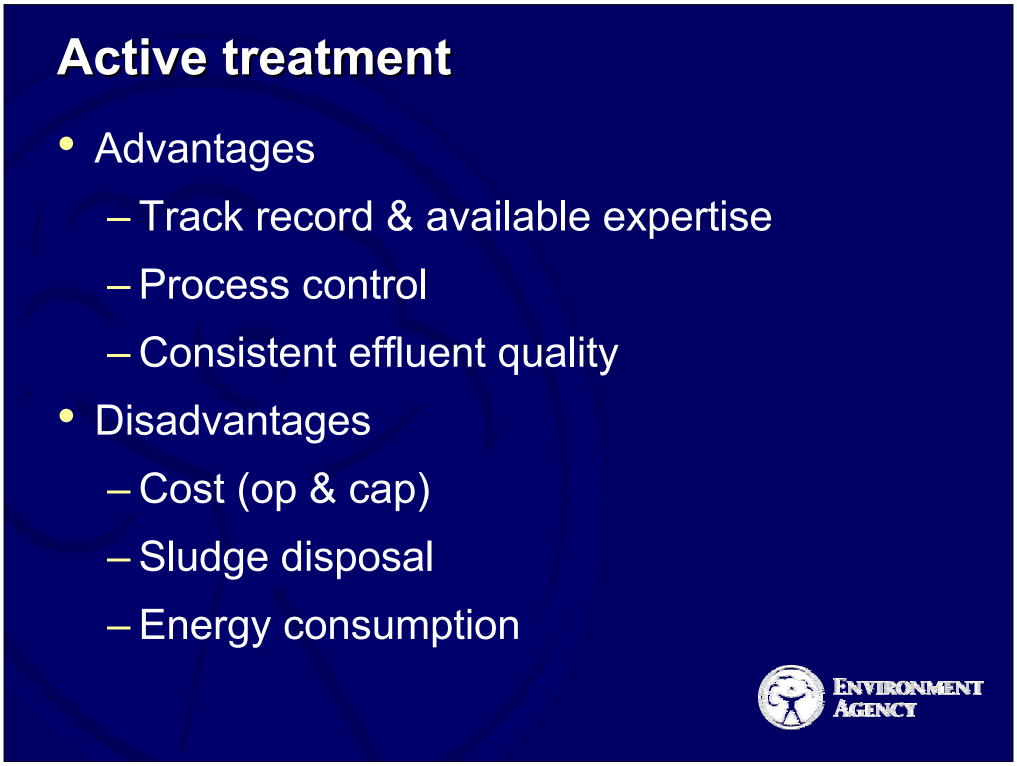
The WFD will require chemical and ecological objectives to be set for each water body. However, diffuse pollution requires creative regulation and innovative approaches to remediation due to the difficulties associated with treatment at source

Proposed directive on management of mining waste has retreated from requiring the identification and remediation of closed waste facilities, but will require an exchange of technical and scientific information between member states with a view to developing methods to identify, classify (according to their impact on human health & the environment) and rehabilitate closed waste facilities. Each member state is to ensure that the competent authority follows or is informed of best available techniques.

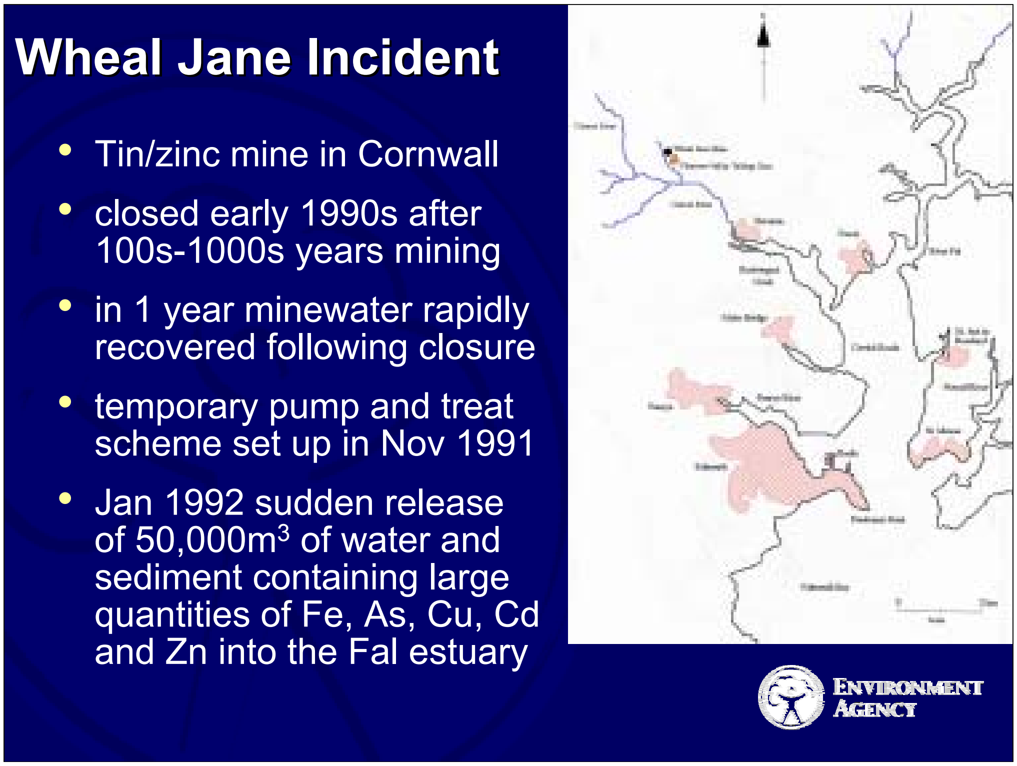


Remedial strategy will involve one or a combination of measures based on an understanding of the site characteristics and knowledge of treatment options available. This may require a multi-disciplinary approach including input from engineers, geochemists, hydrologists and microbiologists.

The selection of a remedial strategy will usually be made on the basis of both technical and economic considerations, including metal loading, land availability, capital and operating costs, and remedial criteria (e.g. water quality objectives).



