Integrated Environmental Technology Series

Disasters and Minewater

Good Practice and Prevention

Harvey Wood

IWA Publishing

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Integrated Environmental Technology Series

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Preface

Minewater, its attendant risks and consequences have throughout time been an area of interest and concern. By studying maps of areas of the developed and third worlds the consequences of mining can be found. The names of water courses are the major indicator that minerals are being, or at one time were, removed from the earth and are, as such, the clue to this activity.

In Spain the Rio Tinto, Romania the Baia Mare, and in the UK numerous references such as the Red River in Cornwall and Redbrook in Gloucestershire, an attractive village set by the River Wye. These names are historic, in Spain, Romania and the UK the rivers were coloured red with the ochre that leached away in the mineral extraction and refining processes at the time of the Romans and even before that.

The name of one of the world's largest mining companies, the Rio Tinto Zinc Company, reflects its nature and claims to historic foundations by the taking of the title of the river. It did, in the 19th century, mine in that region of Iberia.

The first mining engineer to publish his guide, De Re Metallica, Agricola in the 16th century noted that the waters from mines 'drove the fish away', the first published notification of pollution.

The first governmental recognition of mining and its effects on the water environment was the publication of 'Pollution Arising From Mining Operations and Metal Manufactures' a report of the Commissioners inquiring into the best means of preventing the pollution of rivers. Their findings, published in UK by the British Government in 1874, still being of remarkable relevance today.

Across the globe as mining and the need to exploit minerals developed, as it still does, the staining in streams and rivers followed close behind. The red colour of iron in its many forms leaches from waste and working; the tell tale signifier of activity that removes wealth from beneath the earth.

In recent times, within the last 100 years, the staining or pollution of the rivers of the planet has been considered a nuisance and only in the past 60 years has it been thought of as a liability and, in some instances a crime, to pollute fisheries. Previously it was an attendant curiosity.

The development in awareness of environmental care and populations embracing their rights to a clean environment in the last half century have come together to concentrate the will of the industry to demonstrate better self governance which much of historic mining failed to do. In practice environmental care has been poor, if not lazy. The developing world is now, in many instances, better regulated and with more rigorous legislation than many states in the developed world.

This has been the result of governments that have been accepting of the old style of poor practice presenting their environmental credentials on a global scale to protect less sullied regions of the world and are geographically far enough away from their electors that they are unable to compare their own, damaged, surroundings.

Acknowledgements

This work is a short guide to the issues of mining and its effects on the environment, and the catastrophes and accidents that have happened and continue to occur. It looks broadly at the legal and legislative issues globally and considers methods by which the effects of minewater may be ameliorated.

I have been involved with mining and water issues now for more than twenty years and have been fortunate to work with many of the foremost exponents of the several disciplines that are touched on in this book. This list is long and they know who they are.

Those that have helped me bring this book to fruition make up a shorter list. My thanks go to Maggie Smith, who commissioned this work, Dr Melanie Brown my co author and lead writer of the previous volume on minewater published by IWAP in 2002.

Thanks is due to many in the mining industry; Jim Sorbie who gave me free access to the Mines at Silverdale and Annesley Bentinck over several years and has been supportive in all that I have done and John Groom of Anglo American plc, who, with others has done much for the environment and changing much of how the major mining companies operate.

Finally thanks go to Karen Hindle for giving me encouragement in her own way. It may not change life, but it may allow some better informed opinion to be formed.

Introduction

Mining and the processing of mined materials has been a worldwide pursuit since, at least, the Neolithic period. Since these early beginnings the processes have been known to have far reaching effects on the environment and people's length of life expectancy.

At the Iron Age flint mines at Grimes Graves, located in the Brecklands of south west Norfolk, UK, the waste chalk, excavated from the bell pits that were used to access the seams of large workable flints beneath the surface soils is seen to still affect the flora of the site markedly. Plants grow in the vicinity that are unknown in any other part of the area.

Similar mines in Sussex, also in the UK, bear witness to loss of life underground; where a miner killed by a roof fall whist mining flint had been left as if at his labour for the next several millennia. Not an uncommon event, even today, in some remote mining communities.

Moving to the present, on 4th November 2010 a mine process water tailings dam partially failed swamping a village in Hungary with a highly toxic flood. This polluted much agricultural land and killed at least four people in the initial inundation. The long-term environmental repercussions for the area are as yet uncertain.

The recognition that mining has a history of such catastrophes is though under reported and where inquiries have been carried out; the lessons, if not forgotten, are lost in time. The purpose of this book is to give a summary overview of the major minewater and minewater related events that have occurred over the last 70 years; their causes, effects and repercussions, where known.

Alongside the catastrophic incidents, mining has left its mark; red staining and acidic flows into rivers. In the UK over 1,000 kilometres of river had been degraded by iron ochre precipitation polluting river beds by 1980. Since then there has been a concerted exercise, funded primarily by the state, to rectify the environmental legacy of coal mining particularly, and to a lesser degree the legacy of metal mining. Even as some pollution events are remediated other discharges develop, even in areas where such occurrences are not expected to develop.

The national laws of countries around the world and their regulations which are in, or being put in, place to safeguard the environment and local populations will be examined; as will the international conventions and protocols. The natural acceptance of mining and its environmental degradation is now coming to an end in many regions. The globalisation of the industry has had many benefits that have included the environmental safeguarding of many fragile eco-systems. There is though still much to be achieved with regard to environmental protection and the limiting of illegal mineral working in many remote areas that are seldom visited by regulatory authorities.

The treatment of minewater is an issue in both the active as well as the abandoned areas of mining activity. The modern mining company is more aware of the rights of the local populations to a good quality of environmental care and their (the company's) responsibilities to provide such safeguards as may be needed to ensure that environmental probity is exercised. The industry still has the reputation it developed in the past which was not so responsible, and has much to do to prove that it has changed.

Chapter 1

Disasters and Minewater

1.1 DEFINITIONS

The term disaster is an emotive word that is liable to stir up emotions of horror and revulsion. The use of it here is to convey it both in terms of damage or destruction of the human environment and the possible loss of life due to damage to the natural environment and its possible long-term detrimental effects.

Minewater in this context is any aqueous discharge emanating from a mine or any mineral retrieval or processing activity including liquid or semi-liquid storage impoundment; such as tailings dams.

Pollutions to water, however environmentally horrendous, such as took place in the Gulf of Mexico (2009), which are not brought about in the first instance by water, are outside the range of this work.

It should also be noted that listing the minewater incidents by region and nation is not a finger pointing exercise or in any way a suggestion that any country is more profligate or less caring for its workers, populous or environment. The identification of sites of disaster is not to be considered as placing blame; they are there for the purpose of demonstration that such events are universal issues.

1.2 OCCURRENCE

The occurrence of disasters brought about by minewater are many and various: the flooding of workings, inundation from flooded abandoned workings or from an aquifer deep below ground to the collapse or other failure of a tailings dam, its water sweeping away all surface obstacles from its path. Both underground and on the surface minewater has the ability to kill. At the surface it has the propensity to damage the surrounding land and in the worst cases make it unfit for human and agricultural uses for years into the future.

1.3 LOCATIONS

The location of such events does not rest with one country, continent or any other geographical region; it is a worldwide phenomenon that has taxed engineers' intellects since such activities began.

The focus of this work is international and covers the most mind numbing catastrophes imaginable. The best chronicled are mostly in countries that are used to reporting the facts and have not shirked responsibility in being candid. Others have occurred in countries which are more close-lipped who have agreed that an 'incident' has occurred and have left the world community speculating as to severity and reason. These occurrences have been difficult to investigate, and for reasons of honesty and due care the more vociferous or litigious sources of information have not been quoted. This is for the simple reason that there are many environmental organisations who see cover up or malpractice where mistake or error would be more likely. Such parts of the world are beginning to enter the new era of candour and openness and though slow to broadly publish disaster are active in finding reasons and learning from events but beyond the spotlight of the media.

Accidents in the United Kingdom, Italy, Spain, Hungary, Romania, China, Russia and the US are but a few of the countries that have been the scene for incidents that have grabbed the world's headlines and at the same time the majority of these events have only lasted a few moments in the national and international collective memories. This is, though, not true of the local consequences (I hope the narrative allows this to be accepted).

Over the time scales covered by this publication many incidents that have taken place are lost to posterity. Before the main content of the work occurred, much had not been admitted to or those involved did not consider the events worthy of note above that of a hiccup in production or other activity, this particularly being the case with all events that occurred above ground. It is true that great efforts were mounted to save life below ground or to bring out the bodies of those fatally affected; nowhere more so than in the United Kingdom.

Conversely the mine owners have always taken an interest outside the norm of proprietors with regard to calamities underground. This is particularly true of those ill-liked entrepreneurs of the United Kingdom coal barons and their families.

1.4 CALAMITIES

The incidents that are discussed are varied and include: inundation of underground workings due to stopping failure; breaking though into old flooded workings and mining through the bed of the sea. All these have their place but are not relevant to the issues that compound the mass of this work, which instead considers surface water issues, either as rebound, slimes or slurry movement, dam accidents or the boring of exploratory holes to locate the hoped for source of profit.

These events are all to be anticipated, if not actually expected, in the wholly imperfect world of winning minerals. The global population require the products of the industry and all but a very few of the world's population use the bounty of the industry that the mining fraternity provides; from jewels on the fingers of the wealthy to our daily bread.

The best executed of mining plans may be executed but the men or 'pixies' will creep in and re-order the operation. Land movement, earthquake, intense rain, draught or an un explained connectivity between an aquifer and the working face of a mine can all lead to disaster.

The other area of sadness, mining always carries this emotion at its core, is not covered in this work but it leads to continual losses of life: air problems. Fowl air or methane, one stops the breathing like a blanket and the other explodes, can both arise with little or no warning and are monitored for now in any enclosed space globally, but still there are lists of these tragedies annually from across the world.

It is notable that mining whatever substance will leave a fingerprint with which later generations will wish to prosecute those that have striven to improve the world and to provide both the pleasant and the necessary. Old workings will always have a negative aspect to them; not dissimilarly to the opinions of many who look down on those that win value from beneath the ground. The miner is synonymous with 'the hard man' as seen at the end of dictatorship in Romania or if a coal miner's grandson is prosecuted in Kent, UK.

1.5 THE MAIN ISSUES

The areas of mining that engender danger from water are many, and involve a range of engineering responses to deter disaster. Much that the engineer is required to undertake is not state of the art or ground breaking but everyday, and at times boring or tedious; two reasons already for accidents to occur.

Underground inrushes of water have been, from the fist mines in prehistory, the perennial fear of the miner. Drowning in a soup of dust laden water or slowly awaiting the end, as cut off from escape, the flood gradually rises about the person. Rock falls are the most common of catastrophic events that led to the development of mining methods which allowed for safer working even as far back as the stone age. The working of flints at Grimes Graves in Norfolk, United Kingdom was worked by a rudimentary method of pillar and stall, leaving virgin pillars of strata supporting the roof as the miner developed galleries to extract the flints that were the goal of the exercise. This method is still in use around the world today in many mines.

Rebound of groundwater from abandoned mines is a regular sight in areas of historic mining, particularly when dewatering has ceased across whole regions and mineral recovery has closed. Across Europe where the extraction of coal has been abandoned in favour of importation and increased reliance on nuclear electricity, the tell tale ochre staining of the streams and watercourses are common.

Similarly in metalliferous mineral mining areas the water courses show the same iron colouration, alongside a content of other metals such as arsenic, copper or aluminium. These may be as oxides or sulphidic and in some cases the water can be acidic with a pH of 2−5. The effect on the natural environment can be extremely damaging as it can be to human health, for those who come into contact with it. In gold and other precious metal mining areas the chemicals used to liberate the metal are allowed, sometimes wantonly but mostly by accident, to enter the natural environment. Cyanide is a common pollutant of water around sites of such extraction and ore dressing. In many mineral processes these wastes are held alongside washings wastes in dammed containment known as tailings ponds. These, if incorrectly engineered or maintained, are a considerable concern and are a regular source of flooding. Such events having taken place in Romania over the last decade and also in several other countries over the same time span.

The process treatment of bauxite is a special case: unlike other mined mineral refining operations (Hungary 2010) it produces a highly caustic, rather than acid or net alkaline, residue that can have a severe long-term effect on the natural environment. The wastes are known as red muds that are a continual burden, both for the refiners and the environment.

1.6 SUBSIDIARY ISSUES

Other areas of environmental dislocation have been caused by the exploration for, as well as exploitation of, minerals. Some instances considered to be notable include the mineral drilling test that unleashed an apparently limitless discharge of boiling muds that has not ceased for many years in the Far East. Of similar note is the trial project to burn coal in situ that caused untold litres of contaminated water to be vented in a rebound of groundwater that, combined with the super-heated coal below the aquifer, had been ejected from its subterranean confinement.

Mining disasters that impact on the environment are regular occurrences. Those that are not caused by water or involve it in their initial phase will receive and register the impact, notably the Gulf of Mexico oil production platform explosion and the resultant pollution from the failed seal on the production well. Other issues are also allied such as the major tanker groundings and sinkings that occur around the world.

Similarly acts of war and their resultant pollutions are, often after the event politically not noted as pollution incidents at all, as witnessed in Kuwait after the 1993 war. Then, oil production wells were set on fire, many of which burned for several weeks uncontrollably; the environmental effects on the waters of the Persian Gulf have not been reported widely.

Many minewater related environmental events occurred in countries such as the USSR and China before the modern approach to openness and perestroika came into being. Vast pollutions and large numbers of people are believed to have been affected, but it is only now that these events are starting to emerge from the fog of state embargos on information being known.

1.7 THE LAW AND REGULATION

Law and regulation nationally and internationally, with regard to cross border contamination events are no more than an apparent treaty but with little substance. The majority of national governments accept that mineral companies operate in a hugely competitive world market and costs have to be kept to a minimum. These governments are seldom advised by consultants. The consultants being more reliant on the mining companies for the majority of their day to day work. That is not to say that their advice is skewed away from the truth or that their advice is not excellent when governments commission their work. The problem lies in that few politicians are mining engineers or have the time or inclination to delve into the terminology any further than the glossary at the end of the report’s text.

In many instances the mining regulation is stipulated during initial planning stages of an operation and the general site operation is seldom inspected when a site is operational. This is a sweeping generalisation; the construction and maintenance procedures of tailings dams are agreed internationally by the relevant professional engineering bodies that accredit the structural engineers. This acts as a self regulatory junta not unlike the doctors practising in the UK being overseen by the British Medical Council. If a design or management failure occurs those engineers may be required to cease operation in a country or continental region; though seldom globally. It is also to be considered that in many parts of the globe ad hoc mining operations are the norm for much of the mineral exploitation and these operations are totally unregulated at any stage of their operational existence.

Chapter 2

Minewater and Rebound

2.1 MINEWATER CHARACTERISATION

Contaminated minewater is produced where sulphidic minerals come into contact with water and air, thereby creating acidity and a developing, elevated sulphate and mineral content water. Such solutions are synonymous with the development of polluted minewater.

The natural breakdown of minerals, oxidation, is thus accelerated in a mined environment with the eased access for all the elements to come together more readily and rapidly.

The main contamination generating activity areas include:

- drainage from subsurface workings
- drainage from opencast mines
- mine waste tips
- tailings from mineral processing
- mineral storage
- mineral extraction processes from ores

The minewater is often acidic, though in certain circumstances there are mineral loadings (i.e.; bauxite or calcite) that may allow for neutral or net alkaline waters, still holding high metal concentrations.

The creation of contaminated minewaters can be considered a natural process that, through the actions of mining, has been speeded up. The process is a consequence of both the minerals and bacterial action that allows the transmogrification of sulphides to sulphates.

The terms acid mine drainage (AMD) and acid rock drainage (ARD) are commonly and universally used for these discharges though they are not necessarily acidic due to bicarbonates. The bicarbonate buffer that natural waters have, which acts as a natural mechanism, allows a natural regulation of pH. This though may be affected by high concentrations of metal ions that act as catalysts for bicarbonate destruction or neutralisation.

$$Fe^{3+}, Mg^{2+} \text{or } Al^{3+} \text{ ions} > \text{hydrolysis} > H^{+} \text{ ions}$$

This bicarbonate controls the changes in pH. If its system is adversely affected its control of pH is lost allowing large variations in acidity. This can have widespread effects on the ecosystems that the waters enter. Another result of such action is that many photosynthetic organisms that abound in such waters in a slightly acidic regime are unable to survive below pH 4.2, due to that being when carbonate ions are converted to carbonic acid and are lost as a source of feed carbon for the organisms.

2.2 ENVIRONMENTAL IMPACTS OF MINEWATER

The impacts and consequences of minewater entering a natural environment are many and varied; no minewater discharge can be considered the same as any other. All discharges are unique and have a need to be considered on their own merits and considered as separate entities. The main problem elements are, though, possible to justify thus:

- acidity
- ferric precipitates
- other metals
- solids loading or turbidity

These generalisations and their consequences are outlined below, so as the consequential losses to the environment can be better understood.

2.2.1 Acidity

The acidity of the water may be, as already described, variable depending on the local geology as well as the water's general chemistry. The effects of variation of the pH have also been touched on: the more acidic, the lower the pH and generally the greater the environmental harm. This though needs the caveat that this could also be considered variation in the natural biological balance and a realignment of the balances that occur naturally. The action is accelerated in the outside environment as it is with the natural weathering of the strata in a mine system below ground.