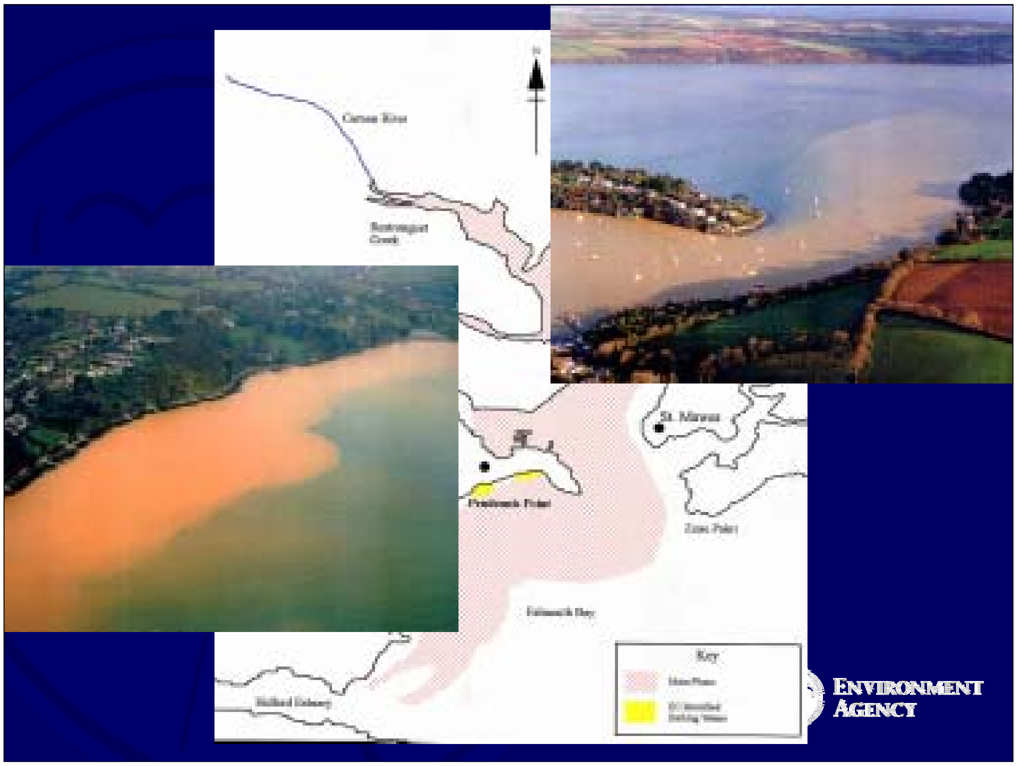
Active treatment - treatment methods that involve the use of external, man-made energy and high management & maintenance to perform a treatment operation. For minewater treatment the main method involves pH adjustment and chemical precipitation. Active treatment is usually considered where metal loading is relatively high.



A temporary active lime-dosing treatment system was set up in Nov 1991 to deal with rebounding minewater (pH ~3) after closure, but this system was overwhelmed when a discharge started from Jane's Adit, rising to about 5,000 m^3/day. A plug was formed in Jane's Adit to prevent discharge and treatment continued to manage the rise in minewater level.

The treatment sludge was pumped to the tailings dam for disposal. Treatment was suspended in December due to high winds and turbidity in the discharge from the tailings dam. The minewater level continued to rise until 13 January 1992 when a sudden release of an estimated 50,000m^3 of minewater with around 100te of suspended and dissolved metals occurred from Nangiles Adit. The sudden release is thought to have been caused by a roof collapse in the adit system - forcing water out and now acting as a throttle to discharge.

The released minewater contained in excess of 3,500 mg/l of dissolved heavy metals, primarily Fe, Zn, Cd, As and Al. The Zn and Cd Environmental Quality Standards (EQS) for the Carnon River at Devoran Bridge (Zn 500ug/l and Cd 1ug/l) were exceeded by 900 and 600 times respectively. The pH of the river at Devoran Bridge dropped from 5.1 pre-incident to around 3 associated with peak metal concentrations. The Environmental Quality Standard for pH is 6-9 (95% of samples).



Ecological impacts of the incident?

Carnon River was already badly impacted by historical mining (adit and spoil discharges) - no fish and few benthic invertebrates to kill!

Fal Estuary is of high conservation value:

coral-like maerl attracting rare fauna/flora

correlation of benthic communities (absence/wealth) with heavy metal concentrations - historical

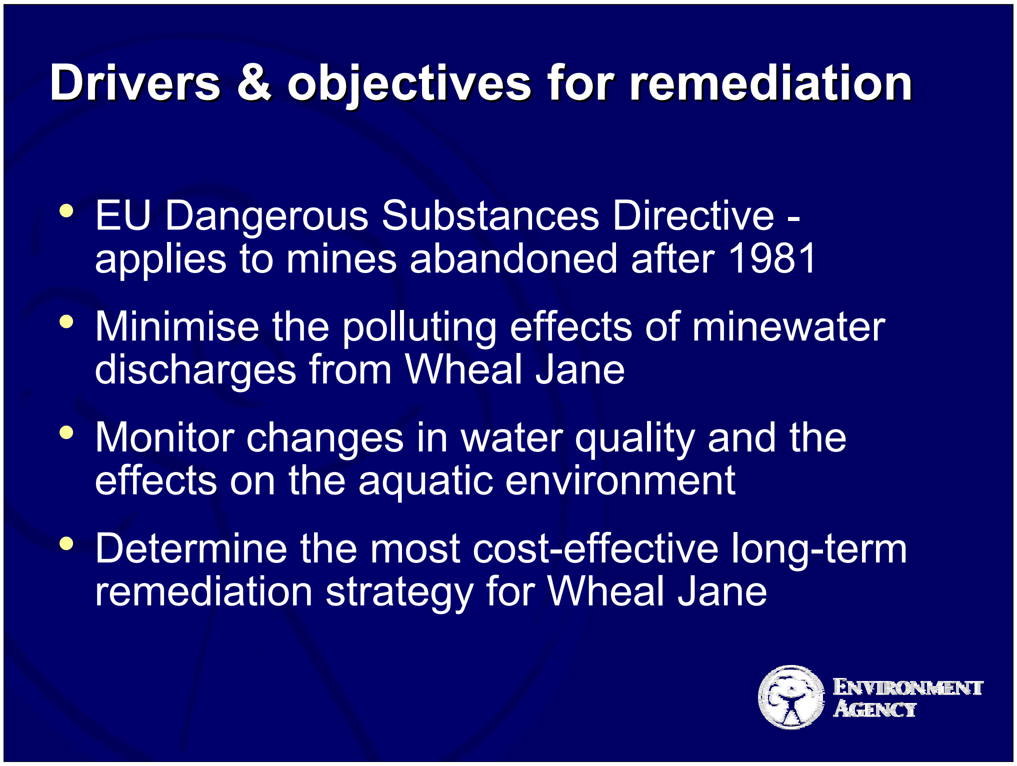
protected metal-tolerant species incl. seaweeds and Couch's goby

swan mortalities 1992-95 attributed to toxic metals, but may not be sole cause

Public outcry as a result of the highly visible plume developed along Restronguet Creek and into Falmouth Bay. Within a few month the discoloration dispersed.

Current Wheal Jane water quality: pH ~3.5, Fe ~300mg/l, Zn ~76mg/l,

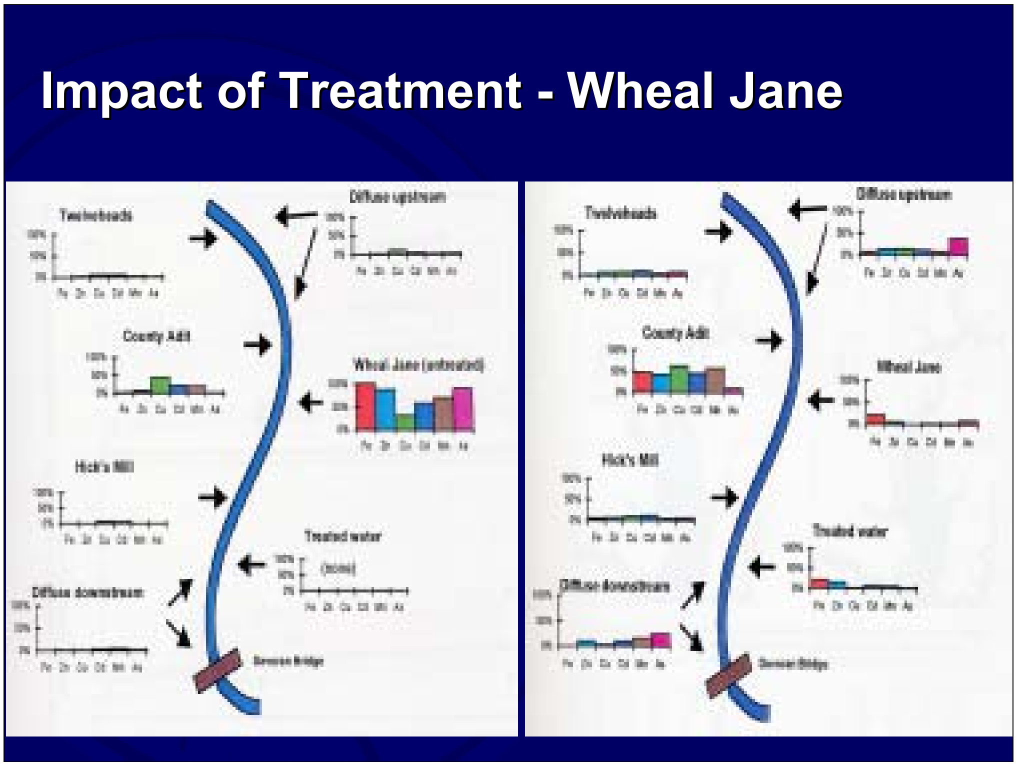
Mn ~10mg/l, As ~6mg/l, Cu ~ 1mg/l, Cd ~50µg/l, sulphate ~1,000mg/l



The remediation strategy identified two key components:

(1) an active treatment system to minimise the impact of discharges from Wheal Jane; and

(2) a pilot system to assess its feasibility as a longer term solution

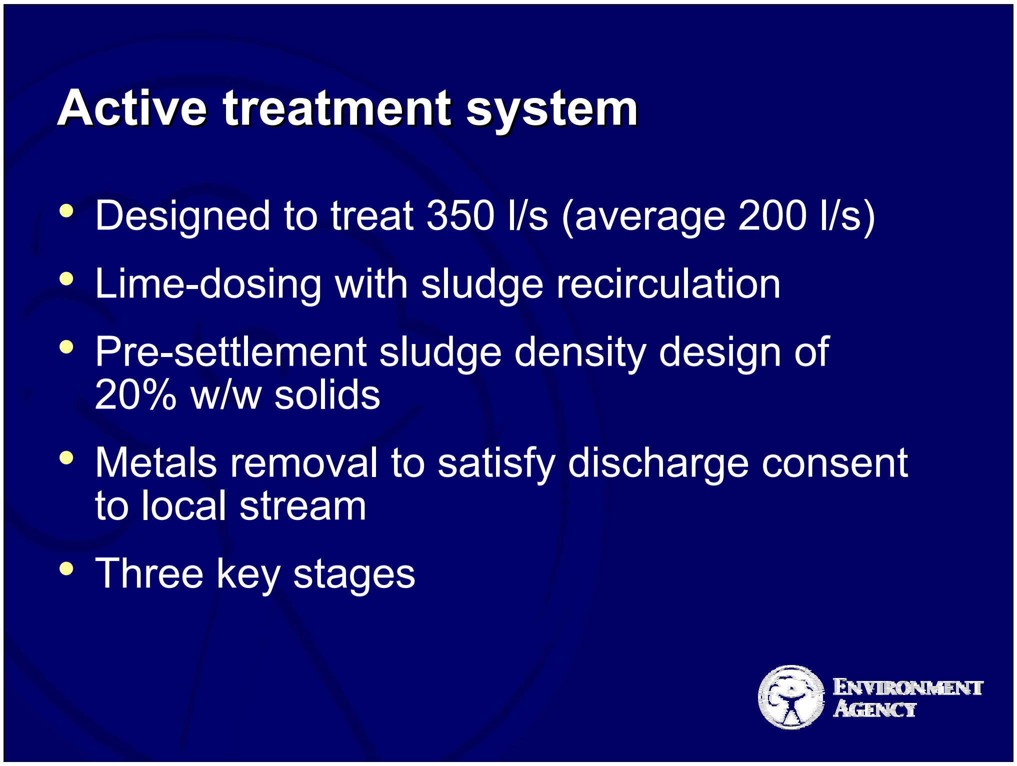


Relative contaminant loading (in % of total) from a number of sources along the Carnon River using an integrated model of the Carnon catchment

Note the significance of the untreated Wheal Jane drainage from modelled impact. Before treatment the Wheal Jane discharge represented the most significant loading of most metals to the Carnon River. Treatment has reduced the significance of the WJ discharge, although still significant for Fe, and highlighted the importance of County Adit for most metals and diffuse sources (waste spoil) for As.

Active treatment Water Quality requirements

Parameter	Influent	ST Consent	LT Consent	Av effluent (22 mnths)	
pH	3.5	6-10	6.5-10		EQS
Fe mg/l	200	5.0	5.0	0.81 mg/l	1
Zn mg/l	50	20	2.5	0.19 mg/l	0.5
As mg/l	3	0.5	0.1		
Cu mg/l	0.8	0.3	0.08		
Cd mg/l	0.06	0.04	0.04		
Mn mg/l	6.0	7.0	1.0	0.31 mg/l	
Al mg/l	23	13	10		



A significant review of the feasibility of a range of active and passive options was carried out and the likely output against a number of treatment scenarios modelled. A system based on lime-dosing and sludge densification was selected to treat up to 350l/s of the pH~3.5 minewater.

System designed to precipitate metals as (oxy)hydroxides by pH adjustment, separate the precipitated metals from water, thicken the sludge for disposal on adjacent tailings dam, and discharge treated water to stream.

Stage 1 reactor. Addition of minewater (large pipe - pH~3.5) AND recirculated sludge to neutralise (pH 6-8) and precipitate (oxy)hydroxides. Sufficient agitation to keep precipitates in suspension - retention time 30 minutes.

Provision for lime addition, but this has not been used.

Stage 2 reactor. Lime slurry addition to pH ~9.25 (controlled at 9.15-9.35 to ensure Mn limits are achieved) and vigorous agitation - retention time 30 minutes. Air blowers introduce air and impeller breaks up the coarse bubbles, increasing the oxygen transfer rate by around 300%.