Generally acidic minewater drainage can be the invisible source of the destruction of ecosystems that have developed in rivers and streams over millennia, resulting in the loss of vegetation, and vertebrate and invertebrate life forms. The loss of water-reliant mammals and birds is the next noticeable consequential change to the ecology of an affected watercourse. The Rio Tinto region of South Western Spain is a good example on a large scale of acidity and the repercussions of an extremely low pH environment. The extinction of the expected aquatic ecosystem though is at variance with the facts; the environment has in many areas developed its own, near unique, ecology over the last 5000 years of mining that has occurred in the area. These are either water and soil based life forms that are resilient to, or have developed tolerance to the negative elements around them or environmentally generated organisms that have abilities to sustain themselves on the negative elements available to them.

2.2.2 Ferric Precipitates

Ferric iron compounds, being the most common elements on the planet, have their place in this short lexicon of characteristic consequences. In air ferrous iron oxidises to ferric iron which via hydrolysis takes the form of ferrous hydroxides. This action is the cause of the characteristic red ochre staining of many streams and rivers. The hydroxide precipitation coats stream beds, suffocates the aquatic fauna and flora, coats fish gills and blocks the stream substrates denying silt living fauna light and causing them to die out.

2.2.3 Other Metal Loadings

Apart from the tell tale iron staining that usually denotes the presence of untreated minewater, other metals are usually present that can adversely affect the waters of a river or stream. Copper, zinc, aluminium, arsenic and any other metal, that is present in the mined strata and has oxidised and come into contact with water, will be present to greater or lesser degrees.

The same is true with waste waters from the processing of minerals. These may be very polluting and have been the source of many of the concerns relating to tailings dam failures. Apart from the flooding, it is the metal loadings and the mineral dosing elements, that have been used to separate the desired mineral components from the host ores, which cause concern. In gold mining and its liberation from its host rock, it has historically been the addition of mercury and in more recent times the use of cyanide compounds that have been prevalent. These have, when liberated by accident caused wide spread pollution at times of accident.

The treatment and reuse of waters in several mineral mining operations globally now require these other natural metals and added substances to be removed so as to recycle the water stream. The economics of this sort of operation are yet to be successfully calculated, as are uses for some of the more toxic elements that have then been removed.

2.2.4 pH and Acidity

Mine waters have a variety of attributes with regard to their constituency, but none more confusing than their pH. In many pollutions by minewater the pollutant is referred to as acid mine drainage (AMD), acid mine water (AMW) or other synonyms that infer acidity. In the reality of many of these discharges, particularly if the discharge is catastrophic such as at Wheal Jane, UK, the initial flow can exhibit an extremely low pH. As time passes and that initial water runs away and the dilution of new water drainage develops the discharge levels of pH climb. In some instances the discharge may become alkaline. This occurrence is not uncommon where large areas of limestone over lay the coal measures in parts of the UK and Europe.

Low pH within the abandoned mine system allows trace metals to be taken into solution from the mined rock and as the water leaves the subterranean environment makes them more accessible to the environment above ground.

Within this area of consideration it is important to consider total acidity; not just those revolving around pH. Total acidity is a measurement of the base neutralisation capacity of a volume of water, including three types of acidity (Hedin 1994).

(1) Proton acidity associated with pH (a measure of free hydrogen ion concentration)
(2) Organic acidity associated with dissolved organic compounds
(3) Mineral acidity associated with dissolved metals

Minewaters generally have very low dissolved organic carbon content, making organic acidity low. However, many mine drainage waters, particularly coal mine drainage, possess high concentrations of Fe^{3+}, Mn^{2+} or AQl^{3+} ions, which contribute to the acidity of the water because they can undergo hydrolysis reactions that produce H^+ ions. A significant environmental impact of high acidity is that it can destroy the bicarbonate buffer system that is an essential feature of natural waters. This buffer system involves a feedback mechanism which controls the magnitude of shifts in pH. If this system is destroyed, large shifts in pH are likely to occur which will have an adverse impact on the ecosystem.

Another effect of the loss of the bicarbonate ion from solution is due to the fact that many photosynthetic organisms use bicarbonate as their source of inorganic carbon. Such organisms are therefore unable to survive in waters below about pH 4.2 as this is the pH at which bicarbonate is converted to carbonic acid, which in turn readily dissociates to water and free carbon dioxide.

Acidity has an adverse effect on species diversity. As a general rule, the number of species present in an aquatic ecosystem reduces as the acidity increases.

2.2.5 Microbial Influence

Contamination of minewater below ground and in many surface mineral extraction operations is a combined chemical and microbiological process. The most widely studied element in the formation of this contamination being the oxidation of pyrite, which is the mineral most often implicated in this process. The microbial component of the minewater contamination is of major importance. Iron oxidising bacteria, such as thiobacillus ferrooxidans, can accelerate the rate of oxidation of ferrous to ferric iron and bacterial mediation throughout the weathering process can increase the overall rate of acid generation by a factor of 20.

These bacteria tend to be most active between pH 2 and pH 4. The weathering of pyrite to produce acidity is thus a self perpetuating process. Initially, the pH may be such as to cause $Fe(OH)_3$ to precipitate. However, this reaction releases H^+ ions, which lowers the pH and results in more ferric iron staying in solution. This ferric iron is then involved in rapid oxidation of pyrite, which results in a further fall in pH. Further to this chemically induced reduction of pH and acceleration of weathering is the increased activity of micro-organisms as the pH falls, which gives additional acceleration of these processes.

In flooded workings the chemical reactions are slowed due to the lack of oxygen and the action of microbial degradation. It does, though, not cease as it is almost impossible to create a purely anaerobic environment due to the levels of dissolved oxygen in natural water.

2.3 MINEWATER REBOUNDS

A rebound of minewater occurs once a mine or mine system ceases production and the voids fill with water that infiltrates the system of tunnels and workings. As the water fills the system it takes into solution the minerals present in the rock structures that it inundates. At its interface with the water and air, it links to the oxygen and the bacteria present within the mine, such as thiobacillus ferrooxidans, allowing a greater rate of mineral take-up within the water matrix and affecting the water loadings.

2.3.1 Rebound to Surface

A surface water rebound occurs once the water reaches a level where it can drain out of the system. Usually via a drift or disused drainage adit it is able to leave the mine system and enter the natural environment, often in a damaging and polluting fashion. Across the globe the red or orange staining of iron marks the flow of such mine drainage.

Events such as that which took place at Wheal Jane in the UK are only these more everyday pollution events, but taking place on an unprecedented scale. The Marcopper tailings lagoon in the Philippines was an old open pit mine which, when being used to store tailings as part of its restoration scheme, leaked catastrophically via an old drainage adit that had been driven through the mine wall at the base of the void to keep the workings dry during the final stages of its operational extractive life. The drainage discharges in both cases took place because the pressure of the water in both their respective systems was too great and totally unexpected.

As stated earlier smaller scale discharges take place around the world. It has been suggested that over 100,000 miles of rivers and streams are contaminated globally from rebounds. These pollutions are a challenge for the 21st Century to rectify.

2.3.2 Groundwater Rebound

The other major aspect of rebound of minewater is that when old workings fill with the polluted waters that result from their flooding, these can threaten water resources, some of which can be of national or international importance. This is due to the nature of the ground that has been mined and the resultant fracturing caused by heave and subsidence. The many aquifers that are located between the mined mineral bodies and the surface above are liable to be polluted.

In the UK the Coal Authority has done much to counteract such threats from the large numbers of coal mines that have closed and the aspects of whole regions are returning to, or near to, the hydrological conditions prior to the start of coal mining.

In South Africa the local and national governments are trying to raise the issue urgently with regard to the Johannesburg area. The mining within the region has come to an end and the threat of 'acid mine drainage' has been identified as a danger to the region's groundwater and its potable water supplies. The perceived threat has also been raised by agencies of the United Nations.

In China and South America minewater aquifer rebound has been blamed for contamination of drinking water resources, allowing concentrations of arsenic and other unwelcome pollutants to enter the public water supply.

Chapter 3
Europe

European mine tailings accidents are mainly occurrences that are brought about as a result of weather events. Much of the rest of the world's tailings impoundment failures are more likely to have been triggered by seismic events; not just earthquakes, but also subsidence or blasting.

3.1 UK

There have been several instances of environmental disaster related to minewater issues in the UK, all of which have been examined minutely and their repercussions monitored and published. Many, where loss of life is at the fore, are not considered suitable for anything else but acts of remembrance and sad memorials. Mining communities are close knit and when tragedy strikes the people involved lock the rest of the world out and those closest to the events close ranks to support the community.

3.1.1 Aberfan 1966

The Aberfan mining disaster occurred in an archetypal mining community that suffered one of the largest mining failures of all time, on a global scale. The social effects have been studied by academics and the management related events have been reported on in public enquires and many publications. The event did not just involve one huge shift in a spoil heap, but resulted in the total transformation of the landscape of the South Wales mining valleys.

On the 21st October 1966 a subsidence took place on the upper section of waste tip 7 at Merthyr Vale Colliery. This land slip was estimated to be 3 to 6 metres and allowed 150,000 cubic metres of liquefied coal waste to travel down from above the village of Aberfan as a 12 metre deep wave.

The result of this occurrence was that 116 children and 28 adults were killed. There were many injured people hospitalised and many in the community today still suffer post traumatic disorders.

The official report was critical of the National Coal Board who owned and operated the mine. It placed the reason for the accident on the location of the tip on top of a hill from which a stream flowed and the torrential rainfall of the previous days.

The effects on the natural environment of the adjacent area were minimal and short lived once the debris was cleared away; the long term human effect was otherwise. The major effect for the whole landscape of the South Wales Coal Field was the change in waste operations and the wholesale remodelling of past spoil heaps and the creation of more naturalistic, stable designs for the future.

It is worth noting that the mining company did not have to inform the Mines and Quarries Inspectorate, part of the UK Health and Safety Executive, as the event had not occurred on British Coal lands and no miner had been injured. The episode did bring about an alteration of the 1954 Mines and Quarries Act in, as much as, that the public needed to be protected from mine waste.

It is worth noting that the waste tip was known to have been placed over the stream. Neither the culvert nor the tip's structural engineering had been inspected at any period of their active life.

3.1.2 Wheal Jane 1991

Wheal Jane was a metalliferous mine located in south central Cornwall, close to Truro. The mine ceased operations and stopped pumping the water from the workings in early 1991.

The event that occurred in January 1991 was a rebound of minewater that was building up at the cessation of pumping at Wheal Jane, in the old workings of a group of neighbouring prospects. These mines included Mount Wellington, United Mines and many interlinked historic workings. This interlinking of workings required the mine at Wheal Jane to pump minewater in excess of 60,000 cubic metres per day from a depth of 450 metres. The pumped minewater was characteristically acidic with a pH of 2.3 and carrying high sulphidic mineral loadings of copper, zinc, arsenic and cadmium.

The mining company that had operated the mine realised that the water entering the now free flowing water system would decant at some point in the future and would need a treatment system to cope with the estimated 5000 cubic metres discharge flow. A start was made to put in place a wetland treatment scheme at the Jane Adit. Though this scheme was in place by November 1991, when the minewater started to discharge into the site, it was incapable of coping with the volumes being encountered. A temporary lime dosing facility was then put in place and a pumping range installed to take the majority of the water back up to the old tailings lagoon above the valley.

A month later, due to operational concerns at the tailings dam, the portal was plugged temporarily to allow time for the issues with the dam to be remedied. During the ensuing few weeks the water within the workings rose a further 4 metres, with minewater leaking out of the stream bed of the Carnon River. In early January 1992 the stopping to another portal of the system failed allowing the Nangiles adit to discharge millions of gallons of highly acidic metal rich water into the Carnon River and on into Restronguet Creek and further still into to Carrick Roads and Falmouth Docks. An area exceeding 6.5 million square metres (RCS 1992).

After a week pumping resumed from Jane Adit, but could not cope with the estimated flood flows of 9.3 million gallons per day. It took till the summer of 1995 to have installed pumping capacity of over 6 million gallons per day so as to stop water decanting from the Nangiles adit except at times of excessive wet weather.

Though no one was physically hurt, the damage to fisheries and the tourist industry ran on for many years at an incalculable cost. The cost of the emergency treatment of the minewaters and their ongoing treatment regime are the financial liability of the Environment Agency and the UK tax payer; the mining company having gone into liquidation. The initial and continuing ongoing costs have not been reported, but the figure is estimated at over £30 million. The present active treatment plant treats over 500 million cubic metres of minewater per annum and is now over 10 years old and the tailings lagoon is coming to the end of its forecast life.

3.1.3 Tilmanstone Aquifer Pollution 1907 to the Present

Tilmanstone Colliery was situated in South East Kent. The practice of discharging heavily contaminated chloride rich waste waters via unlined lagoons situated on the native chalk rock began in the area in 1907 and continued through to 1974 when a pipeline was commissioned to discharge the minewater directly to the sea. Snowdown Colliery, close by, added to the problem with its own saline discharges through similar unlined lagoons.

This practice had a catastrophic effect on the underlying aquifer which had chloride levels of over 300 mg/l in the 1920s. In the 1970s test bore hole chloride concentrations of 3000 mg/l were reported and rose to above 5000 mg/l.

The plume of contamination extended over an area of 25 square kilometres and was noted to be 1100 metres thick (Carneiro 1996).

This pollution was not a short term affair but gathered momentum over time. It left the water providers of the area with a loss of resource that with time and colliery closures (1986) most of which has returned close to the theoretical baseline qualities prior to commencement of coal extraction.

The mine closure program did add to the pollution of the aquifer one last time in that the ponds and lagoons were finally drained by putting boreholes into the chalk as drain sinks to empty them.

3.2 ITALY

Italy is regarded by many mining engineers as the academic home of the Saxon 16th Century engineer and writer, who composed the first and predominant text on mining and the issues of minewater: Agricola. His *De Re Metallica* was first published in 1556. Its Latin text was not translated till 1912 when Herbert and Lou Hoover's translation was published. Though by that time mining technology had moved on, the intrinsic truths and common sense the books extol still bear scrutiny.

3.2.1 Stava Tailings Dams Failure, Trento 1985

On 18th July 1985 two of the tailings dams at Prealpi Mineraia Fluorite Mine failed. The resultant collapse of the structures allowed a wall of liquefied dam wall and tailings, around 190,000 cubic metres in volume, to destroy the village of Stava and all in its way for a distance of 4 kilometres. (The total volume of the containment had been 300,000 cubic metres.) The land area affected was 43.5 hectares in a ribbon of destruction along the river corridor.

The two dams had been upstream containments that were built with the second of the two dam walls partially established on the waste or slimes deposits of the lower lagoon. When the second dam liquefied, the pressure build up of the event breached the first containment wall precipitating the disaster.

The subsequent enquiries, of which there have been several, would suggest that the pair of containment structures were not fit for purpose from the design stage to their emplacement. The initial collapse was caused by one or all of the following events: a drainage pipe through the impoundment wall was distorted, blocked or leaked into the dam makeup; the dam had excess pore pressure allowing the slippage of the base of the structure that had been partially bedded onto the slimes or that persistent rainfall at the time, or embankment seepage, had weakened the stability of the base soils on which the two structures were sited. The dams' design, with embankment slopes ranging from 1.2:1 to 1.5:1, was also cited.

Earlier that year two small dam breaches had occurred, both to the lower containment cell. In one a decant pipe blocked causing slumping in the wall of the structure. The second was a broken decant pipe which caused loss of surface water and tailings to leak forming a sinkhole in the area of the break. Both incidents' damage was repaired. There was no way of knowing if their occurrence had had any bearing on the catastrophic failure.

The death toll of the disaster was high with a total of 268 persons killed.

3.3 SPAIN

The main metal mining area of Spain is known as the Iberian Pyrite Belt. This region spans the border with Portugal and has been actively mined since the

Phoenicians traded to buy copper to mix with the tin that they had acquired from Cornwall, UK.

The river systems are of this metalliferous area are all highly polluted, the best known being the Rio Tinto which for a large part of its length runs as an acidic stream with a pH of 2.5. The vegetation of the mining areas at first glance is scant though on better acquaintance the micro flora is remarkably varied, sharing many similarities and commonalities with that found in the Yellowstone National Park in the United States of America.

Coal mining areas of the country are located towards the North; south and east of Zaragoza. Much of this mining region drains towards the Rio Ebro.

3.3.1 Los Frailes Tailings Dam Failure 1998

The Los Frailes tailings dam is located at Aznalcollar, close to Seville in South West Spain. The mine was producing lead and copper. On the 25th April 1998 a part of the tailings dam broke away depositing about 1 million cubic metres of liquid tailings waste and water into a nearby river: the Rio Agrio, a feeder river of the Rio Guadiamar. The flood further inundated several thousand hectares of agricultural land. The incident drew wide attention as the Donana National Park, a UNESCO World Heritage Site, was considered under threat.

The dam impounded an area of around 200 hectares and the dam itself was mainly constructed of waste rock from mining activities in the area. The impoundment was constructed in two sections, so that it allowed for the deposition of pyroclastic waste in the Northern section and pyritical in the Southern.