Slurry is then mixed with a flocculant and passed through a clarifier with lamellar plates to increasethe effective surface area and promote settlement of the solids. The solids settle to the base and are either pumped to the tailings dam or recirculated to the Stage 1 reactor (automaticallyvaried in response to flow of minewater). The treated water overflows and is discharged to stream via a V-notch.

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Active treatment system - summary

- State-of-the-art active treatment plant commissioned in 2000, cost £20M to build and operate for 10 years
- High density sludge system is very successful, solid content of 50% w/w achieved in tailings dam
- Tertiary filters & presses not needed - saving £1.7M
- 1st 22 months of operation >12 Mcu.m of water treated and >3200te of metals removed (overall removal efficiency 99.2%)

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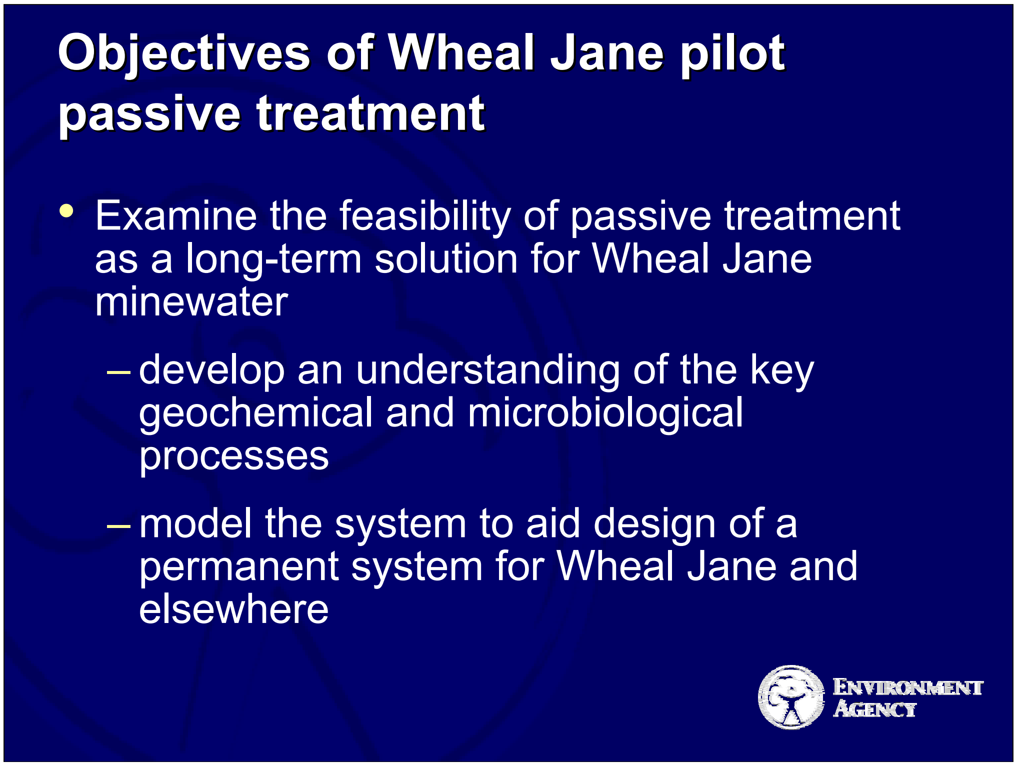
Cost for design, commissioning and 1st 10 years operation around £20M. Sludge density of 50% w/w solids achieved in tailings dam - saving around £1.7M in costs of further dewatering (tertiary filtration & pressing). 70% w/w solids could be achieved by pressing if long-term strategy requires off-site disposal of sludge.

Dam capacity is available for several decades - estimated now at 50 years due to the density of sludge achieved.

Future strategy wrt other sources & legislative drivers?

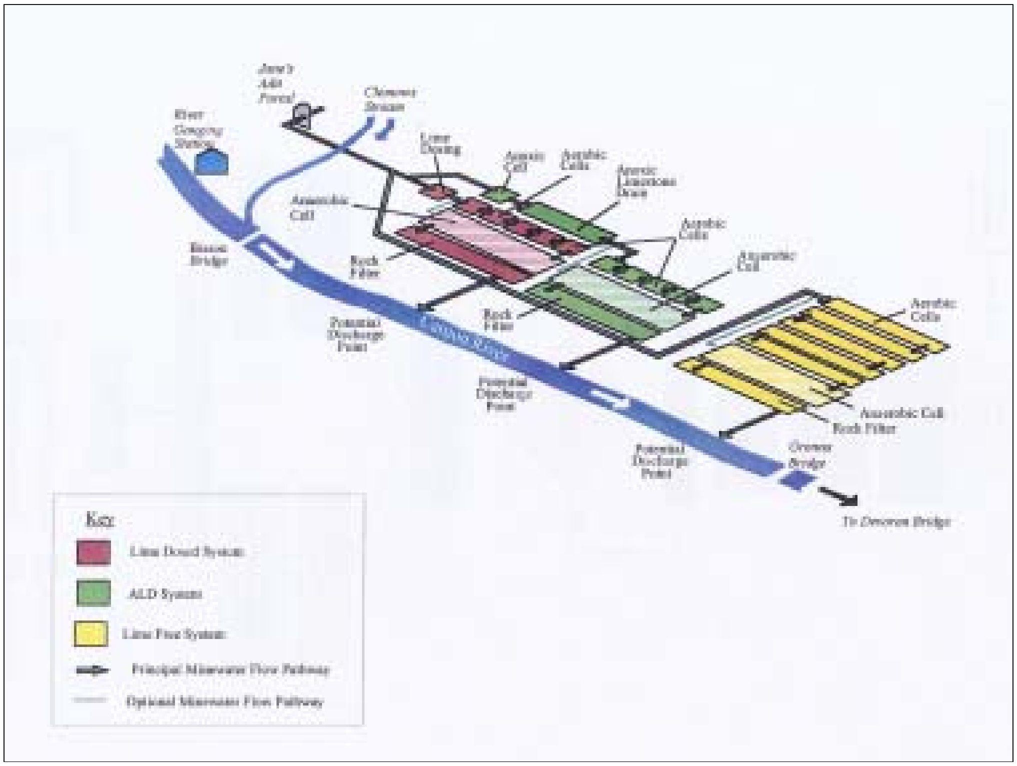
Passive treatment is where treatment is carried out utilising only natural sources of energy (e.g. gravity, microbial metabolism) in systems that require infrequent maintenance. Note: this is NOT a no-maintenance option. Passive systems are traditionally considered to b appropriate for relatively low metal loadings.

Potential "hidden" cost of passive systems - decommissioning - such systems have only been used in the UK since 1994.