The event that brought, about the catastrophe was a small movement, it is agreed, of the soil beneath the retaining wall and the lagoon. This movement was of a metre towards the Rio Agrio on an approximate 20 metre front. This occurred at a junction between the two sections of the dam structure. Both parts of the tailings system taking separate feeds of waste water/slurry. This foundational movement was inline of the wall between the two sections. The movement was enough to cause the main dam structure to crack and then breach abruptly. The breach then shed around seven million cubic metres of water and liquefied tailings slurry into the river.

The volume of the inrush raised the level of the river by 3 metres and forced it to alter its course considerably, cutting its new channel in places down to the underlying base rock, and removing the historically polluted alluviums of the river bed and flood plain as added slurry to the tide of contamination.

The only truly agreed cause of the incident is the earth movement, but the ongoing tide of media interest and enquiry, particularly by the Spanish media, helped muddy the waters still further. Legal argument and claims for restitution to the courts continue.

The suggested causes of the incident include poor management and maintenance of the dam, seismic and other stability monitoring equipment was inoperative and the tailings impounded were of too high a water content.

3.3.2 Alcaniz Blowback

The events that took place at this pan-European funded project site (1993–1998) have been rewritten to a great degree so as to solicit funding and commercial partners for future research (Firth of Forth, Scotland, UK 2011).

The gasification of coal in seam by burning in situ has been experimented over many years. The most successful operations in this sphere were carried out in the old Soviet Union period. Two of these schemes still operational today are Angren in Uzbekistan and Yuzhno in Russia. In the UK a seam was set alight in Derbyshire, during the 1950s. The problem that developed was to put the conflagration out; which was eventually managed by open casting the site to physically remove the coal from around the burning seam.

This project was located at El Tremedal, a remote rural location near Alcaniz. The intention was to burn a seam of deep coal in situ, thus testing the foreseen needs of directional drilling and all the allied technology that the partners in the project needed to assess.

The project began well and proved much of the engineering that was to be tested. The failure was that an aquifer, situated above the coal seam that was being burnt, flooded the ignited area causing a blowback of phenolic liquor which passed under pressure to the surface, coating the site with residue.

On visiting the site a short time after the event everything had been cleaned and the site was spotless, new limestone chippings covered the ground about the area.

Fortunately no long-term damage appears to have been done to the environment and no personnel were hurt in the event. The project has been hailed as a success in the technology's research and development which allows for significant private investment going forward.

3.3.3 Huelva Phosphate Tailings 1998

In December 1998 50,000 to 400,000 cubic metres of phosphoric acidic waste water (pH 1.5) and other liquefied phosphate wastes, including uranium, discharged into the Ria de Huelva, a part of the tidal estuary of the Rio Tinto in South West Spain on the Gulf of Cadiz.

The tailings dam was constructed and commissioned in 1997 to take the residual waste from a phosphogypsum fertiliser, green acid plant. The phosphate used was imported from a phosphate mine in Morocco via the docks in Huelva. Previously the liquid fraction of the waste residues had been discharged directly to the estuary.

The cause of the failure of the dam was placed with the severe storm that happened at the time with both the dam filled to capacity due to the rain and the sea water eroding the dam wall creating the breach.

The spill, though of great potential severity, was uncharacteristic in that the actual environmental consequences could be argued to have not been as severe as in any other location as the Rio Tinto is a river already polluted by minewater from mining operations some of which date back 5000 years.

3.4 HUNGARY

3.4.1 Kolontar Caustic Tailings Failure 2010

The Kolontar dam, at Devecser, failure took place on 4th October 2010. The tailings dam received the red muds that are the main waste arisings from the transformation of bauxite to aluminium oxide which is then further processed to aluminium. The muds are, by the nature of the bauxite treatment, highly caustic with a pH of 14.5.

The failure of the dam allowed 700,000 cubic metres of caustic mud to flood through three villages and cover an area of about 8 square kilometres. The final death toll was put at 10 with many more injured, mainly suffering from caustic burns. The pollutants travelled as far as the Danube though there was no demonstrable contamination.

This pollution was certainly the most photographed such incident in history with over 5000 different sets of 'red mud' images available to the media. The colour and the consequent staining made many of the alarmist tendency put fear into the local population rather than reassurance.

The initial reasons for the failed section of the dam are speculative but include pore water pressure and foundation materials having little tensile strength.

3.5 ROMANIA

3.5.1 Borsa Tailings Rain Event 2000

The 10th March 2000 saw the failure of the Borsa dam in Romania, releasing 22,000 tons of metal rich waste water to contaminate the Vaser River a tributary of the Tisza River. The rainfall that had been torrential and an accepted contributory factor in the dam failure also helped greatly in lessening the environmental impacts.

Much of the events and the reasons for their occurrence have not been reported due to the Baia Mare Mine accident that occurred a few weeks previously and on a much larger scale.

3.5.2 Baia Mare Gold Tailings 2000

The Baia Mare event took place on the 30th January 2000 when, during severe weather conditions with much of the tailings lagoon waters frozen with significant frozen snow cover, rain fall that was flooding the surface of this accumulation (36L/m2) (United Nations Environment Programme [UNEP] 2000) caused an inner dam to become saturated. This resulted in the first retaining wall failing which allowed the tailings to flood out into another outer perimeter lagoon which overtopped. This allowed 100,000 cubic metres of liquefied acidic and cyanide rich (50−100 tons) (UNEP 2000) tailings to flow into the natural environment.

The discharge entered two rivers, the Somes and Tisza causing large scale fish mortality. The slick of pollution reached the Black Sea via the Danube. The

UNEP Report does infer that the dilution was sufficient for the major environmental consequence not to reach the Danube. It is known that significant stocks of dead fish were collected from the Danube, their origin being the initial two rivers polluted.

3.6 BULGARIA

Due in the main to the political regime that was in power for many years, and the consequent lack of openness with regard to mishaps and mining related incidents, little has been published as to the reasons for several of the growing number of accidents that took place post the second World War.

It did become state policy in 1966 that no tailings impoundment should be built without the aid of a civil engineer.

3.6.1 Maritsa Istok Cinder Slide

It is recorded that an accident took place that involved the accidental or catastrophic release of around 500,000 cubic metres of mine tailings. This occurrence was due to the dam wall breaching. There was no reported damage ensuing from the incident.

3.6.2 Madjarevo Tailings Dam

This mine tailings dam was the location of a tailings impoundment failure which had unreported and as such, unknown consequences on the area's ecology.

The area now is a well marketed tourist destination with an emphasis on the Thracian past rather than the metal mining that was carried out in mines in the area during the 20th Century.

3.6.3 Sgurigrad 1966

The tailings impoundment at the metals mine at Sgurigrad failed in 1966 allowing 220,000 cubic metres of metalliferous acidic water to escape the confines of the dam.

Two reports give somewhat different accounts for the event and some of the outcomes.

The dam suffered a fundamental degeneration of stability caused by wave action during a protracted rain and storm event. The tailings flood destroyed a village a short distance away from the site claiming around 107 victims. The tailings flowed over at a large area and travelled over 6 kilometres.

The dam collapse was caused in part by workmen cutting drainage trenches on either side of the dam which allowed the whole structure to buckle and fold over under the pressure of the retained tailings. After the event a spring was discovered that would have been actively liquefying the tailings and so making the structure unstable. This spring was unknown to the engineers at the time of the dam's creation (1958) and had only started to issue water due to the unprecedented weather at the time. The waters travelled 6 kilometres to the town of Vratza causing severe flooding but with no evident loss of life.

3.6.4 Mir Mine, Rainfall Management 1966

The 1st May 1966 was not the holiday that the citizens of Sgurigrad, 1 kilometre from the Mir Mine, expected. 450,000 cubic metres of tailings from the mine demolished half their village and travelled a further 7 kilometres. The death toll was over 480 with an unspecified number injured.

The reasons for the dam's failure were stated that due to heavy rainfall and poor flood control, the flood relief channels that were in place failed to carry out their function and the pressure built up. The mine was extracting lead, zinc, copper, silver and, it is thought, uranium. The route of the flood discharge is marked by the variation of the flora today.

3.7 YUGOSLAVIA

3.7.1 Zlevoto 1976

In 1976 the No. 3 tailings lagoon at the Zlevoto lead/zinc mine failed, releasing 300,000 cubic metres of acidic metalliferous slurry into a local river. The consequences of this pollution are unreported.

The reasons for the failure are that the tailings fines size allowed the material to pass through and liquefy the dam wall causing it to breakout.

3.8 SWEDEN

Sweden has many mining interests that are held up by the national government as examples of environmental best practice, but accidents are unavoidable in the mining and minerals industry.

3.8.1 Aitik Mine Tailings Management 2000

The Aitik Copper, Gold and Silver Mine is located above the Arctic Circle in Lapland near the town of Gallivare. It has been operational since the 1960s and the tailings dam which failed was developed as an impoundment structure in the 1990s. At the time of the initial failure in September 2000 the larger proportion (2.5 million cubic metres) of the contents of the structure were directed towards and relocated to a neighbouring settlement pond. The remaining 1.5 million cubic metres of contaminated water and sediments were discharged into the local water environment.

The long term effects of this release have proved to be minimal. The mining company has been mindful of its responsibilities.

3.9 FRANCE

French minewater issues have historically been poorly reported though there have been several events that have failed to keep a totally low profile.

An area of mineral extraction and processing has been that of uranium. The French minerals industry mined uranium at several sites in the Massif Central region. The mines have since closed and in at least one instance rebounded with the returning groundwater. Much of the sediments and vegetation downstream of the mine are polluted and are more contaminated than many identified nuclear wastes.

Around France there are waste sites which are redundant mineral workings that have been used for uranium waste disposal and are now being monitored for pollution to the region's groundwaters. Parts of Normandy, Champagne and the Limousin District have been cited as of concern.

As part of the coal mine closure plan of the Northern Coal Field a system of pumping stations to protect the environment from minewater rebounds were put in place in the 1990s and early 2000s. These, allied to the major financial considerations given to the miners, protected the then upcoming elections from any adverse criticism such as was seen in Britain in the 1980s.

3.9.1 Malvesi Elevated Nitrates 2004

Malvesi, Aude in March 2004 was the site of an evaporation lagoon failure at a uranium concentration plant. The discharge that has been agreed is that 30,000 cubic metres of liquid waste, officially stated as being composed mainly of rainwater, discharged into the Tauran Canal. The flood waters demonstrated elevated levels of nitrates (170 mg/l) for several weeks (Department of the Interior, 2011).

3.9.2 Carnoules Metal Soil

The area is based around a now closed metals mine made up of a redundant metal tailings impoundment and mine spoil heaps. The site is located in an arid area but still the site drains to a small stream: the Reigous.

The discharges from the site and the site's meagre rainwater runoff allows the stream to develop a loading of arsenic at >300 mg/l, iron >2999 mg/l and sulphates at >6000 mg/l. This discharge is at present not being addressed. The majority of the contaminants precipitate out of suspension swiftly onto the riverbed. This natural decontamination is, though, of only a temporary nature and every time storms take place the flood waters move these polluted sediments down to the main river sporadically causing damage to the ecosystems downstream on the Amous River.

Chapter 4

North America

4.1 UNITED STATES

The majority of minewater related accidents in recent years have involved phosphate plants. The number of reported water incidents runs into several thousand.

The rebound of many hundreds of small mines of all types has led to a major focusing of attention on low cost, sustainable methods of abandoned minewater drainage. The funding of such remediation works has been carried not just by mining companies, where they may still exist to do so, but by the federal and state governments and their agencies. The locally affected populations have also, in many cases, funded remediations.

4.1.1 Kingston Fossil Plant Fly Ash Failure 2000

Kingston Fossil Plant is a coal powered electricity generating station. Its fly ash pond of prodigious proportions set atop a fly ash tip failed on 22nd December 2000. The failure of this containment allowed over 4 million cubic metres of pulverised fly ash and water to flood over and, at points, bury the landscape to a depth of a metre and a half over an area of nearly 2 square kilometres. Nobody was killed though property, houses, power lines and a gas pipeline were destroyed. The Emory River was severely polluted with suspended solids and metal contaminants.

The reasons for the event are reported in a document of several volumes and the responses to the findings were as robust as can be expected in the litigious society that is the US in the early years of the 21st Century.

In summary the containment failed due to several reasons: the ground geology was water retaining, the embankments were waterlogged, and the seepage that was designed to help drain this construction's slope was not functioning and eventually liquefaction occurred.

The Tennessee Valley Authority who oversaw the environmental clean-up of the area with the US Environmental Protection Agency (USEPA) had to seek permits to dispose of much of the wastes deposited in the river in the Gulf of Mexico.

4.1.2 Riverview Impoundment Demolition 2004

The 5th September 2004 saw the landfall of Hurricane Frances, one of a string of serious cyclones to land on the Florida coast that season. It was also the day that the hurricane helped destroy the tailings lagoon of phosphate process wastewater located atop a stack of phosphogypsum waste at Riverview, Central Florida.

The water and muds that were liberated were acidic, low in dissolved oxygen and had a high phosphorus and nitrate loading. Unfortunately only a fraction of the cascade of waste, 227,000 cubic metres, was retained on-site most of the water entered the Archie Creek and thence on to the sea at Hillsborough Bay. There was much damage caused to both the river and marine environment.

The main reason cited for this event was the hurricane and the gale lashed pond eroding the south west retaining wall away from the inside out. The force of a body of water lagooned over 100 feet above the surrounding area and holding three quarters of a million cubic metres of water in those conditions made the event unavoidable.

In the same hurricane season the same company (Cargills), at another of their phosphate plants close by, was again to fall prey to a similar destructive force from Hurricane Jeanne which helped unleash another large volume of tailings from a similar impoundment. The 40,000 cubic metres of liquefied waste that flooded out of the dam failed to leave the mine site and did not reach the Peace River.

Another phosphate impoundment burst took place in April 2005 at Bangs Lake, Jackson County, Mississippi. An approximate discharge of 64,000 cubic metres of acidic liquefied waste left the pond, the majority of which was deposited into a local marshland area. The initial effect was dramatic in that a large amount of aquatic and marginal plant life died, as did the fauna. This though has been largely restored by natural revegitation and colonisation.

The reason for the event was cited by the Mississippi Department of Environmental Quality as being that the company that owned the site was raising the walls of the impoundment without proper attention. The company itself cited an unusually intense season of rains.

In 1997 and 1988 the Mulberry Phosphates plant, Polk County, Florida had a pond fail allowing 200,000 and 100,000 cubic metres, respectively, of acidic phosphate process water to flood into the Alafia River with the elimination of all aquatic life in that river.

The issue in this instance was that the causes or full establishment of liability for the event never took place as the company, Mulberry Phosphates Inc., filed for bankruptcy and ceased trading immediately. The State of Florida and the Federal Environment Protection Agency had to take on the abandoned site and decommission the other ponds and the numerous other potential environmental hazards themselves, all at huge cost to the state.

4.1.3 Inez Mine Workings Collapse 2000

October 2000 saw the Inez coal mine, Martin County, Kentucky suffer a coal slurry spill that deposited 950,000 cubic metres of coal minewaters into the Tug Fork and tributaries of the Big Sandy River. Apart from a major fish kill, several towns downstream had to stop abstracting water for potable supply.

The reason for this catastrophic event was that old mine workings beneath the lagoon had collapsed causing major subsidence at the surface and breaching the containment wall of the slurry lagoon.

4.1.4 Abandoned Leadville Mines

Leadville, Colorado has been shown to be in active danger of the rebound of several metal and rare earth mining operations that were worked for around 150 years.

The Environmental Protection Agency (EPA) as a US federal agency had developed plans to use a treatment site operated several miles distant that was under the management of the regional reclamation agency who objected to the use of their facility whist the federal agency had access to Super Fund finances. This dénouement went on for several years, until it was agreed that the EPA would provide funding from federal funds.

Simultaneously due to the present (2011) market conditions, for some rare earths, plans are being developed to dewater part of the closed mining district to begin mining again commercially. If this does commence the threat and the small pollutions from minewater seeps will be brought under control for the foreseeable future.

4.2 CANADA

Much of Canada has hosted mineral and mining activities of one form or another over the last 400 years. The nation saw early exploitation of metal ore bodies and then coal extraction. Later came the major gold finds and now the continuing successful prospecting for an ever increasing suite of exploitable minerals.

4.2.1 Pinchi Lake 2004

The mercury mine at Pinchi Lake, British Columbia was the source of a major metal rich pollution in 2004. The pollution had serious repercussions for the lake itself, which received 8,000 cubic metres of the waste.

The accident occurred during restoration of the closed tailings impoundment. The activity on the surface caused the walls of the dam, 100 metres long by 12 metres tall, to partial liquefy at their foundation.

4.2.2 Sullivan Mine 1991

In 1991 a tailings facility failed at the Sullivan Mine, Kimberley, British Columbia. The minerals that were being mined included lead and zinc. The failure led to a spill of at least 80,000 cubic metres of liquefied acidic waste. The whole event was captured by a pond located below the site of the failure and contained on-site.

The foundations of the dam were laid down in 1951 with the structure that failed being developed in the 1970s. The dam had been raised almost annually and the resultant heavy equipment use would have caused excess pore pressure in the aging foundations as the constant development of the structure grew.

The event occurred at the time that the mining company was raising the dam wall further so as to increase capacity. The pressure of the new loading and the vibration of the site during this activity liquefied the foundations of the dam.

4.2.3 Matachewan Consolidated 1990

This was an unusual event that caused much damage to property and the environment, and was an event that had no active mining activity to promote it.