The traditional assumptions about the limitations of passive systems re metal loading are being challenged by investigating the potential to more efficiently use the land available at Wheal Jane to passively treat the discharge in the longer term. The pilot system was commissioned in 1993 and operated for about 5 years, looking primarily a the hydraulics and geochemistry f the system and characteristics of the accumulated sludges. In addition, from 1999, a consortium of UK universities has researched the geochemistry and microbiology of the system in detail to increase knowledge of how such systems work.

The system was designed to treat acid discharge (pH3) with key metals Fe (100mg/l), Zn (80mg/l), Mn (20mg/l) and As (2mg/l) under design flow of <1l/s with or without pre-treatment to raise the pH.



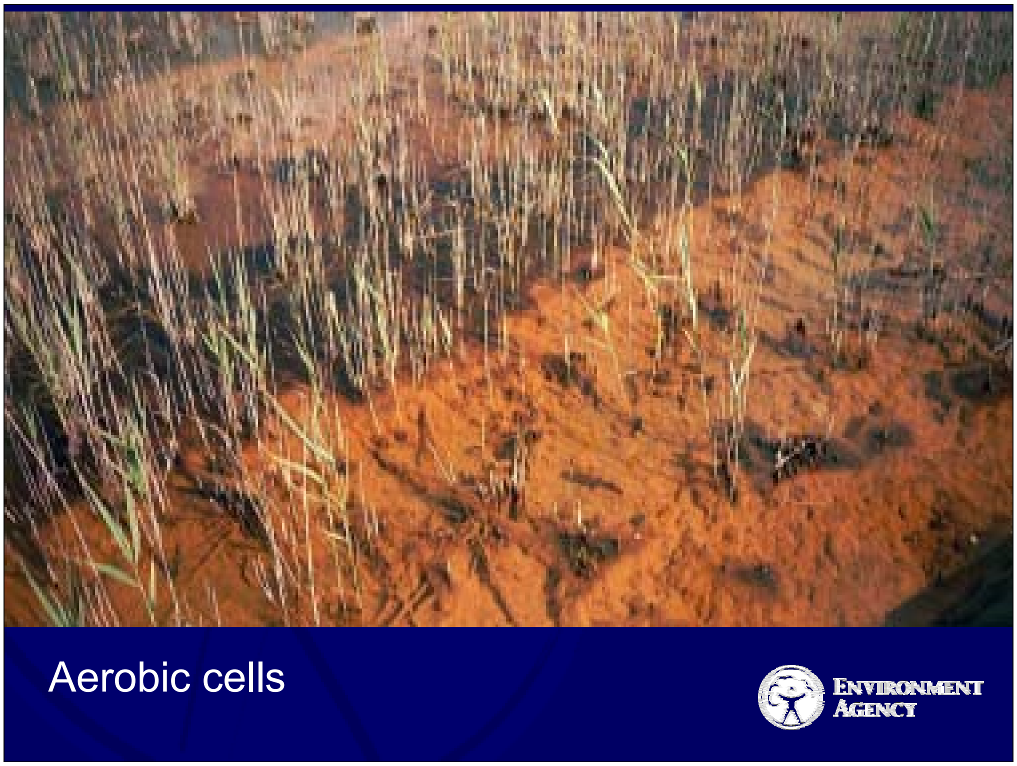
This diagram shows a conceptual layout of the pilot passive treatment system with 3 different treatment routes for minewater from Jane's Adit:

lime-dosing to pH 4.6-6.5;

pre-ALD anoxic pond (reduce oxygen) and anoxic limestone drain. This design was subsequently modified to include a lime-dosing step to remove Al; and

untreated minewater.

Each system then comprises 5 aerobic cells (reed beds - removal of Fe, Al & As), an anaerobic cell (removal of heavy metals as sulphides) and rock filter (for Mn & BOD removal). Discharge was pumped up to the active treatment plant for treatment and not discharged to the river.



Significant deposition of ochre (Fe(III) oxyhydroxides) at front of first aerobic cell (80-98% of Fe(II) oxidised). Photo June 2002.

	Inflow	C1	C2	C3	C4	C5 approx, allmg/l
Fe(II)	130	15	0	0	0	0
Fe (TS)	130	50	20	15	10	8 (poss colloidal)

Ferrous iron oxidation and precipitation takes place rapidly (microbially mediated), particularly in the first half of the first cell, accompanied by a reduction in pH to around 3 in each system (hydrolysis of ferric iron produces 3 protons for each molecule of Fe). pH adjustment of the influent makes no difference to the oxidation rate or pH of effluent from the aerobic cells.

Acidiphilic bacteria are present that can couple the oxidation of organic matter to the reduction of iron - resolubilising both iron and any co-precipitates (e.g. As)

Macrophytes play little part in removing metals at high metal loadings, but can be significant at the final polishing stage when Fe has dropped to a few mg/l. At Wheal Jane the plants appear to be counter-productive wrt removal of iron and provide the carbon to catalyse the reduction of ferric to ferrous iron.

Anaerobic reactor - geomembrane-lined cell filed with mixture of straw, sawdust and manure - long and short-term source of organic carbon. Limestone was also added to the untreated source to add alkalinity.

The cells were covered and vegetated.

The anaerobic cell for the lime-free system was closed for almost a year due to operational difficulties and, on resuming flow, raised pH from 3 to 6-7, with a healthy population of sulphate-reducing bacteria and reduction of both sulphate and iron in the effluent wrt the influent.

The pre-treated systems were operated immediately and the effluent showed an increase in ferrous iron and sulphide wrt the influent, with only modest pH increases from 3 to ~5.5. Fe and S oxidising bacteria were present in high numbers in the effluent, in contrast to sulphate reducing bacteria.

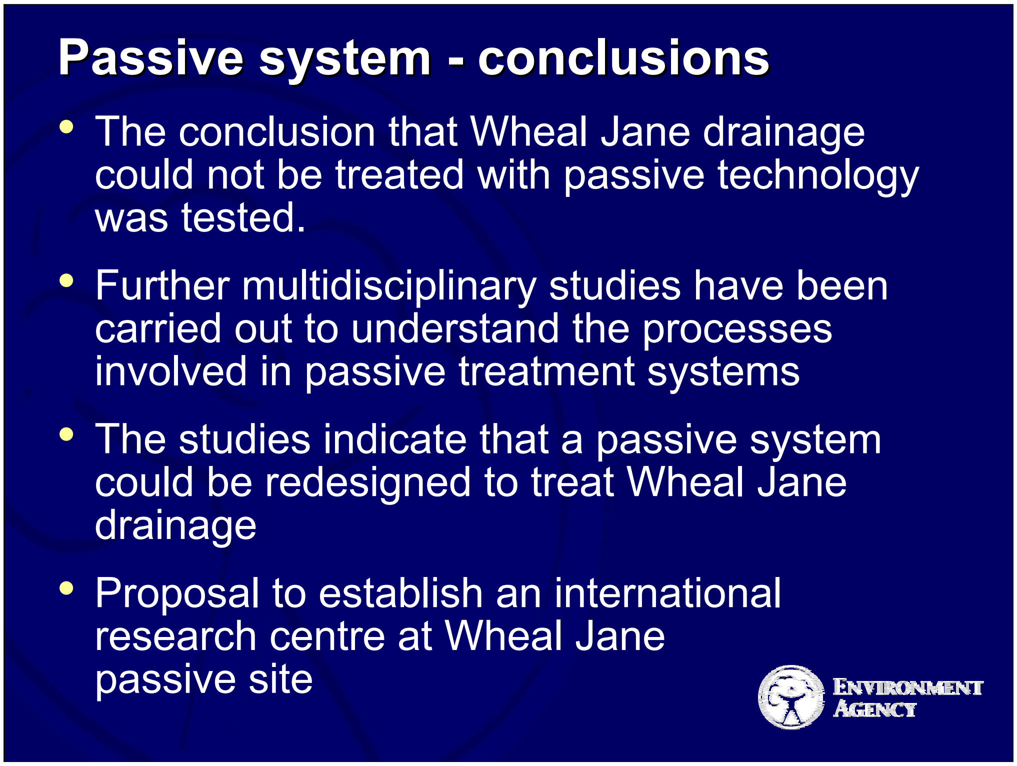
Rock filters - algae-colonised shallow rock pools relying on oxygenic photosynthesis to locally raise the pH to precipitate Mn. pH was typically 5-6, too low for Mn precipitation.

Reasons:

(1) sulphide and ferrous iron in effluent from the anaerobic reactors cause acidification in the aerobic rock pools

(2) insufficient sunlight in Cornwall and/or silting and vegetation of the rock pools

Alternative system using Mn-oxidising microbes shows more promise, precipitating Mn at a pH as low as 5.



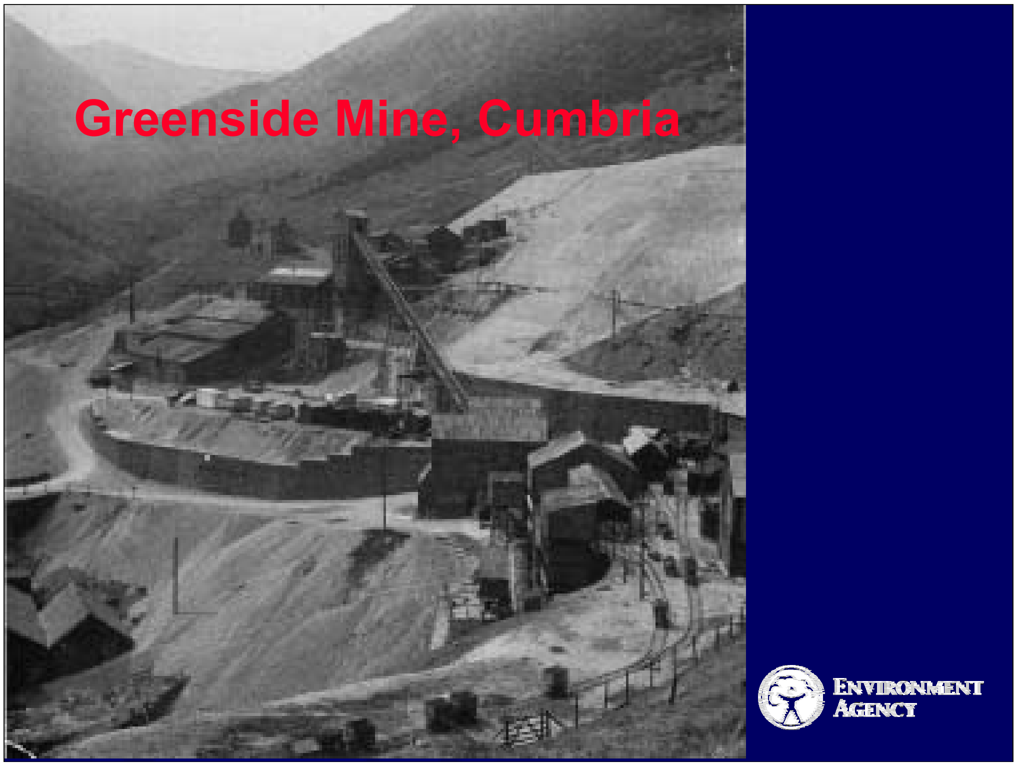
The microbiology of the passive system is of critical importance to the success of both aerobic and anaerobic components and the original conclusion that the WJ drainage could not be treated with passive technology needs to be reviewed.

Such systems are not “passive”, but need to be managed and maintained.

There is a knock-on effect with pH through the system - pH adjustment before the aerobic cells not effective in increasing the rate of iron oxidation or in controlling effluent pH as hydrolysis of iron releases protons. This in turn affects the performance in the anaerobic reactor and rock filters.

The passive system could be re-engineered and optimised to treat a higher flux of metals. Key design and construction issues apparent from the studies include the pH balance through the system, the presence of plants in the aerobic system (catalysing reduction of ferric iron), and establishment of beneficial microbes in the anaerobic reactor.

Prevention and control measures taken to limit discharges or emissions from abandoned mines or mine spoil/tailings can involve diversion of water courses, grouting of underground workings and capping of waste spoil or tailings.



Greenside lead mine is located in a steep-sided valley some 5km from Ullswater Lake in the Lake District National Park. It is in a popular tourist area and adjacent to a well-used footpath and Youth Hostel. The area suffers around 2,500mm of rainfall a year, mainly falling between October and March.

Lead mining commenced in the late17th C and ended in 1962. Two tailings dams were formed for the disposal of mill tailings following complaints from local residents of milky water in the becks (streams). The photograph shows the mine site in 1962, with tailings dam no. 2 upslope of the mill. Tailings were pumped from the mill via 4 inch pipes and discharged via perforated pipe running around the edge of the dam. Between 1940 and 1962 some 1 million tonnes of tailings were disposed of, comprising 70% silica. Significant efforts were made to establish vegetation on the dams.