The tailings dam had been an active site first as part of a gold mining operation and subsequently as a minerals mill for other mines in the area. It operated between 1933 and 1953 when it was abandoned.

The dam waters linked across to a nearby natural lake; Otisse Lake. The lake combined with the tailings waters and at the breach sent nearly 200,000 cubic metres of floodwater causing severe environmental damage.

The cause for this event was that since the dam had been abandoned the level of the combined dam and lake had risen by 2 metres causing overtopping. The reason for this rise in water level was that beavers had built a dam at the outfall of Otisse Lake. Their enthusiastic engineering had contained vast quantities of water.

4.3 MEXICO

Mexico is a major player in the world of minerals production, producing silver, in particular, and many other metals as well as quarry products. Minewater has been an accepted though unwelcome side effect of much wealth production from the mining industries. Not just river pollution, but also that of major aquifers has taken place across large areas of the country. The fact that much of the country is sparsely populated has been a reason for lack of knowledge of minewater events as has the industry itself suppressing such information.

The situation has changed only during the last 15 years with the development of new laws that were inspired by United Nations advisors and a realisation that international aid funders would be more attuned to a more environmentally attuned government. This has led the country to develop laws that mimic those that the United States and other more developed nations would subscribe to.

The major mining interests within the country are controlled from outside the nation; Canada, Italy, Argentina and others all have companies mining and prospecting across the land. These companies have given rise to much bad feeling due to practices that are out of place with the spirit of, if not the actual, legislation. They are further considered to have little interest in the people of the regions in which they are operating, or the environments around their operations.

The arid nature of much of the country shows little concern for minewater pollution except for that which may arise to harm groundwater qualities. Surface water events have taken place but there are no records of their occurrence. There are though many political organisations that operate in the country and others that attack the environmental credentials of mine operators from outside.

The home-grown environmental activism is mainly fronted by the labour unions which use and manipulate the concerns of the environment as an initial opening to begin negotiations with the mining company in question.

Chapter 5

Africa

Across Africa there are and have been many ad hoc mineral extraction sites and illegal workings that are unable to be detailed as very little, if anything, is known about their operation. Even less has been recorded formally. Many such operations have been actively encouraged by local councils or land owners. This has been in the knowledge that no regulation can be brought to the sites and if it was attempted the operations could be simply relocated elsewhere. These mining operations are notorious for their safety record and the laissez-faire attitude to safety and the handling of such commodities as cyanide and mercury used to liberate gold and silver from their host rocks.

Many thousands of both local and migrant workers have been killed or disabled working on these sites for little more than slave wages for, in many cases, tens of years.

In many of the countries in which these operations have been prevalent the income streams have been annexed to fund rebellion and civil strife. The legitimate governments are unable to regulate the situations where these sites occur due to security issues and also the vast areas that need to be policed.

5.1 NCHANGA, ZAMBIA 2006

In November 2006 the rupture of a pipeline taking liquefied mineral waste from an ore treatment facility at the copper mine at Nchanga, Chingola to the tailings dam facility at Muntimpa occurred. The discharge entered the Kafue River and high levels of copper manganese and cobalt polluted the stream. Local communities were unable to use the river as their primary water resource for some time.

The volumes of waste discharged are unquantifiable as are the full environmental impacts of this occurrence.

5.2 HARMONY MINE, SOUTH AFRICA 1994

The tailings dam at Harmony Gold Mine at Merriespruit, breached in 1994 due to exceptional rain over a protracted period. The breach allowed 600,000 cubic metres of metal rich acidic waste waters and suspended solids to flood across the surrounding land and enter a river.

The flood killed 17 people and badly damaged the township and the waters of the local streams. The reason for this occurrence could be laid down as poor lagoon management as the storm waters might have been released to protect the viability of the dam.

5.3 ARCTURUS, ZIMBABWE 1978

In 1978 the gold mine and processing site at Arcturus had its tailings dam fail. The water overtopped the dam and took the upper part of the dam with the flood. The volume of the discharge was not on the huge scale of some failure events, being in the region of 30,000 cubic metres.

One person was killed but the local water systems were heavily damaged by sediments from the mine, including mercury and other heavy metals. The valuable pasturelands were also negatively affected. The failure of the dam was reported to be due to severe rain over a protracted period.

5.4 BAFOKENG, SOUTH AFRICA 1974

The platinum mine and refining works at Bafokeng failed in 1974. The tailings dam shed over 3 million cubic metres of acidic tailings into the environment. A proportion of the waste water flooded one of the mine shafts on the site killing 12 miners below ground. An unspecified number died on the mine top and in the area of the inundation. The local river was polluted for 45 kilometres of its length.

5.5 MUFULIRA, ZAMBIA 1970

In 1970 the copper mine at Mufulira suffered a failure of one of its tailings dams. The wall liquefied in part, releasing 1 million cubic metres of toxic mine tailings. A large proportion of this waste water entered the mine via one of the shafts and drowned 89 miners who were working below ground.

Chapter 6

China

In China, as in many countries around the world, there have been a large number of minewater related incidents that are noted as having occurred, but have not become widely publicised, or had their causes publically enquired into.

6.1 HUAYUAN

The manganese complex at Huayuan in Hunan Province reported a 50,000 cubic metre loss of liquid tailings from its tailings dam. This loss set off a landslide that killed at least three people. The reverse scenario has also been put forward in that the landslide, brought on by seasonal rains and common in the area, had caused the retaining embankment of the tailings lagoon to rupture.

6.2 TAOSHI 2008

A reportedly illegal iron mine in September 2008 near Linfen City, Shaanxi Province lost its waste water impoundment. The resultant mudslide, which was several metres thick, buried a three storey building as well as a market and several homes. The death toll was put at at least 254.

6.3 ZHEN'AN GOLD MINE 2006

April 2006 saw the Zhen'an gold mine near Miliang in Shaanxi Province have a major tailings failure. The incident killed at least 17 people who were entombed in the waste flow and the Huashui River was polluted with potassium cyanide waste for a 5 kilometre stretch.

The collapse of the dam was brought about by ground engineering failure during the reported sixth raising of the dam's height. The excess weight caused a slump in the fabric of the structure's infill.

6.4 NANDAN 2000

At Nandan, Guangxi Province a tailing facility failure in October 2000 killed at least 120 people with large scale destruction of housing in the area below the implacement. No further information was available at the time of writing this.

6.5 JINDUICHENG 1988

In April 1988 a failure of a tailings dam occurred at the molybdenum workings at Jinduicheng in Shaanxi Province. The occurrence liberated 700,000 cubic metres of waste water killing around 20 people.

The reported reason for the accident was that a spillway that was meant to take away excess water from the impoundment failed to work due to a blockage, so allowing the hydraulic pressure behind the dam to exceed its capacity.

6.6 HUANGMEISHAN 1986

In 1986 an iron mine waste water lagoon located at Huangmeishan was the cause of 19 deaths. The supposed reason for the failure was that the wall of the dam was too porous and the core of the structure liquefied, exacerbated by slope instability.

Chapter 7
Asia

The countries in the region including those of India, Pakistan and Bangladesh, all have a long mining history. Apart from human factors and engineering derived accidents the climate can have a pronounced impact on the mining industry and its water concerns.

7.1 INDIA

7.1.1 Goa 2011

During the monsoonal rains a metal mine became inundated with surface run off or drainage water. The flood overtopped defences and descended the mineshaft, causing part of the working to subside, killing at least three miners.

7.1.2 Tanzanite One Mines 1998 and 2008

Torrential rain and the consequential loss of electrical power, due to storm affected supply, were in both cases responsible for the loss of many miners' lives at the start of the monsoons in these two years.

The Tanzanite mines which are a group of highly interlinked workings could not manage to keep water levels at bay and when power supplies were lost and pumping ceased much of the workings were inundated. Many of the workings are accessed by shafts with poor access facilities including unsecured ladders and climbing ropes which descend to below 300 metres from pit top.

In the first event at least 200 miners were lost. The figure is uncertain as the exact number of people underground is unknown and many bodies were not recovered. The second event resulted in a similar loss of life.

Rescue work was hampered by the fact that other miners had to leave the workings before the ventilation staff stopped work for lunch.

7.2 PAKISTAN

In Pakistan, as elsewhere, the pollution of groundwater is often only discovered after its effects exhibit themselves in local humans and the exhibition of symptoms are taken seriously enough for medical intervention.

7.2.1 Kasur Groundwater Contamination 2000

Research carried out over a period of time and reported in 2007 (Farooqi 2007) describes the pollution of large areas of groundwater supply around Kalalanwala in the Kasur District. The contamination was primarily high levels of arsenic and fluoride that were having a highly detrimental effect on the local population.

The source of this contamination proved to be from the local brick earth quarry and allied factory. The brick manufacturing process required large amounts of water that mostly percolated back to groundwater taking the pollutants with it derived from the earth that was made into bricks. The other source of pollution came from the density of the polluted dust that the manufacturing produced which, during rains, carried the pollutants to ground and to the groundwater table.

7.3 THAILAND

7.3.1 Ron Phibun Groundwater 1990s to 2003

The Ron Phibun region of south-eastern Thailand suffered and its shallow wells are still contaminated with very elevated concentrations of arsenic. Many very young children and infirm adults became victims to the poisoning though exact figures of mortality are impossible to ascertain.

The cause of these pollutions to the groundwater was found to be the wastes residue from the local tin mining industry; both load mining and alluvial extraction had been actively carried out in the region over many years. During the active mining period arsenopyrites, that are associated with this form of mineralisation, had oxidised during the period of dewatering when pumping the workings to keep them free of water during the mineral winning process. Once the mineral workings closed the systems recharged with water and the oxidised polluting mineral was liberated into the actively exploited groundwater.

Chapter 8

Pacific

8.1 JAPAN

Japan has a history of earthquakes of the largest sort. Many bring tragedy as in this present year (2011) with the tsunami that so badly damaged the North East of the country and its infrastructure. Japan has, though, an enviable reputation of building structures that do not fail because of seismic activity alone.

8.1.1 Mochikoshi No. 1 1978

In 1978 the gold processing tailings dam known as Mochikoshi No. 1 failed. The spill, much of which was made up of the dam's materials, deposited a contaminated layer of 30,000 cubic metres of tailings waste.

One person was killed by the acid flood and several kilometres of river were contaminated. The reason for the event was that an earthquake had liquefied part of the dam structure and it slumped with the volume of waste it was retaining.

8.1.2 Hokkaido 1968

The mine at Hokkaido suffered an earthquake in 1968 that liquefied the site's tailings dam voiding 90,000 cubic metres of tailings slurry. Fortunately little damage was reported with no loss of life.

8.2 PHILIPPINES

8.2.1 San Marcelino 2002

Two tailings dams on the site near Zambales were being decommissioned in 2002. During the two months of August and September, the heavier than normal rain, plus the re-engineering and redistribution of volumes of rock and fill, collapsed both of the two structures. The metal wastes leaked from their impoundments into the nearby Mapanuepe Lake and via that water body into the Santo Tomas River.

After several weeks of slow discharge of liquefied tailings, the dams totally collapsed flooding several villages that had already been evacuated. The actual volumes of waste material are unclear.

8.2.2 Surigao del Norte 1999

The gold complex at Surigao del Norte developed a pipeline rupture in 1999. The pipe failure was not immediately recognised and the break was allowed time to fracture completely. This allowed 700,000 cubic metres of acidic, cyanide contaminated, liquid waste to discharge into the natural environment. Many houses were swamped and over 50 hectares of rice paddy were deemed unfit for use after the event.

The apparent reason for the occurrence was lack of maintenance.

The same mine had a dam collapse in 1995 which allowed about 50,000 cubic metres of acid minewater to escape. The resultant flood, though small, killed 12 people and polluted an area of the coast.

8.2.3 Marcopper 1996

The Marcopper operation on the island of Marinduque, was the site of a 1.6 million cubic metre copper tailings pollution in March 1996. The tailings were stored in a worked out open pit mine excavated from the bedrock of the island. It was an arrangement of remarkable engineering ability and as such it avoided dam collapse or cataclysmic seismic events common to the area.

The pollution occurred when an adit, or drainage tunnel, at the bottom of the excavation became unplugged and allowed the contents of the site to empty. The event caused the evacuation of 1200 residents and polluted 18 kilometres of river with acidic metal rich contamination.

The mining company, which was 40% Canadian owned, paid US $80 million in compensation to the Government and people of the island.

8.2.4 Padcal 1992

In 1992 the No. 2 tailings dam of the Padcal copper workings failed. The volume reported as being lost to the environment was 80 million cubic metres of acidic, high metals and other contaminants, mine waste. The results of this spill are unreported.

8.2.5 Sipalay 1982

This copper mine suffered a dam failure in 1982 due to the clay soil matrix of the foundation slipping: a spring developing beneath the dam due to heavy rainfall gave momentum to the base movement. The dam shed 25 million cubic metres of liquefied waste material over an unspecified area and it lay up to 1.5 metres thick.

There were no fatalities reported but much of the land that was inundated was agricultural and was taken out of production due to the contamination levels.

8.3 AUSTRALIA

Several incidents across the Australian continent have occurred. This is a worldwide phenomenon, but the details have gone unrecorded. There has been a lack of coming to terms with the issues of why failures of dams or other events took place and the consequent pollution effects are also unrecorded. A site in Captains Flat is known to have damaged the environment in 1939, polluting a local river for a length over 15 kilometres. This event taking place when it did may be reason enough for the lack of recording, but globally many other such occurrences are hardly recorded.

8.3.1 Olympic Dam, Roxby Downs 1994

The Olympic Dam at Roxby Downs, South Australia was discovered to have leaked over a period of at least two years. The period of two years spanned 1992 to 1994 when the leak was discovered. The loss of over 5 million cubic metres of contaminated water resulted. The minerals processed at the site were copper and uranium and the contaminants would be metal rich and acidic.

Research into methods of attenuating the damage to the regions hydrological integrity continues.

8.3.2 Ranger Uranium 2004

In 2004 the Ranger Mine in the Northern Territories was found to have exposed many of its workforce to minewater heavily contaminated with uranium. The mine was closed for several weeks until the State Legislature was confident that health and safety structures were in place.

The same mine discharged contaminated water to a nearby creek. This was more a scare rather than an actual pollution event but such occurrences now draw attention from national and world media.

8.4 NEW ZEALAND

New Zealand has always, over the last 60 years, at least, been aware of its nation’s quality of environment and has done much, both governmentally and privately to protect the country’s multiplicity of ecosystems.

8.4.1 Golden Cross 1995

In December 1995 the tailings dam at Golden Cross Mine started to move. The structure containing 3 million cubic metres of metalliferous, acidic waste water was stabilised before all but a small fraction was lost.

8.5 JAVA

8.5.1 Sidoarjo Mud Flow 2006

The mud flow at Sidoarjo, East Java, is a remarkable freak of mineral exploration and possible tectonic interplay. The event started, in May 2006, with a gas exploratory well being started, it reached a depth of over 2000 metres before technical issues required the drill to be removed. At about the same time a major earthquake took place 200 kilometres away in Yogyakarta, which killed many people. The following day a fissure 200 metres from the drill site opened and started emitting hydrogen sulphide gas, steam and mud. This developed over a matter of days into a growing mud volcano. The average mudflow is today reckoned to be in excess of 100,000 cubic metres a day. The mud has spread out over a vast area of over 100 square kilometres. Further, the volcano has developed a height of over 140 metres above the original ground level of the trial borehole site. Tens of thousands of people have been affected by the event that, at best guess, will last for at least 30 more years. The volcano has been named Lusi.

The causes of this phenomenon are conjecture with many earth scientists, geologists and volcanologists all agreeing that they have not seen anything comparable but beyond that point of agreement little is accepted as certain. The gas exploration company state that the mud volcano was set in motion by the severe earthquake and its aftershocks reawakening a fault system that has other mud volcanoes, on a much less impressive scale, in the region. It is known that the sub stratum in the area is under huge tension with tectonic drift straining the strata in several directions. Some geologists, including some from Durham University, UK, note that the earthquake had nothing to do with the Lusi event and pointed out that no other mud volcanoes had appeared after it; the test borehole had by some mechanism started the fault movement itself.

The exploration company has been required by the Indonesian Government to pay compensation to the local population, to pay for work to stop Lusi from growing and to plan the remediation of the land once the event has concluded. The combined costs are estimated at over US $1.5 billion. The company has become insolvent.

8.6 NEW GUINEA 1990s

New Guinea is a source of many valuable minerals and metals, gold and copper amongst them. The exploitation of such materials has been on the whole by incomers as the majority of native inhabitants have not exploited the native geology for jewellery or 'wealth'.

8.6.1 Ok Tedi, Papua

A mining company was preparing a mine site including a tailings dam. Due to technical faults in engineering the site, a landslide removed the location for the setting of the dam. The mining regulation department of the Government was loath to lose the mining company's future royalties.

After the landslide occurred any other tailings operation on-site was considered overly expensive and technically difficult. Permission was then granted that the mine need not bother with a tailings cleaning operation as the discharge would be inert and only contain quantities of suspended solids. As the Fly River was already highly turbid it was considered an acceptable option. The river ceased to be able to sustain its value as a fishery and source of water once the mine began using it for a discharge channel.

Unfortunately for the mining company the people of the Fly River disagreed and took civil action against the mining company in its home country. The outcome of this is that the uneconomic tailings dam is being built at the cost of many millions of dollars.

Chapter 9
Russia

The vast land area of Russia covers the sun baked deserts of the south-east to the tundra deserts high above the Arctic Circle. It is certain that there have been many incidents of minewater disaster and accidents here, but the nature of the country and a certain lack of openness have made the reliable reportage of most events unreliable. In other instances the politicisation of some occurrences makes for uncertain facts and a lack of either candour or inaccurate data.

The knowledge that the development of mineral operations in the high Arctic and into the frozen oceans continues does give rise to many concerns with regard to both openness and technical abilities in these areas for the future.

9.1 KARAMKEN 2009

In August 2009 the tailings dam of the gold mine at Karamken failed with the resultant flood carrying away 11 homes in the associated mudflow. At least one person lost their life in the incident. The reason for the event has not been officially stated though geo-technical stability issues have been cited.

9.2 PARTIZANSK 2004

The coal powered generating plant at Partizansk voided about 200,000 cubic metres of coal fly ash and contaminated liquid via a drainage canal into the Partizanskaya River, in May 2004. This discharges into the sea at Nakhodka Bay in Primorski Krai east of Vladivostok. The environmental repercussions have not been reported officially.

The spill was fortunately comparatively small as the lagoon that ruptured held 20 million cubic metres of liquefied coal waste.

Chapter 10
South America

South America is a continent that has seen many terrible mining accidents and major pollutions take place. The examples that follow are illustrative only. The real numbers are far greater and have been accepted as part of the mining process, as is loss of life.

Many illegal operations have been responsible for much environmental damage over the years and nothing has been done to remediate the waterways and lands that have been affected. The local populations have allowed natural processes to attenuate the damage caused.

10.1 BRAZIL

Brazil, like most South American countries, has a history of illicit mining and a corresponding selection of small scale pollution issues. The scale in the majority of known events is small. Alluvial mining, especially for gold and gem stones, on an industrial scale is common along branches of the Amazon River and its tributaries. These are well regulated as are other mineral operations for uranium and other metals. The ad hoc mining is exceedingly hard to monitor in parts of the Amazon Basin due to dense forest canopy cover and small boat transport on the rivers being common.

It is notable that many mining operations in the country are of only recent investment and for this reason much of this investment masks many accidents of the past. Alongside these developments, regulation is being developed rapidly to focus on best practice. The Government has a wish to be able to receive taxes and royalties. Alongside this it also wishes to be seen to be demonstrating internationally that it is a strong force regarding the environments around and downstream of mines and their development. At the closure of mining operations in most parts of the country, large restoration and remediation works are mandatory on mining operations that want to enter previously mined areas. It is further being encouraged that local populations, in many instances, be consulted and involved in the redundant sites' restorations and final uses.

10.1.1 Mineracao Mine 2007

In January 2007 a tailings facility at the Mineracao Rio Pomba bauxite mine in Minas Gerais State overtopped. This caused a partial dam failure which released an unspecified amount of polluted water.

The incident resulted in several dozen deaths and over 5000 people being made homeless.

10.2 CHILE

10.2.1 Cerro Negro 2003

In October 2003 the copper mine at Cerro Negro in Quinta suffered a tailings dam failure. Fifty thousand cubic metres of acidic mineral spoil polluted a 20 kilometre stretch of the Rio La Ligua.

This mine had a similar failure in 1985 that vented 500,000 cubic metres of mine slurries into the local river. The event was activated by an earthquake which caused the foundations of the tailings dam to liquefy.

10.2.2 Sebastiao das Aguas Claras 2001

In June 2001 several surface workers at the iron workings in the Nova Lima District were killed by an acidic discharge of minewater waste from the dam, the resultant plume of pollution travelled 6 kilometres from its confinement site.

10.2.3 El Cobre New and Old Dams 1965

The El Cobre copper mine suffered a violent earthquake in 1965 which caused both its old and impoundment structures to fail simultaneously. The resultant combined flood of 2.25 million cubic metres of acidic waste slimes devastated the local environment, destroying the town of El Cobre 12 kilometres downstream of the site. The death toll numbered over 200 persons.

The same earthquake caused two other copper mine tailings dams to fail. The first, La Patagua, had a new dam which was caused to liquefy as was the other mine's at Los Maquis. They shed 35,000 and 21,000 cubic metres of mine waste respectively. Both were responsible for minor environmental damage.

10.3 BOLIVIA

10.3.1 El Porco 1996

1996 saw the El Porco mine suffer a major dam failure when 400,000 cubic metres of acidic slurries escaped. Three hundred kilometres of the Pilcomayo

River were contaminated. The pollution was dissipated by heavy rain during and after the event.

10.4 PERU

10.4.1 Huancavelica Tailing Dam 2010

A mine tailings impoundment ruptured in July 2010 in the Huancavelica Region of Peru. The dam break allowed over 100,000 cubic metres of polluted water to escape. The effects on the area were the flooding of more than 1500 hectares of farmland and the local village and the pollution of the drinking water of at least 4000 people.

The pollution entered six of the local rivers and caused fish mortality.

10.4.2 Amatista 1996

The metals mine, Amatista, near Nazca suffered an earthquake, in 1996, that liquefied part of its tailing impoundment, which allowed in excess of 290,000 cubic metres of waste liquids to escape its site.

The area covered was not great due to the majority of the liquid entering and polluting a river close by. Some crop lands were contaminated and crops destroyed.

10.4.3 Marsa 1993

In 1993 at the Marsa mine, a gold mining and refining operation had its tailing impoundment fail. Six people were killed in the acidic toxic waste water flood. Little is known about the volumes shed from the dam or any considered reason for the event.

10.5 GUYANA

10.5.1 Omai 1995

The gold mine at Omai had its tailings dam collapse in August 1995. This event released 4.2 million cubic metres of cyanide tainted acidic minewater and slurry into the Essequibo River, causing the national government to declare an 80 kilometre stretch of the river a national disaster site.

The reason for its failure has been attributed to internal erosion of the dam, possibly through leaking drains within the dam wall and spill ways.

Chapter 11

Law and Regulation

Law and regulation are areas of great importance and of issue internationally, with most governments around the world making much play as to the regulation of the mining industry and those that process minerals. This is most noticeable within groups of nations that have actually been subject to events that have been recognised as catastrophic. In reality though, once the weeks have passed and the media have dropped the story from their headliners, it is usual for the issue to be shelved.

The need to 'over regulate' a sector that is only operating in an area to extract a commodity, and will move away once that commodity has been removed, is felt to be temporary and in reality a nuisance rather than a long term regulatory concern.

This aspect of governmental thinking appertains to gravel extraction as it does to coal and other mining. This arrangement is remarkable when quarries are usually extended or the deep coal mines can have lives of up to a century or, as in the UK, much longer. Communities have become accustomed to their areas being the homes to certain extractive industries or the process centres of bulk products such as phosphates.

It is worth noting that the countries of the G8 and allied economically similar nations have put mining to the back of the political agenda in the last 10 years. In Britain, there was much rumpus made by those of the legal and political professions with regard to mine and water issues, such as Wheal Jane, and the continued growth in the number of minewater pollutions from the abandoned coal mining areas would be legislated for with the aim of seeing a termination of such events. In the last 10 years it has been noticeable, almost globally, that the states of the world have taken on the legacies 'in-state' rather than passing retrospective or corrective legislation. The mining and minerals industry, at the same time, has worked assiduously behind the scenes to both limit legislation and put its own house in order with regard to future environmental and social repercussions of end-of-life workings closures.

As noted above the legal profession is able to put the case for or against the minerals industry, but in most cases the will of the courts is not there to rewrite or, as would in reality be the case, reinterpret laws in a draconian fashion, rather than taking the less prescriptive and mild nature of the narrative of present day legislation internationally.

11.1 UK

The UK is a good case in point with regard to the law and regulation of this industrial group of operations as its governments have been involved in their regulation longer than those of any other country.

11.1.1 Working Mines

Discharges to the environment from working mines in England and Wales are controlled by the Environment Agency. In Scotland the function is overseen by the Scottish Environmental Protection Agency and in Northern Ireland by the Northern Ireland Department of the Environment. These mines are all controlled by the same mechanisms of consents under the Water Resources Act 1991 and the more recent Environment Act 1995. These consents or permissions include conditions relating to the quality, quantity, discharge method, monitoring and reporting of the minewater. The operators of the sites are also required to have separate permissions for the other operations and discharges that may be carried out above ground which may include activities from mineral processing to wheel washing of machines. Any failure is taken seriously by the enforcing agency and prosecution is the standard chosen route. The mine companies, apart from being fined, are forced to pay reparations to put right any damage that has been inflicted on the environment. This is known as the ‘polluter pays’ principle.

The workforce or residents close to a mining operation are protected from any hurt or damage by the various health and safety regulations enacted over the years. There is still an area of legal loopholes that dates back to before the Aberfan disaster which accept the element of Acts of God as do the mineral companies’ insurance providers.

The planning mechanisms in the UK play a major part in the issues of regulation of mineral extraction, both above and below ground. The Town and Countryside Act 1990, and its amendments and the amended Planning and Compensation Act 1991, require all Mineral Planning Authorities (usually county councils or unitary authorities) to prepare strategic mineral plans for their areas. These plans need to be carried out with wide consultation, with the regulators, neighbouring mineral authorities, the mining and mineral operators and the general public. It is in relation to these plans and the normal planning process that permissions may be granted for new workings in an area. (They are also the cause of much misunderstanding within the planning process with claim and counter claim for statutory review of decisions of the planning authorities. They have also been used to imply financial threats to individual members of the planning authorities.) During the planning process there is a need for the applicants to produce environmental impact statements and environmental background reports that are open to public scrutiny. The permissions that are granted are subject to conditions that are placed on the mineral company concerning the minimisation of environmental effects and also ensuring adequate reclamation and restoration on cessation of extraction.

The issues relating to historic pollution and abandoned mines is a much more convoluted area of legal endeavour.

11.1.2 Abandoned Mines

The working of minerals and many of the safeguards are well established in UK law and regulation; much of the legal infrastructure is in place to protect the environment. The legal aspects of mines and mining are far more contentious after an operator ceases operations.

In the 19th century the Department of Trade set up a Department of Mines to inspect the operating mines in the UK. Their task was in part moral, insomuch as the care of children working in mines was concerned. It also allowed for the eventual banning of females working below ground. Towards the end of that century the Mines Inspection and Regulation Act 1870 was put in place. This required mining companies to inform the inspectorate of a mine’s closure within two months of cessation of mineral extraction. In 1872 it was further enacted that, with regard to coalmines, regulations were introduced that required all abandoned workings to be recorded for health and safety precautions. It was further required that at least one accurately drawn plan was to be drawn by the mine’s surveyors of the last worked seams and this was to be delivered to the Secretary of State within three months of abandonment. This was required for planning control and development purposes.

The mining regulation regarding the metalliferous sector of mining activity has changed little from the 1870 Act. Metal mines have recorded their operational surveys and at cessation of mining occasionally lodged their last surveys with local records offices voluntarily or if some person thought to do so. This lack of compunction and the geological make up of the ground in which they are found leads to the subsidence risks in metal mining areas being totally unlike those in mining the coal measures.

The regulation of tailings dams has been an area left to the planning authorities, under the many Town and Country Planning Acts, and the mining companies to come to individual agreements. These have always required the adoption of best practice at any given time. The unfortunate aspect of their regulation being that when many mines, particularly metal workings, ceased operations the mining companies also ceased to exist. Many metal mining areas of the country have vestigial tailings dams and lagoons that have returned to nature and stand witness to their engineering strengths.

The legal requirement to notify abandonment of a mine remains from the 1870 Act though the act does not hold any environmental legislative purpose. The Mines and Quarries Act 1954 requires that the District Inspector of Mines is notified of any abandonments, either in total or if a seam or load is taken out of production. The time scales for notification is two weeks after mine closure and two months in the case of a load or seam.

The Town and Country Planning Act 1971 requires that an abandoned mine may not become an eyesore, but no provision is made to avoid pollution.

The Water Resources Act 1991 section 85(1), which was section 107(1) of the Water Act 1989, contains provision to prosecute a mine operator of an extant mine if their activity:

> '*…causes or knowingly permits any poisonous, noxious or polluting matter or any solid waste matter to enter any controlled waters.*'

Whereas the same Act section 89(3), carried over from section 89(3) of the Control of Pollution Act 1974, removes mine owners liability in the case of an abandoned mine:

> '*A person shall not be guilty under Section 85 by reason only of his permitting water from an abandoned mine to enter controlled waters.*'

This is due, in part, to the manner and nature of many metal bodies, the historic long-term mining of coal (all but a very few mines in the UK have only had one owner) and that the workings are, on the whole, extensions of historic workings. It is only in reality that when a mine closes wholly, it is only the curtailment of an episode of actions that could date back several generations and in some instances (particularly in metal mining) many hundreds or even thousands of years.

There has been one prosecution carried out by the state regarding the rebound of a coal mine, Dalquharran, in Ayreshire, Scotland in 1981. In this instance the Crown argued that the owners of the mine, the National Coal Board, had sunk the pit (1974–77) and it stood alone. Following their action of closing the mine in 1977, the Board should have expected that the system of workings would flood and polluted water would rebound to surface, thus causing pollution.

The water rebound was remarkable in that it killed all aquatic life in the River Girvan, an important salmon fishery. The pH of the minewater was between 3 and 4, with 1300 mg/l of iron and a flow rate of 26 l/s. Ship owners in Girvan harbour complained that some of their vessels' hulls had been damaged by the waters. No action was successfully taken against the National Coal Board.

The Crown was able to bring about the prosecution citing Section 22(1) of the River (Prevention of Pollution) (Scotland) Act 1051. This is a unique event in UK legal history.

11.1.3 Tailings Dams and Impoundments

Tailings dams are in the main governed by the planning processes appertaining to the conditions appended to the planning agreements that, may, have been issued at the time of their initial and subsequent planning permissions.

Under the law they have been considered temporary structures and in the past have not required any governance as to their impacts on the environment or their design as these would be agreed individually with the planning authorities. The legislation that is relevant to tailings impoundments are: the Reservoirs Act 1975, Mines and Quarries (Tips) Act 1969 and Regulations 1971, Environment Act 1995 and the Record of refuse deposited on active classified tips, Regulation 14 ‘A’.

The Reservoirs Act 1975 is the most important in that it requires that all active dam and water retaining structures are recorded by the local authority’s Inspecting Engineer in whose area they are located and that there should be an annual survey of the structure’s stability carried out. The owners of such structures should have a surveyor (Supervising Engineer) who is ‘competent’ in such structures available at all times in the event of a structural emergency. This Act only applies to active impoundments, of which there are few in the UK. Historic or redundant sites have fallen under the responsibility of the local authorities with regard to technical security and safety issues.

An Inspecting Engineer is only allowed to inspect a particular site for a period of five years before being appointed by the Government to another site.

Under the 1975 Act it is required that any abandonment or cessation of use of an impoundment structure needs to be notified to the Secretary of State by the local authority and not the mining undertaker.

The Mines and Quarries (Tips) Act 1969 was the government of the day’s reaction to the Aberfan disaster and the Regulations 1971 were the mechanisms that afforded the Act’s limited workability. The most compelling part of this regulation is the statutory requirement to keep the public away from mine waste, even in the event of trespass.

The Environment Act of 1995 in some ways pre-empts the EC Landfill Directive 1999/31/EC which requires the record-keeping of volumes and make-up of waste deposited in a waste holding structure. This is in so much as the waste is neither inert nor exempt. Most mining waste is at present considered exempt waste from the regulation though there are wide ranging debates regarding the issue.

Thus there is an ambiguity in the 1991 Act which still remains a legal loophole. That is that a mine owner may abandon a mine and if that mine rebounds causing pollution there is no liability to that person or company. Mines such as at Wheal Jane were abandoned and the owners were able to walk away, regretting the pollution but not unable to do anything to ameliorate the situation and with it not being their responsibility in law.

11.2 EUROPE

The main piece of pan-European legislation that relates to mining is the Waste Regulation Directive 1999/11/EEC. This though appears to be lacking in regulation as the courts across the European Union fail to use the Directive, where it has been adopted by member countries, due to the complexities of the technical mining issues of waste and the mechanisms of liberating minerals from their parent rock or strata.

The effects of tailings dam failures in several European states has brought forward no prosecutions of mining companies and only criticism of individual states for not having national legislation in place to address the issues.

Civil actions are taking place in Spain, Hungary and other states, but resolution of this swing one way and another with different proceedings. The vacillation of blame and unforeseen/blameless accident is expensive and removes the need for more enforceable legislative powers using the international industry guidance available today.

Since 2005 the EU Council have been working to put legislation in place to rectify this area of apparent weakness in legislation and governance. There are though many problems regarding the definitions of waste and discrepancies in mining terminology within the member states of the European Union.

The legislative areas of pollution to natural waters by contamination may be classified into three areas: discharge of waste and hazardous substances, increasing quality objectives and specific industrial areas. The titanium dioxide industry is the main example of such attention in the UK.

The area of pollution by waste and hazardous substances is guided by a set list of Black List substances which are considered toxic, persistent or bio-accumulative in the environment. Such, mainly, organic substances are prioritised for elimination from discharges to the environment. This Black List was published in 1976 as was the Grey List consisting of metals and other materials that were awaiting elevation to the Black List. Little regarding the elimination of the Black List substances has been achieved.