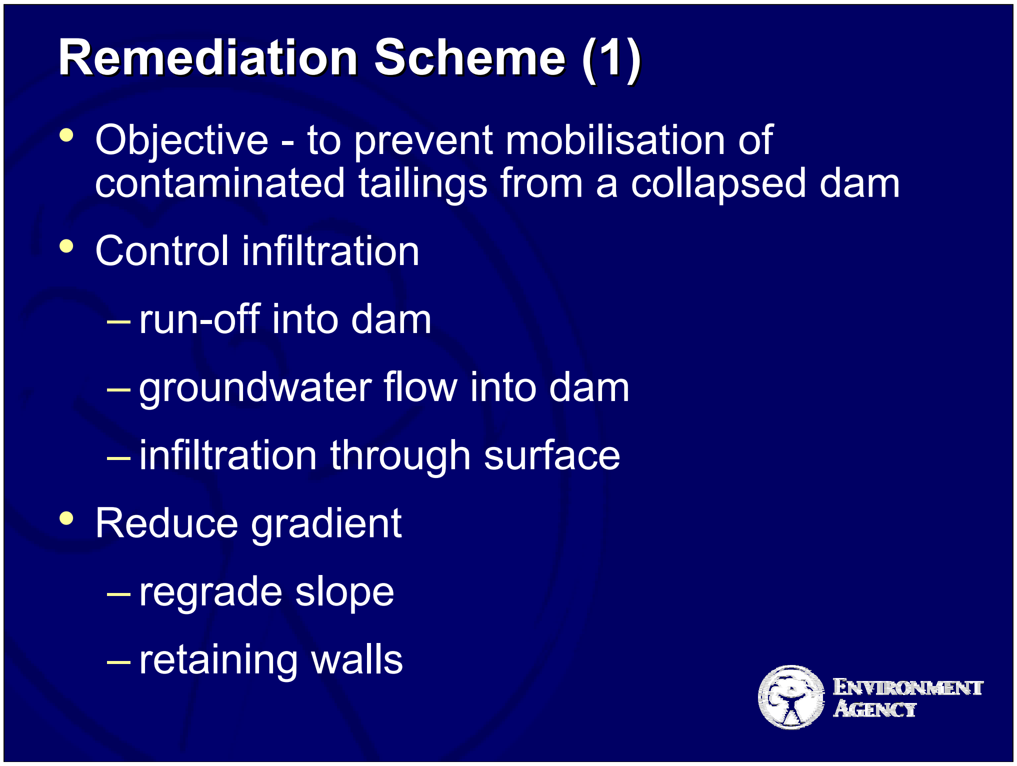
The flank of dam no.2 collapsed during a period of heavy rainfall in 1989, releasing an estimated 4000te of tailings into the becks and ultimately Ullswater Lake. A further collapse in 1997 widened the scar and transported more material into the surface water system. This dam was considered to be unstable with the potential for further collapse to release tailings into the surface water system. The second dam is in a more stable condition, but may be prone to collapse if the water levels within it were to significantly rise.

Tailings range from coarse sand & gravel to very soft, low to intermediate plasticity silts and subordinate clays. Water levels are variable & highest toward rear of dams. Some show peaky response to rainfall. Leachate is circum-neutral with elevated Pb, Zn, Cd and As

The local becks are already impacted by toxic metals from a number of sources, including the tailings dams, resulting in failure of Environmental Quality Standards for Pb, Zn and Cd. Glenridding beck supports a salmon fishery downstream of the mine site, and this may be at risk in the event of a significant release of tailings.

Concerns were raised in the 1990s over the ecosystem and water quality in Ullswater Lake as a result of increased nutrient loading and the influx of metal-rich sediments.

Ullswater Lake is one of the largest and deepest lakes in England divided into three sub-basins. It contains a population of a rare, protected fish, the Schelly, is a potable water supply and used for recreational pursuits. It appears to be showing long-term nutrient enrichment with algal blooms dominated by plankton that rapidly sink, leading to deoxygenation in the deep basins. Lake sediments contain Pb to 23g/kg & ca. 60% and 46% Pb & Zn is potentially available. The change in redox potential in the deep basins increases the potential for release of toxic metals into the water column, already observed for Mn, Pb & Zn.

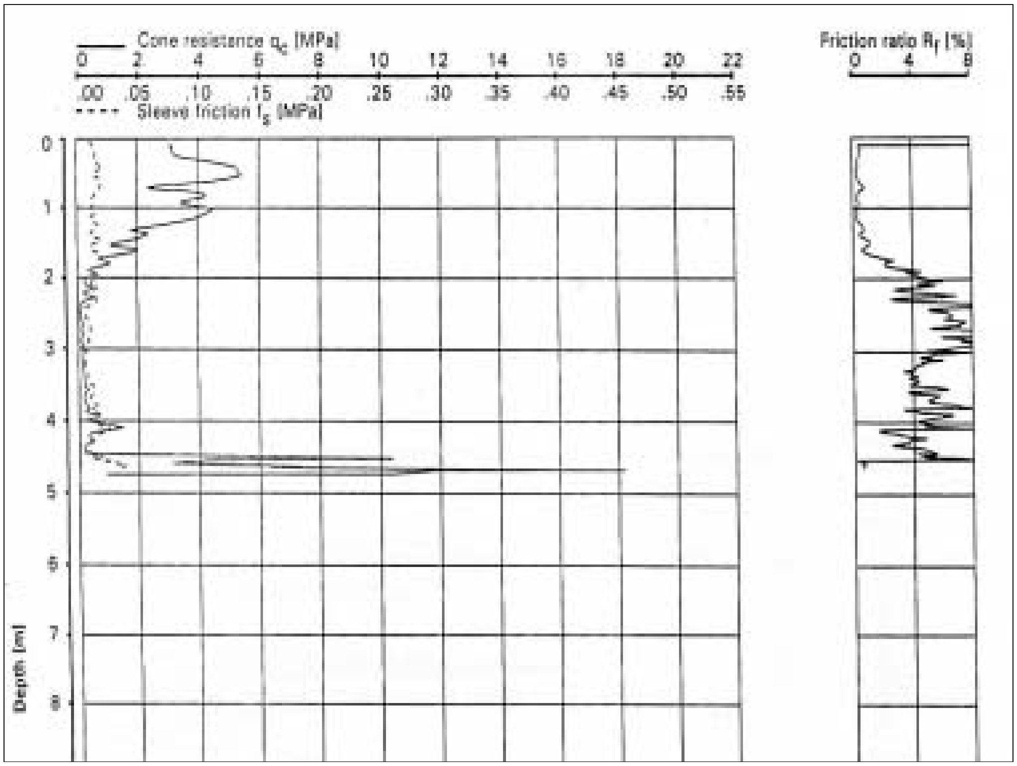


Investigations into the tailings dams and potential environmental and human health impacts from the tailings were completed in 2000. The most pressing concern was the continued instability of the tailings dam and the potential for an uncontrolled release of tailings.

A remedial strategy was designed to stabilise the dam and prevent future mass release of tailings to the surface water system, comprising two becks (Glenridding and Swart) and Ullswater Lake. The long-term goal is to reduce the metal flux to the lake, especially particulate, and create a buffer layer between the contaminated sediment and water column. The remediation may not significantly reduce the flux of dissolved metals.

A stone-filled French drain was installed locally through scree behind an area of elevated water level in the dam to intercept and discharge shallow groundwater flow through the scree. The surface drain at the back of the dam was widened and deepened to capture surface water run-off and shallow (<1m) groundwater from the screes. The width of the drain was overdesigned to permit easy access for maintenance.

As the site is a Scheduled Ancient Monument all walls had to be stone-lined using local stone. Walling was labour-intensive and stone could only be sourced from a single quarry (not permitted to use locally available scree) - expensive.