The EU requires all member states to concentrate their environmental strategies to defend against pollutions or eliminate sources of pollution.

11.2.1 Sweden, a Case in Point

The regulation and legal liability of tailings dams is covered nationally by guidance and regulation of all dams, hydro-electric reservoirs for public water supply and other water holding needs, alongside that of the minerals industry. In this regard there are about 10,000 dams located in the country. There have been few failures.

One on record was in 1973 when a small dam broke on a tributary of the River Klaralven, which breached, and one person was killed.

This accident resulted in much media concern regarding dam safety but, apart from a legal right for the planning authorities (County Administration Boards) to take action against owners of dams if they were unmaintained, nothing legally tangible was placed on the statute book.

The laws regarding dams are covered by the 1918 Water Act but only in so much as they were structures in water and required their authorisation by the Environmental Court. The actual planning and method of construction was considered part of the planning procedure, which lay with the planning authorities who required only that the dams were designed for their purpose. The actual construction was left to the owner's own presumption that they were designed for their purpose. The dam owners have through time proved to have been conscientious in their role as designers, specifiers and operators.

Since the 1990s Sweden has put together a set of principles that have been expected of dam builders and operators. This has been in great part at their instigation and the major issues covered have been developed by the industries involved. These are known as the Swedish Environmental Code and enshrined in the Water Act 1999. The responsibility for ensuring compliance still rests with the Supervisory Authorities as local planning authorities but with the knowledge of their own expert advisors.

The state and the regulators are jointly working to develop an independent dam inspectorate that will maintain the regulation and develop methods of best practice, both in Sweden and also to aid countries as yet devoid of regulation and at risk from accidental discharges or wanton acts of pollution.

11.3 US AND CANADA

Both the United States and Canada have similar mining codes and mimic each other in many ways with regard to federal/national and state control of both environmental and human safety. Similarly with regard to the minerals industries, both mining and processing.

Canadian legislation is, though, more entrepreneurial, in that it allows the creation of a great number of small exploration companies that have linkages to major operators but stand alone. This is a protection mechanism in the litigious environment that the mining companies find themselves in, in North America.

11.3.1 US

In US law mining regulation is mainly legislated for by state legislatures. The federal interest in mining legislation has been with regard to revenue raising by levying royalties on the various minerals mined. The first federal mining act was the Mining Law Act of 1872, which was to limit child labour underground and ban women totally from that environment. More importantly it levied the first royalties from the mineral claims that were being established across the country as new areas were opened up to the population.

There are though more than three dozen environmental laws enacted as Federal Acts that in some ways affect mining and mineral industries. The ones most affecting the industry have been the National Environmental Policy Act, which required an integrated interdisciplinary approach to environmental decision making, and The Federal Water Pollution Control Act or Clean Water Act which ensures that standards are set for the qualities of surface water and the control of discharges to those surface waters.

The best known of these acts is related to the 'Super Fund' scheme that is in place to address manufacturing sourced contamination of land: the Abandoned Mine Restoration Fund which requires financial bonds to be lodged with the Secretary of State for the Interior as a central fund which may then be allocated by need to individual states. This piece of legislation is unique, being the only piece of legislation in the world that is using present mining derived funds to pay for reclamation of historic pollution (Mining Control and Reclamation Act 1977). In reality this fund is over subscribed by need; the liability far outstripping the funds available and local groups and philanthropic funding are needed to rectify the shortfalls in revenue (Brown et al. 2002).

11.3.1.1 Washington State Guidance

Washington is highlighted as an example of regulation and as an opportunity to understand the legal guidance regarding United States mining and water management.

The issues of mining and water are regulated by the Washington Department of Ecology. The department's remit is to 'ensure purity of natural waters with regard to public health and public enjoyment, the protection of wildlife and the industrial development of the state.' The same department controls the licensing of landfill and dumps (mine wastes, including tailings) and hazardous waste such as acidic or otherwise contaminated minewater. The department also licenses the planning and implementation of wetlands for the treatment of minewater discharges.

The issue of wetland planting is also managed by Washington State's counties' environment protection agencies' responsibilities due to the need to avoid certain plants crossing county or state boundaries. This can cause problems for the establishment of such entities for the treatment of minewaters.

The State Solicitors Office has been considering both local and federal Acts that may be of use to regulate the minerals industry. They have identified over 80 individual entities, but after attempting to prove their viability have found that the mining industry is outside their spheres of influence.

In many instances as in other states (Pennsylvania, Dana Mine, 2011) the environmental protection and regulation authorities have to co-fund remediations of mine contamination as such expense can be argued as too costly for mining companies to fund.

11.3.2 Canada

As already stated much of Canadian mining and mineral law mirrors that of the United States. The country, though, has taken steps of its own to safeguard the vast areas of virgin country in its least populous regions. This is due in part to the growing awareness and resolve nationally to care for its pristine environments. It is also acknowledging the Canadian indigenous peoples of their rights to unpolluted and undisturbed hunting grounds. This area of legislation is being queried vigorously by all sectors of the minerals extraction industry.

The majority of legislation regarding environmental consideration is delegated to the provincial legislatures. Though when incidents occur or mining issues are raised in the courts the national government's view overrides the local legislation. Mining is considered in the national interests of the Canadian nation and may be absolved of wrong doing under national jurisdiction. The mining sector is of strategic importance to the state and has a buffer of impregnability through this. Today there are several pending actions under the bi-partite North American Commission of Human Rights that may be willing to award judgement against mining companies if they are considered to have infringed civil liberties. The environment and accidental damage to individual or group rights to an undamaged environment have yet to be tested in this manner. A veto would be certain from federal government if it felt that such a treat to the nation's fiscal well being would be sure to be lodged.

Much of the emphasis of gaining redress to incidents affecting the water environment rely on such legal texts as the Quebec Civil Code, the successor and assign to the former Civil Code of Lower Canada which accepts concepts of riparian rights and their obligations of care. Much that occurs in the North West of Canada that may be considered detrimental to Alaskan interests is taken to the United States civil court system under pan-North American convention agreements. The outcomes of such actions are contentious and may not be binding on Canadian National companies.

There are attempts in the national Parliament to control Canadian mining corporations internationally. It is reported (Info-Mine) that 60% of world mining and mineral exploration corporations are based in the country. The legislation being considered is that catastrophic events superintended by such companies would lose their rights to Canadian state fiscal support through the nation's investment body, Canadian Pension Support (Mostly Water 2011).

New mining ventures in Canada do find that their environmental liabilities are underwritten by the processes that license mineral extraction in the wilderness and state lands. The historic major pollutions of rivers from the issues of abandoned mines are still to be dealt with in legislation. As in the UK this liability is likely to fall either on the national or state financial resources.

The main issues of law are that damage to property by flood is a civil issue, though covered in the Environment Protection Act which prosecuted the ex-owners of the Matachewan Consolidated tailings dam that discharged after abandonment when the cause was, as previously discussed, due to the actions of beavers.

11.4 RUSSIA

Mining and disaster legislation is scant, as it was in the period of the USSR. The majority of mining regulation is aimed at ensuring the state receives its dues and royalties. The environment and the underwriting of its care and wellbeing are only just starting to be an accepted area of litigation; the national government, though, has yet to develop a framework for monitoring many areas of concern. This is particularly true with regard to the mining and mineral prospecting activity above the Arctic Circle. The regulation of such an area, much of which is perpetually frozen is exceadingly difficult. The Russian regulators are, though, constantly vigilant with regard to collecting the revenues of exploration and royalties for exploitation. This allows the state to monitor vast areas of the nation as comprehensively as during the old Soviet Government era.

The other aspect of this ability to monitor and know the mineral exploration and exploitation of the Arctic allows the rest of the country to be prone to economic surveillance.

In 2010 the Russian state laid claim to the mineral rights of much of the frozen Arctic Ocean continental shelf. This claim gave rise to an immediate concern for other signatories to the several international protocols that are in place to underwrite the protection of the region and the importance and inviolable protection that was agreed for this frozen ecosystem. Fears were expressed as to the possible damage to such a fragile set of interlinked ecosystems, if the Russian minerals industries began an advance into these harsh climactic regions.

Much thought has been put into perspective in 2011 with the general research being carried out into prehistoric and/or pre-industrial lake waters in parts of this same region. The Russian state wishes to be seen to be taking the international conventions for the environment as national obligations.

It is the nature of the country that each region has certain autonomies and as long as the regulatory dues are available to the state much malpractice is considered to be, if not acceptable, tolerated. The state is developing methods to begin to kerb the current laissez-faire regime that is prevalent at the present time.

It is worth noting that, due to the lack of past regulation, the legislators are starting with a blank canvas on which to work. There is a growing acceptance within many industrial sectors that environmental solutions and best practice are routes to travel as there are financial benefits as well as better public relations gains. There is a move to further the elements of ethical behaviour being championed by energy and infrastructure companies as they develop out of their Russian home area into the global sphere.

The Organisation for Economic Co-Operation and Development (OECD) states that increase in mineral resource extraction, "particularly hydro-carbons has been accompanied by a decrease in environmental care and there being a widening number of offences and corruption. The regulatory framework is subject to frequent change and, therefore, the costs of environmental compliance are often unpredictable thus increasing investment risk."

In the light of the above OECD statement the President of Russia, Mr Dmitry Medvedev, restated (June 2011) what he had already promised in 2010, which was a full overhaul of environmental legislation and regulation.

11.5 CHINA

China's environmental laws with regard to safeguarding the environment are only now starting to be developed. Initial regulation of the sector began in the 1980s but the years since 2000 have seen China's growth of manufacture which requires all manner of mineral material to feed the raw materials to fuel the growth in manufacturing. This need is seeing China not just increasing its home based industry, but also developing mineral exploration and mining interests in many other parts of the globe, including the Philippines, Africa, South America and Asia. The main mineral materials are usually where their main utilisation can take place, e.g. coal, where power is to be generated and similar examples. This means that large regional centres of mineral exploitation and their use have developed populous centres. The rural areas of China, though, are also rich in minerals, but are not of a major deposit. This will allow for ad hoc artisan mining operations. These small regional operations are found to be the most polluting. Pollution of rivers, ground water and agricultural land are regularly reported as taking place.

These artisan mining operations are not licensed and are considered illegal. Corruption and local fiscal need are apt to protect these operations from the eyes of the regulator. They eventually are discovered and are then closed. Once the regulator's attention is taken to other areas, these operations re-open.

In many instances these illegal, or at least under regulated, operations are the major suppliers of many important economic minerals. In 1997 the production of bauxite, antimony, coal, phosphate rock, tin and tungsten contributed between 40% and 70% of national output.

This sort of production has now been understood and new regulations are being drafted to accommodate such mineral and mining operations into the mainstream of recognised production. This also allows for the welfare of workers and other health and safety considerations.

The major mineral operations, though regulated, have been allowed to mine and win minerals without the 'heavy' hand of regulation. The reality of the economic growth that has overtaken the country in recent years has been at some major cost to the environment. The United States' Environmental Protection Agency are working with their Chinese equivalents to develop ways of regulating and monitoring that could be put forward as models of desirable best practice in the United States as well. This initiative is under the aegis of US Aid.

To make the proposed new regulations and legislation more readily acceptable to the industry there are to be long lead-in periods so as to enable the changes in working practices to become a part of the general routine. This is due to the figures of mine activity residues: 85% of the nation's annual waste production and 10% of the waste waters. The State Environmental Protection Administration state that only 4.45% of these wastes is estimated to be treated and properly processed.

11.6 PACIFIC NATIONS

The Pacific nations include Australia and New Zealand, both of which are discussed below. Other nations, such as the Philippines are only now awaking to the problems of mining and the lack of native legislation. The vast economic growth of the region, emulating mainland China, has created a market for raw materials that only these smaller states can supply. Indeed much of the mining activity in these smaller nations is being undertaken by that regional giant, mainly as part of the complex aid agreements supplying modern infrastructure developments.

Legislation has lagged behind these mineral developments and has had to be reactive rather than setting the agendas. There have been many unreported pollutions and much hearsay reports of environmental bad practice or wanton disregard for any environmental care. The new legislations that are now catching up are much more draconian due to the need to kerb the excesses that have taken place previously. Issues of corruption are now the new area of concern, as are the proliferation of small illegal mining operations that smuggle their outputs onto the black market.

11.6.1 Australia

Australia has one of the most buoyant historic mineral mining industries; it is also a country with sound mineral and environmental laws. The nation's Environment Protection Agency has worked closely with the industry to create codes of practice to cater for nearly all eventualities and issues.

The vast size and the complexities of its geology allow for nearly every mineral in one form or other to be encountered and also the environmental challenges that are to be expected. The country was poorly served by its legislation, but during the 1980s there was a great change in Australians' perception of their varied environments and the need to protect it as well as to exploit its vast mineral wealth. To a great degree today the mineral waste is the main funding source for the protection of the national environment.

Mine law requires that all scenarios are anticipated by initial planning procedures, even for prospecting activities. Before they are developed, mines have their closure and restoration plans approved. Many mining companies take it onto their company's liabilities to attempt to ameliorate the damages that are the inevitable results of mining and processing operations.

11.6.2 New Zealand

The laws that appertain to the minerals industry in New Zealand are similar to, and as stringent in their care for both the population and the environment as, the Australian laws and the minerals industry is accepting of them. As in Australia the industry goes to great trouble to not just offer lip service but to take its responsibilities beyond that which is required.

The Resource Management Act 1991 brought together legislation governing land, air and water resources. The Act introduced a novel approach to environmental management in that it introduced an integrated approach to any development. This allows an 'eco-system approach which recognises that all parts of the environment do not stand alone. All human activity does not stand as a discrete entity.

This legislation embraced the Rio 'Earth Summit' of 1992 and its widely embracing concept, requiring environmental sustainability as well as economic viability and social justice.

With the above Act, the Crown Minerals Act 1991 requires that though a mining permission may be granted the environmental aspects override any other consideration. The only aspect that is waived is the element of sustainability regarding the activity.

The New Zealand Government, with the minerals industry and the utilities providers, have an ongoing research initiative considering and researching methods of pollution remediation. Its findings are offered to less environmentally prepared countries or other entities.

11.7 SOUTH AMERICA

South American legal exertions into regulating the huge minerals industries across the continent are all allied to one another. There are specific elements that relate to each nation's own particular experiences, both environmental and political. The major international mining companies are setting the main environmental agendas.

This is an element that is unexpected as for many environmental activists and the media they are considered major despoilers. The reality, though, is so vastly different. Many international corporations now have many shareholders who expect and require that such repositories of their owner client's funds are invested in ethical concerns. This aspect of the minerals industry has driven huge changes in how their core activities are carried out. The aspiration of the majority of mining companies is to be based in London with their shares traded on the

London Stock Market. The small exploration companies are usually found to list themselves on the Canadian ‘AIMs’ Market.

The Main economic powers of the continent have had the majority of their environment and mining legislation written for them by the largest global companies. They are amongst the most stringent pieces of legislation with high morals and high expectations of the industry. It is remarkable but such regulation allows more freedom for these corporations. The strong regulation makes it more difficult for small scale operations to compete for mining licences. It does not, though, stop pollution from illegal mining activities which are common across the whole land block.

The illegal operators have several reasons for their operations, all fiscal but ranging from financing and arming rebels to funding drug gangs or educating the children of an area. The common denominator is that many of these illicit funding operations caused pollution and, once discovered, their closures can be exceedingly violent. The spirit of the Conquistadores is still alive across the continent.

11.8 AFRICA

Africa has much to be considered and needs to be considered as at least three latitudinal regions: North, Sub-Saharan and South. The three have remarkably different attitudes to minerals and also to pollution. Much of the continent has environmental codes, there is widespread corruption and there are also many avoidance and illegal activities to contend with.

11.8.1 North

The countries making up this group all border the Mediterranean Sea. Law is based on that of Islamic teaching, though now some of the issues that have to be addressed are beyond the basic tenants and beyond the realm of most imams. Though the law does champion respect for the people generally and as individuals and respect for the environment is fundamental as the earth is to be respected and not degraded or damaged.

There is a need for raw materials and there has been an increase in global trade. The markets for most of the nation’s minerals lie to the North in Europe and this has led to a long period of mineral exploration. Phosphates, oil, and gas are major components of this trade and many others, such as cobalt, gold, copper and rare earths have made significant contributions.

Environmental control and legislation have lagged behind the development in exploitation. This has to be accepted as there are now codes of practice for the industry. Many of these are based on the international conventions that outlaw the continuance of pollutions entering the Mediterranean. This has led to one country switching the location of phosphate processing to the Atlantic seaboard.

The elements of law and the environment have been longer understood in Libya than any of the other nations in this section.

11.8.2 Sub-Saharan

The Sub-Saharan nations are rich in the majority of minerals that are both needed and desirable, they have also, in great part, been governed in manners that have been unsustainable, environmentally profligate, ungoverned and anarchic. There have been, and there still are, many civil wars and other continuing instabilities across the region. Environmental laws have been formed and forgotten before their enactment. There has been little stability. It is this stability that is needed to allow environmental consideration and legislation to be implementable.

International organisations and Non-governmental Organisations (NGOs) have attempted to limit many mineral based pollutions and actions that enable them to take place. These have in most instances failed due to the desire for funds that can be generated through the black markets for arms, drugs, influence or just greed.

Where stability is achieved, and that is now in the great majority of nations, the governments are looking towards the large international mineral corporations to take on the mineral development of these nations. These companies are able to bring about remediation of the previous workings in some areas or develop virgin sites and at the same time develop both local and regional good will. They also, alongside the international agencies and the governments, develop codes of practice, many of which lead to national legislation that allows the operation of new indigenous mine workings, though many of which in the past had been highly polluting. The number of catastrophic accidents involving water have gone unreported but there are many hundreds of damaged sites in this region that demonstrate that such events took place.

An unexpected benefit of the development of international mining activity is the protection of many threatened indigenous species that would otherwise be at threat from poaching.

There are some nations with longstanding regulation but in many areas the rebellious activities of disaffected groups include sabotage in attempts to induce economic sabotage as a tool for their ends. The main loser is then the environment which is more damaged than national or international revenue streams.

11.8.3 South

The South of Africa is now a stable group of nations that are both mineral rich and now much better regulated to control environmental catastrophes. The size of the land area does preclude a totally regulated mineral regime, but the size of illegal operations is far smaller and their propensity to create major pollutions is subsequently reduced.

The nations have put much reliance on international companies to mine much of the region's minerals. This region has also spawned some of the largest mining companies and allied environmental consultancies that now operate globally.

11.9 ASIA

The vast region of Asia is broken down into four, along geographical and socio-political areas: The Middle East, from Turkey to Afghanistan; the Sub Continent; the East, including Laos and Vietnam; and the Central Region, lying between Russia, China and the first two areas of this Asia section.

11.9.1 The Middle East

This region stretching from Turkey to Afghanistan and Iran is a vast and varied area, rich in minerals and many issues of pollution caused by mining at some sites where there is water to despoil. The general lack of water throughout the region adds to the unusual conundrum of major damage to dry river beds or wadis. The elemental concern is that any moisture allows growth which may also become contaminated and poisonous. Where there are waterways of any size, they are usually transnational, passing through several countries, such as the Euphrates River, the River Jordon and several others that are less well known.

The nations are all signatories to various environmental codes and initiatives. The problems that have emerged they are not able to deal with, or respond with any planned response, as there are few countries with responsible agencies to meet any environmental threat. The minerals industries are in many countries, made up of small, indigenous, and in many cases totally unregulated, operators.

Apart from Israel, Turkey is the only country with operational environmental legislation and an agency to propound the benefits of environmental care. The country is beginning to adjust its environmental controls on the extractive industries and is looking towards Europe, both for membership of the Community, but also to encourage large minerals companies to develop operations in the country. There have been numerous, unrecorded, environmentally damaging events that have, by suggestion, damaged the country's faith in their own national regulation and its enforcement. New codes and practices for both the areas are envisaged to be enacted over the next few years. (Private interview at the Turkish Ministry of Development and Commerce.)

11.9.2 The Sub Continent

The environmental law and regulation of Pakistan, India and Bangladesh are, with regard to mineral mining and the managing of effects on the environment, fairly established. There are some criticisms that governments are still influenced by the old colonial attitudes to the industry; these are more to do with internal posturing with regard to local political ideology rather than the actual concrete issues.

The governments at national and state levels are aware of the large resources of their nations and regions, the needs of the rapidly expanding industry based economy, and the finite nature of the resources that are being extracted from the ground. They are also conversant with, and actively seeking to avoid, mine related environmental damage. The nations are careful to rely on strict guidelines and planning procedures with relation to both surface and ground water issues and their protection and also the problems of impoundment.

There are small mining and mineral processing operations across the whole region that exploit any available mineral that is of value. These are, in the main, illegal operations that in many instances cause pollution far outweighing the mineral worth that most operations generate. The use of cyanide or mercury to liberate gold has been found to be widely abused. Many small rivers and streams have been badly contaminated (WHO 2004). Similarly many groundwater sources have been polluted.

As has been found in Africa and elsewhere, illegal mining is practised, though there are few records kept, particularly of wastes discharged or even minerals exploited. Pollution goes unrecognised and is an accepted aspect of general existence. If such a mining venture is challenged by authority the operation may close down for a period only to be resurrected when the authorities are occupied elsewhere.

11.9.3 The East

The region includes the old designation, Indo-China, Burma to Vietnam. The whole region has both large mineral concerns and artisanal small scale operations. The number of mines is unknown in several states, particularly Burma, and no state has any comprehensive inventory of environmental incidents. Water issues are, in several areas, not considered to warrant consideration.

In Burma there are a number of major mining companies present, including at least one UK managed concern, who have set both themselves and the industry a high level goal of environmental stewardship and good practice in the field of copper mining. The somewhat invisible government has used these high level companies and their presence in the country to demonstrate their awareness and ability to protect the environment from degradation, though this is not through governmental policy but through in house good practice and management. The unfortunate problem in the country is that it is ‘black listed’ by most insurance companies and the major mineral extractors have had (since 2005–2006) trouble in procuring, to their satisfaction, any acceptable environmental liability insurance cover. This is due to the larger underwriting companies being aware of the Burmese Government’s record of abuse of fundamental rights of its citizens and withdrawing offers of insurance as part of the general worldwide boycott of granting services to the country. These mines have either closed or been put into a care and maintenance holding state whilst the mining companies await development. The world copper markets are also minded to follow the insurance companies' example and cut trading links, as with the diamonds mined in Sierra Leone in west Africa during the period of internal conflict when that trade was curtailed by similar boycotts. The problem is that it is almost impossible to state the origin of copper, unlike diamonds, once the copper is refined.

This situation has led to a large growth of small scale 'dohtar' or small scale artisanal mining. Burma having little environmental legislation and as a nation having a need for copper and other minerals to satisfy the domestic needs of the country is relaxed about the development of these ad hoc operations. One area around Monywa has taken to this method of mineral working, due to poverty and the degradation of the agricultural land due to small scale mining pollution over the years. The rejoin is blighted by acidic waters and contaminated soils. The social structure, which acknowledges a form of serfdom where workers are bound to masters, also allows for an underclass to be subjected to working in intolerable conditions.

The development of these mines is spreading further afield, and as such mining and its attendant practices continue and the environmental damage develops and is, in many instances, severe.

This unregulated set of problems is at odds with the situation in Vietnam, where the mining sector finds that the environment is so regulated and regulated in such a way that no regulation is workable. The protection of the environment and the regulation of mining are well considered at a national level with regard to engineering structures and discharges. There are areas administered my several ministries, primarily the Ministry of Science, Technology and Environment, but other ministries' regulations interfere in the administration of the legislation. This overlay of responsibility is exacerbated by regional or provincial governance and regulation. These regulations would be expected to mirror national governmental policy, but they fail to do so. This situation is further exacerbated by the lack of responsibility with regard to policing the rules or encouragement of good practice. It is this administrative muddle that is claimed by several groups to be responsible for several severe cases of ongoing water pollutions as well as one off events.

11.9.4 The Central Region

Mongolia and those nations that once made up a large part of the old USSR are very much in flux with regard to the adoption of environmental regulation. All the countries are signatories to protocols of best practice and regulation, though there is still much that has yet to be achieved.

Recently, since 2005, there has been much research carried out by the individual governments to identify the many problems that emanate from the minerals industries and their effects on the environment. This research has also studied the environmental law, regulations and regulators and their interaction with the industry and with the individual nations' mineral exploration and production ministries. Across the board it has been found that there are fundamental flaws that allowed the mineral extractive industries to exploit their locations and exploit their locations' environments. The re-regulation, if any, has not been exercised. Corruption and a blind eye have allowed much pollution to take place and at worst this pollution has totally violated many hundreds of kilometres of rivers and other water bodies.

There have been no well reported events of this despoliation, but most nations' environment ministries admit that major events have taken place. Many large companies have been instructed to change working practices and have been encouraged to use European or North American expertise to bring about change and to set rigorous targets. Many of these changes have been advised to several governments by outside consultancies.

Much of the terrain of this region is sparsely populated and the small populations have, as they have throughout history, been reluctant to acknowledge regulation sent down. There is an ad hoc semi autonomous regard to the whole issue of mining as a form of wealth generation. This also addresses the aspects of environmental pollution. The isolated nature of such mining communities requires a certain self sufficiency of agricultural practice and the need for an unsullied eco-system. These communities are now under considerable pressure due to economic changes and the development of the industry as a major developer of regions, bringing modern infrastructure and risk of pollution on an unprecedented scale.

Other mining activities are more primitive or rudimentary, including ad hoc panning and other small scale examination of gravels freed from the frozen tundra in the spring and early summer. The lack of scale prevents any damage to the river in the environment though the results of such industry have attracted prospecting interest and by such development the resultant new mining has given rise to severe environmental damage.

11.10 INTERNATIONAL AGREEMENTS

International agreements regarding transnational rivers, waterways, lakes and seas are a hugely varied and complex set of fora. Similarly the mining companies have their own fora that cover such issues as tailings dams and environmental management.

The shared waterways issues have come to public notice in Europe twice in 10 years with regard to major treats to the Danube River which was considered severely threatened by mine/mineral waste water pollutions. These incidents emanated from, firstly, Romania and, secondly, Hungary. The Danube is considered an international waterway which flows through and takes water from 19 countries; this makes it the most international river in the world. The fears that this major waterway was under threat were real but did not materialise in the horrific proportions that were predicted. The pollution did reach the Danube via the badly polluted tributaries, but due to dilution factors there were no notable effects. The pollutants were monitored along the river from the confluences with the polluted streams through to their passage out into the Black Sea via its delta.

The Danube has developed, over the 60 years of the catchment management system of the river, a system that ensures that if needed there is an available taskforce to help along its length to minimise or prevent any pollution event. The river system is monitored along its length and the various environment regulators are practised in working together.

The Mediterranean Sea has developed, over the last 30 years, a similar but less vociferous working alliance which is working to prevent mineral working and processing discharges, amongst many other pollutants, entering this near landlocked area of water. (Since 1990, the Baltic Sea states have established an international water/pollution management strategy group to attempt to limit the pollution of its waters.)

Many mining companies, national governments and academics have grouped together to promote safe minewater and encourage informed regulation of this source of many pollutions, significant damage to property, ruination of many environments and large losses of life internationally. The Commission Internationale des Grands Barrages group has published a major report: Tailings Dams Risk of Dangerous Occurrences; Lessons Learnt from Practical Experience. The committee sadly felt that, their report should have ‘no legal force’ it was also only for ‘use of experienced professionals who are alone equipped to judge their’ (the report’s findings) ‘pertinence and applicability.’

This report and the committee’s recommendations, contrary to the committee’s wishes are, fortunately, actively being considered to be used as the basis for future industry regulation by many countries.

The European Commission is constantly looking towards best practice regulation to benefit the environmental wellbeing of the member states of the European Union and beyond. The Commission is using its aid program to spread the ethos of good practice and strong regulation of the minerals industry in donee countries. The outcome is producing receiving nations with stronger environmental legislation than the donors’.

It is a sad reality that disasters are needed for many of these and other groupings of similar interest groups to take their roles seriously. Too often it is seen that catastrophe is the source of invention, mediation and action.

In Africa, there are many trans-boundary rivers that have developed water protection treaties that include the protection from pollution and mineral industry damage. The Nile Basin Initiative was formerly agreed by most of the countries through which it flows in the 1990s, taking into account the Stockholm Treaty of 1966 and The Shared Watercourse Systems Protocol of 1995 which was initiated as a South African Communities initiative. This has bearing on several other sub-Saharan rivers, such as the Congo and Niger.

The Nile agreement is primarily an agreement on sustainable flow regimes and the allowance of each nation the river passes through to make use of its ‘share’ of the water. This has predominantly been with regard to dams involving the development of hydro-electric generation capacity and irrigation of agricultural land. The protection of its vast fisheries from pollutions is only a small part of the agreement and is currently being developed further.

The Niger River is under threat from huge mining operations in the Nubian aquifer in south Libya. The mining has though been for water rather than mineral gain. The headwaters of the Niger River emanate from the Nubian sandstone aquifer that stretches beneath much of the south eastern Sahara. The scheme to mine water on a scale that has never been considered by any African country before feeds the cities of the Libyan Mediterranean coastal strip, irrigates crops and is planned to supply many rural communities. This use of ancient water is seen as a direct threat to the fragile economies of the affected sub-Saharan nations to the South.

In South Asia, Pakistan and India there are several agreements on the protection of water rights. The Indus River Catchment is an international diplomatic exercise that is ongoing and the inter-state agreements regarding the protection of the River Ganges has shown success in limiting mineral industrial damage to the watercourse.

11.11 LEGISLATION AND MINERAL INDUSTRY, FUTURE CONTROLS

Internationally the minerals industry is coming under scrutiny as to its environmental responsibilities and liabilities. The Internet and other methods of communication allow no part of the globe to be totally cut off from the world community. The freedom to act in a manner that subjects the rivers of countries to pollution by accident, malice or greed, and retain anonymity is now ended. The main limiting factors of pollution events being hidden are only managed by states themselves. The ability to disallow access to regions or areas is rare except with the at least tacit approval of national governments.

The other consideration is that pollution or the perception or fear of such events is used to bolster other organisation's claims to greater power or aid funding.

These concerns have been seen internationally. In Ethiopia the Awash River and its valuable water supplies for power generation, irrigation and fishery are held up as an example of corporate pollution, though the problems arise from the drainage of the capital and its near 4 million population, and are not, as is often quoted a method for removing an ethnic group from the region by purposely poisoning the waters.

Future international mineral and mining controls and legislation will look to each country to develop, where it has not already, a specific set of rules and guidance. The specifics of detailed legislation and encumbrance of failsafe regulation may incapacitate the development of minerals that nations need to develop. Legislation cannot be seen to impoverish the lives of people who need to access work and the environmental concerns and regulation should, and are likely to, enable this to develop.

The minerals of greatest value to each country will in many cases be the basic necessities of development. Sand and ballast, phosphates for agriculture, roadstone and gypsum for plaster are all regulated sparingly. This is beginning to alter as the communities where they are won require the same respect as other citizens and expect similar rights. The high value minerals, particularly gold, will tax the ingenuity of human kind to tease out the precious fractions of the mineral from ore bodies holding less and less of the precious material. In the case of gold, mercury or cyanide leaching to remove the ore's precious load results in the remaining residues being some of the most demanding environmental wastes to remediate. The legislation that is developing in many countries and trading blocs is driving these issues on. As the commodities' base prices rise the regulatory pressures are more readily applied.

In the nature of precious metal exploration and exploitation many of the finds are prospected for by small companies of enthusiastic explorers whose funding is derived in many instances from adventurers in the capital markets; venture capital. Once a prospect is identified and proven the venture is allowed to go to the market for sale as a viable option. The finance in the modern economic world requires big players, the major companies with international experience of not just mining but also the markets for the finished commodity. As has been seen earlier these companies are apt to be more zealous of their environmental practices than the host nations.

As has been previously noted these companies do not benefit from having poor environmental records. Their reputations for high standards of environmental consideration is a bench mark by which they wish all other minerals ventures to be judged rather than they be likened to a small illegal operation that may cause considerable damage to local and national reputations.

In many ways the Australian Environment Protection Agency foretold and pre-empted these ways of working when publishing a series of notes on environmental considerations and planning guidance notes in the 1990s. These considered not just the regulatory issues of governance, but the ethical and moral issues of locating and operating a mineral concession and its product development, the processing and final abandonment.

Mining and the minerals industry have changed much in the environment over the many thousands of years since the first natural materials were removed from the ground. Sites of historic mineral exploitation from primitive times are still identifiable, Grimes Graves in the UK, being a good example where there are 40 hectares of alien ecosystems that resulted from the removal of nodal flints from the chalk bedrock 3000 years ago. Today a major minerals operator may try to leave a site as if it had not been worked and hope the landscape remaining could be seen as similar to that which was there before human interference 3000 years ago. Some sand and gravel quarry sites in the Trent Valley, UK are able to carry this out under creation or recreation of wetland habitats, which are considered to be in short supply across Europe.

The whole habitat creation or reintroduction idea has been seen as a desirable way forward by the mining industry as the only other method of restoration that is acceptable to planning authorities is that the landscape would be returned to its former contours and former uses. This option has now been lost to the councils and other planning authorities in many parts of the world, particularly within the European Union, due to the other environmental regulations regarding landfill limitation and recycling initiatives. These make it impossible to find waste in volumes to fill the void space being created in timeframes that communities could tolerate.

Chapter 12

Tailings Dams

Tailings dams are of many and various design, though in this work the standard simplified terms of upstream, downstream and centred are employed. There are all kinds though that may be only two or three feet in height on valley floors or old void spaces from closed open pit mines. They can also be tens of metres in height.

As has been reported above, many catastrophes are laid at the feet of these structures. Though many have been the cause of or source of flood and other horrors, many thousands around the world have proved to be sound and have survived many stresses that have tested their security and strength.

Tailings impoundments are an integral part of hard rock or metal mining operations. The operations of all but the most basic are imposing structures that have the ability to melt into the landscapes in which they are placed. They also stand as silent witnesses to the past activities of an area long after the mineral activities are over.

This longevity has led to several concerns as to the stability of long closed structures whose operators have long since ceased trading or otherwise left the stage. These situations have proved costly to the public purse in the United States and the UK.