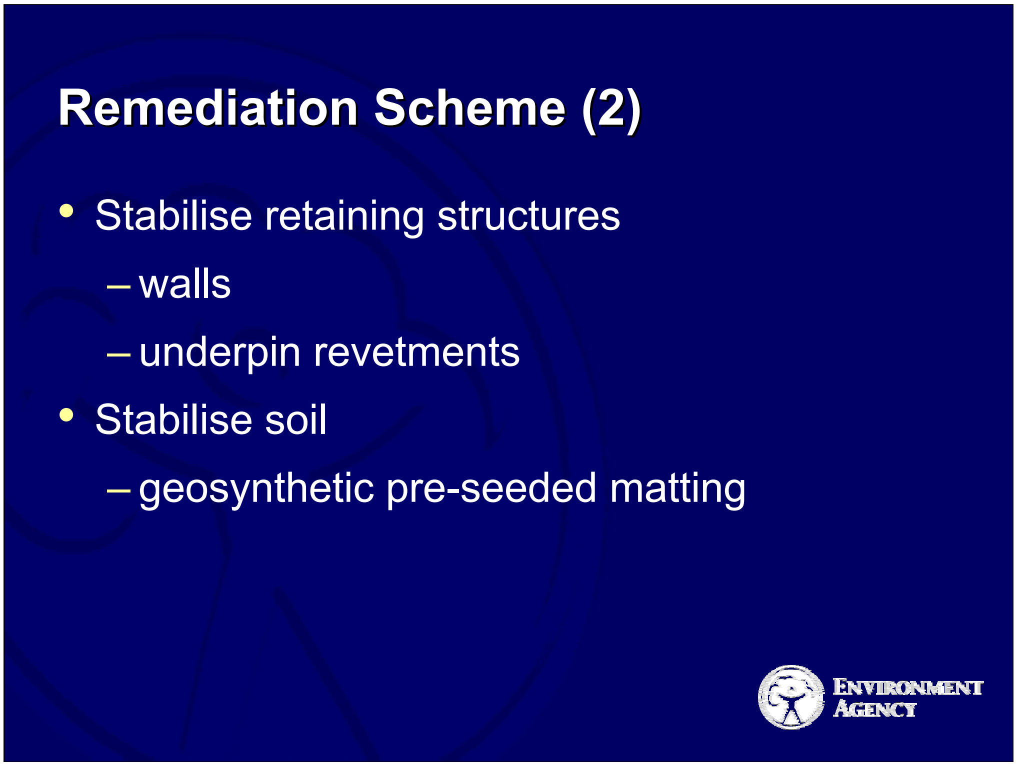
Reprofiling the slope - steep-sided valley with little space for redeposit of the tailings and problem regarding the nature of the tailings. Cone penetrometer profiles can be used to interpret soil conditions using cone end resistance and friction ratio (ratio of side friction to cone end resistance), although the correlations are derived for natural soils. The profiles show medium dense to loose sands over very soft silt & clay (slimes)(between 2.3-4.0m) - limiting the scope to cut without mobilising thixotropic slimes.

This was a challenge and resulted in reprofiling that involved both cutting back the slope and construction of retaining walls to reduce gradients.

Gradient reduction, exposure of tailings kept to a minimum by progressive application of soil cover. The crest of the slope was cut back and in places increased in height to improve the fall back to the drain behind the dam.

Cutting back the gradient and fill of the failure void with coarse to medium sand tailings in compacted layers, progressively loading the toe and improving the stability of the failure scar.

Reducing the gradient - local construction of stone-filled gabion baskets on concrete foundations with stone-faced walls. As Scheduled Ancient Monument, archaeological investigations were needed before walling could start.

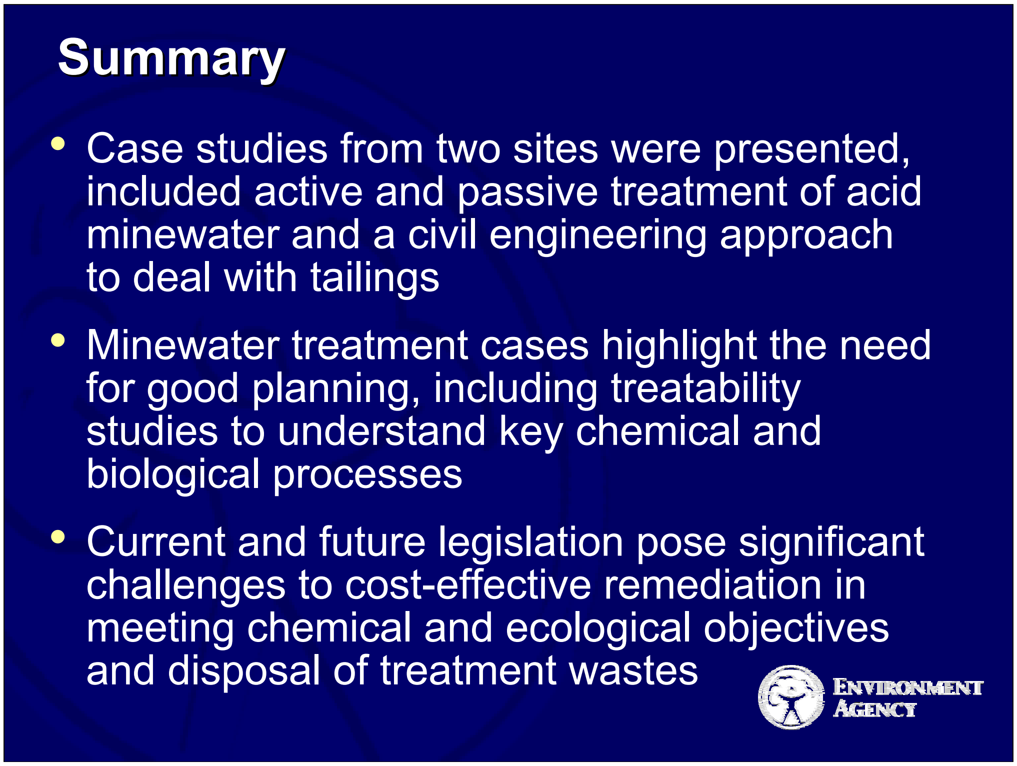


Stabilisation works included walls and undercut revetments that support the dressing floor, and rapid seeding of the dam using pre-seeded geosynthetic matting.

Work on the revetments along Swart Beck - the beck was sandbagged to divert flow along the constructed temporary culvert and shuttering constructed to allow concreting works.

Reprofiled dam with improved drainage, reduced gradient and stabilised walling. Note the grass growth through matting, mid-slope stone drain and sheep!!! Note also the two new retaining walls at the toe of the dam.


August 2003



EA Wales has a strategy for dealing with abandoned metal mines, but one is currently lacking in England - remediation being carried out on a reactive absis. A strategy is required to assess and prioritise sites for remediation, to make most effective use of the limited resources available. The EA is currently establishing links with key academics and research organisations in the UK to establish a science base in the UK for the assessment and treatment of minewater and mining waste from both the coal mining and metal mining sectors.