12.1 A TEMPORARY NUISANCE

All mining activity is considered temporary as the minerals that are exploited run out in the areas where a mine operated. The majority of mines are designed with infrastructure that is easy to ship in and equally easy to ship out again to be re-erected elsewhere. In many places where the mining has taken place historically and before pre-fabrication, the old and redundant mine buildings were used to fill the shafts after the mineral extraction was completed. Where those mines closed the remnants of their buildings are still visible and are now a notable addition to both the landscape and the heritage of the areas.

In some areas such as the Forest of Dean in the UK it was a prerequisite of the permission to mine for the mining infrastructure to be removed after such activities ceased. Discoloured minewater discharges are now in many parts the only reminders that mining took place at all.

The tailings dam, though, is not a structure that is able to be removed from the landscape once mining has ceased. At cessation the dam or dams in many instances are made to be as stable as possible by draining residual waters from their loadings of slimes and waste. In many instances this has to be carried out over many years. The surfaces at the summits of these sites have to be capped as soon as it is viable to preclude normal rainfall from accumulating in the dam and slowing the stabilisation process.

12.2 THE NATURE OF TAILINGS

Tailings are the waste residues of the milling and refining processes that are commonly used to extract the desired minerals from the host rocks that have contained the goal. The same criteria is true for coal washings that need to be stabilised. During the extraction processes the waste materials have been ground and milled to an extreme fineness.

Normally the mineral that is extracted from the host rock is only a very small fraction of the whole body of the ore. This major waste arising after extraction of the required material is in the form a fine, liquid slurry. These tailings further contain any additives that might have been used in the mineral extraction process. These total residues, containing heavy metals and allied or alien substances are usually toxic, by their nature, to the natural flora and fauna of the area. The tailings themselves cannot just be heaped up due to the extreme fluidity of their nature. Hence the need for impoundment structures to retain them safely in a manageable area. Due to the fluid nature of this waste its stability is poor and even over years, long after sites have ceased to be operational, many dams have to be monitored to avoid any concerns regarding dam site stability.

12.3 THE NATURE OF DAMS

Tailings dams and impoundments are, at their largest, amongst the biggest man-made structures ever built. That their safety and structural integrity may be questioned is a major modern day concern for the mining industry. The protection of life, environment, property and their good name are put at risk if anything untoward occurs to any of their structures. The accepted notion that mining structures need only be temporary gives rise to an understanding in many instances of the nature of the catastrophes that have occurred in many countries around the world.

Due to the nature of mineral working, some tailings structures may only be a few metres in height. Some, though, have started as small structures but over time have expanded and grown. In some areas they can dominate landscapes, towering up many tens of metres above small river valleys.

Examples of tailings impoundments failures are many and include:

Martin County USA, where a million tons of coal waste slurry contaminated rivers and threatened drinking water supplies.

Aitik mine in Sweden, which released nearly 2 million cubic metres of tailings contaminated water.

Borsa and Baia Mare in Romania in the same year.

Placer, Surigao del Norte, twice, where 100,000 and 50,000 cubic metres of cyanide rich water contaminated a large area, killing many people and destroying homes in the Philippines.

Huelva in Spain, which lost 50,000 tons of toxic sludge and waters into the local estuary.

Aznalcollar in Spain, where 5,000,000 tons of contaminated liquidised waste was lost to a river and polluted the surrounding land.

Pinto Valley in the US, where 250,000 tons of liquidised wastes polluted a river system.

El Porco in Bolivia, which released nearly 500,000 tons of slimes into the water environment.

Omai in Guyana, where wide spread destruction to the environment was caused by the release of 4.2 million tons of waste water containing cyanide residues which entered the rivers and flooded the surrounding land.

Merriespruit in South Africa where 500,000 tons of liquid tailings destroyed 2 miles of waterway and adjacent land was contaminated; 17 people lost their lives.

Stava in Italy, which killed 269 people.

Arcturus, Bafokeng, Buffalo Creek, Mufulira, Marcopper, Saaiplaas, Jinshan, Pica Sao Luiz, El Cobre … the list could continue into the hundreds.

These are the known events but the actual list could be far longer. Most have gone unreported due to no one being able, governments containing the news or due to the isolation of the events.

The impoundment dam is an engineered structure that, by its nature, has to grow with the development of the production of the mine or mineral processing facility. The costs of such a structure have always been considered to be ‘lost’ revenue and the consideration to use anything but locally available materials in the construction as wasted money.

The notion that mine structures are all temporary is a fallacy. The tailings dam needs to be considered as a permanent fixture within a landscape. It may, like many landfill site operations, be located in a derelict void or other redundant mined space, but due to the volume of material deposited within its confines the emplacement is to be considered a permanent emplacement.

In many areas where a void space is unobtainable the creation of a form of terraced set of revetments that over time can leave large earthen walls, apparently, suspended above the sides of valleys is common. The tailings dam at Wheal Jane in Cornwall, UK, is a good example that curves along one side of the Carnon River valley. Other impoundments have used the physical form of natural valleys; some set in dry ground others having their valley streams or rivers rerouted or culverted away from them.

There are several styles or forms of tailings dams: upstream, downstream and centre line. There are many different design alternatives and configurations to these basic options. The considerations in dam building are different for tailing impoundments to that of a water retention dam. Primarily since water retention structures for such sites as reservoirs are normally built to a complete conclusion, whilst tailings dams grow with the amount of slimes that they have deposited within them. This can lead to a development of dams, each using its predecessor as the foundation of the next.

The materials used to construct these installations are as previously stated, locally sourced and are of an earth fill nature. The nature of such a method allows water to drain through the constructed dam and needs capture at the toe of the structure so as to avoid channelling and instability occurring. The water is usually returned to the dam by pump. This does not occur with a water retention dam as at its core there is an impervious barrier to avoid water loss.

The design of tailings dams is not dissimilar to coastal or riverine flood defences and they are constructed to withstand the actions of water subjected to severe weather conditions, flood and wave generation.

At many tailings emplacements the slurries, as they enter the installation, are treated with flocculants to aid the suspended materials to leave suspension as quickly as possible. By so doing the sedimentation of the waste materials can be separated from the water. The separated water is then drained off the surface either to a liquid treatment plant or, if benign, into the natural environment.

Once a tailings facility is closed it may take many years before the surface is stable enough to be developed or even restored to pastoral use. The present preferred strategies for the mining companies is to end the productive life of such sites by either leaving the lagooned area as open water or developing the top as a wetland habitat. The long-term management is now a liability internationally which 20 years ago was not considered. In the UK it is not uncommon for old tailings facilities to start to slump or slide and remediation has to be carried out by local planning authorities or land owners who have taken the land back from the mining companies.

Internationally it is now accepted that tailings dams need to be stable structures for the long-term. There is no legally binding definition as to the exact time scale that this indicates. It has been suggested by several national dam agencies that the long-term could be considered 1000 years. There is little wonder that no organisation or government is willing to consider such long-term legislation or business opportunity. There is much literature that tackles the issues of decommissioning tailings impoundments and the remediation of the sites, but the long-term management is not understood and as yet little of note has been published that has any reliable guidance value.

The stability of many water impoundments over the long term is questionable, the life span of tailings dams is unknown, they have only been utilised over a comparatively short period. Their purpose is to stop the traditional practice of purely discharging all mining derived waterborne waste to surface waters. As each structure and the makeup of its contents are unique, the expectation that one solution fits all is far from the case. The same applies to the issue of cost for the long-term care and maintenance that these structures will require over the coming years.

There are an astonishing number of large scale dams internationally. It is estimated that there are in the region of 30,000–35,000 tailings dams around the world. That is likely to be a low estimate and the likelihood of a further 10,000 can be surmised (Swedish Mining Association 2001).

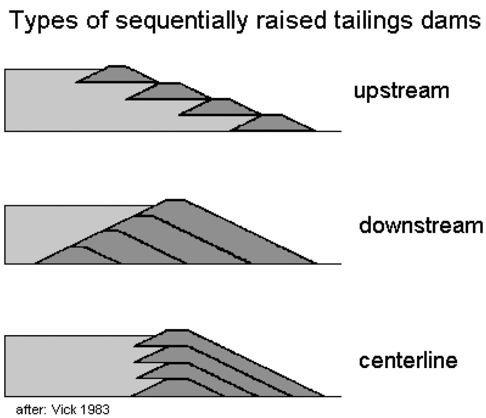
12.3.1 Design Decisions

The two main types of dam structure used to retain tailings in impoundment are the raised embankment type or retention type. Raised embankment is the most common. Either type can be used to form different types of configuration. These may include Ring Dyke, In-Pit, Specially Dug and variations of the Valley Dam design. The choice of design is primarily influenced by the topography of the land on which the impoundment is to be built. The majority are valley designs as, apart from the easier engineering aspects, such constructions are considerably less expensive to achieve. Another consideration is the price of land in which such works are to be placed. This alone encourages the consideration of a smaller base size and allows for the presumption of taking the impoundment dams higher instead. Across the board the costs element is important. As already noted, local base materials and mine waste, tailings and rock are inexpensive by-products that are at hand.

The Valley impoundment may be designed as a single cross valley structure or as a series of similar structures, these giving the appearance of terracing in the landscape. Again the reason for cross valley designs being favoured is that they are much easier and less costly to construct. As has been said previously, any natural surface water flows can be rerouted around the impoundment to minimise such waters causing excess water to enter the impoundment.

Other types of valley structure may be used where large surface water catchments or lack of suitable valley bottom topography is encountered. Commonly the valley side impoundment is favoured, giving rise to artificial engineered growths swelling from the valley sides. If valleys are broad and land is available broad valley bottom tailings ponds can be an option, as was the option in the lower Carnon Valley in Cornwall, UK. These Valley designs are the most popular due to economic considerations, particularly in that at least one side of the emplacement is the floor or side to the structure.

The foundation of any impoundment wall has to be considered as of the first importance. Foundation characteristics, strength, load bearing capabilities and permeability have to be considered. The permeability of the foundation of the impoundment and the ground up slope of the structure can influence markedly the stability of the dam structure and determine the development of the height and containment capacity of the structure.



Lining or other methods of controlling permeability may be considered, so as to limit water seepage around the dam structure. This is often achieved, crudely, using local clays and slimes from the mining operation at an early stage in the mine's establishment. It is rare that geotextile or bentonite type liners are used, as the expense and the topography of most dam sites would preclude their use. Few tailings dams do not interact with the underlying hydrogeological regions.

If valleys in their entireties are unavailable Ring Dyke constructions may be considered. These use the valley side as an anchor and build out embankments to create a pond or ponds in relays up the valley side. The walls of the dyke systems that are to retain the liquid waste are gathered from the impoundment area. Most of these constructions are of the downstream model. These constructions are less prone to ponding or collection of surface water drainage, allowing the impoundment to manage, near exclusively, mining-derived water only.

Another form of impoundment is by the use of excavated and abandoned mine voids. The lack of exposed banks and an almost totally controlled and stable environment makes these ideal but infrequent options. There are still issues that need to be regulated such as any galleries or drainage adits that may allow uncontrolled drainage as has been witnessed more than once.

One main consideration in mine tailings impoundment designs is the phreatic surface within the embankment. This is at its simplest level of saturation in the impoundment and embankment. This is the level at which the pressure in the fluid equals atmospheric pressure. In natural hydrological systems this may be called the water table.

This phreatic surface has much control over emplacement stability, both in static and seismic stress. The idea is that the phreatic surface should be as low as it can be engineered, close to the dam embankment face. This allows a continued pore pressure at the face lower than atmospheric pressure plus the mass of the embankment material and maintains the face of the dam. The usual, and primary, method of maintaining a depressed phreatic surface close to the dam embankment face is to increase the relative permeability or hydraulic conductivity of the embankment in the direction of gravitational flow.

Issues that may have bearing on the phreatic surface will, as already noted, have an effect on the engineered stability of the whole structure. Factors that need to be considered are the characteristics of the tailings (permeability, compressibility, grading of particles and density, which can vary over the lifetime of an impoundment) plus site specific and certainties of the foundation make-up, the hydrogeology and hydrology of the area being impounded upon and that of its setting.

If the phreatic surface rises the likely risk of catastrophic dam slip can occur.

12.3.2 Upstream and Down

Upstream tailings impoundments appear to be the most accident prone form of mining related water retaining structures. It is also the most commonly used form of dam construction method and the most economical to construct. Because of its low cost and greater susceptibility to failure great care needs to be exercised in its construction and management.

Initially the tailings are discharged from the crest of the starter dam so as to develop a dike or dam in which the waters can separate from the tailings and a beach that protects the dam and creates the base foundation for the next level of the dyke or dam to be developed onto. The beach is where the coarser tailings naturally congregate. The upstream face of the structure may be coated in the slimes deposits to reduce the permeability of the structure.

The most important aspect of the upstream construction method is that the tailings beach must form a competent foundation for the support of the next dyke. A sand content of up to 60% is necessary. Lack of such material may require a change in design concept to a downstream construction where the downstream face of the dam is widened to allow the development of the dyke's next layer. By using this adaptability the structure is able to be returned to an upstream impoundment at the next phase of its construction.

These structures are highly susceptible to liquefaction under severe seismic ground movement which may be earthquake, mine blasting or the movement of heavy equipment.

The stability of these structures is endangered if the rise rate is too fast. The raising rate if greater than 15 metres a year may be hazardous as the tailings particles need time to compress and expel their water fraction as they are developed as the beach. If the particles do not settle sufficiently, it can produce excess pore pressure within the deposit and decrease stability.

12.3.3 Downstream

The downstream design requires the same good foundation as the upstream method. If the starter dam is created using low permeability material, internal drains would need to be introduced into the design. The downstream dam is developed because each stage of the dam's development is supported on the top of the downstream slope of the previous section, thus moving the centreline of the top of the dam downstream as the dam stages are progressively raised. Commonly, if coarse tailings are in short supply, to raise the dyke to the next elevation other local borrow or quarry waste may be employed. If course or poorly bedding rock is used the upstream face of the dam needs to be made impermeable to limit through-structure water movement that would threaten the structure's integrity.

12.3.4 Centreline Dams

The centreline dyke or dam is one that rises vertically at each stage of its development. It relies on a solid central core and the leading and trailing edges are developed on the upstream beach and with matching development of the downstream face.

These structures are more stable than either of the two, more usual types of impoundment structure, but are also the most expensive to install.

12.3.5 Other Dam Issues

The majority of tailings dams have not been lined with any artificial impervious membrane to minimise the leaching of tailings waters to pass from the body of the impoundment and in most instances they do impact on the natural groundwaters of the area about the site of the dams. There are many technical arguments employed as the reason for this decision, but the main issue is that the cost of installing a liner would be detrimental to the economics of any mining or refining process. If any lining is deemed as a necessity the fine slimes from the tailings stream are used to limit conductivity between the dam waters and the natural groundwaters. These slimes do not stop such cross migration of waters but certainly can slow it substantially.

Management and maintenance are the most important issues with regard to their long-term safety and stable longevity. As has been noted earlier in this narrative, in the past these important elements have been poorly carried out and beaver dams, and even ill-maintained spillways, have been the accepted reasons for catastrophic events. Weather and seismic events need consideration but seldom do tailings dams have such acts of god engineered into their initial design.

Chapter 13

Floods and Inundation

Floods and inundations of working mines have been a perennial concern in the mining industry. The occurrence of underground workings being swamped by water is a nightmare that has been realised many times over the thousands of years of mining.

The main occurrences of such events are caused by old workings, that are flooded and their presence unknown, being mined into, releasing a wave of murky, destroying water at those working at the cutting face and elsewhere within the mine system. Other occurrences include mining too close to aquifers that have released their load of water into the mine and mine stoppings, which have protected working mines, giving way allowing flooded workings to decant into the working levels. All are standard operational blunders or mistakes. There have been others that have been caused by pure foolishness or greed and others still due to poor surveying or brought about by outside agencies.

13.1 LAKE PEIGNEUR, US

The Diamond Crystal salt mine was worked up to 1500 feet below Lake Peigneur. The lake was a shallow, 11 feet deep, fresh water body that was linked to the Gulf of Mexico by a 20 mile long, canalised, waterway. The surrounding area is a busy oil and gas production and exploration area.

In 1980 a drilling platform, looking for gas deposits beneath Lake Peigneur mistakenly drilled through the roof of one of the mine galleries 1300 feet beneath the lake. The ensuing whirlpool emptied the lake of its 3.5 billion gallons of water and drew water from the Gulf of Mexico into the void. The drill rig, another operating close by, five barges from the canal and a motor tug boat were all lost in the vortex. A 70 acre island also disappeared as did much shore side woodland.

After two days the lake refilled with water from the Gulf. The mine was abandoned and the lake left as a 1300 feet deep salt water lake. Remarkably there were no fatalities. The accident was put down to 'human error' by the subsequent inquiry.

13.2 WORKINGTON, UK

The Lady Isabella Pit disaster was a remarkable event that occurred in 1837. The coal mine was worked out under the Irish Sea. The working faces were around a mile distant from the shore. The coal strata at this point rose towards the seabed; at the same time the pillars of the workings were being robbed to increase production. The closeness of the sea and the instability of the columns allowed for a catastrophic failure of the seabed allowing the sea to enter the mine. The event gave rise to the development of a spectacular whirlpool which was viewed by many from nearby cliffs. The event saw the death of several men, boys and girls. The disaster was a cause for the creation of the first mine safety law, which banned girls from working beneath the ground in England and Wales.

These flooded workings were the cause of another set of fatalities in the 1860s when the old workings flooded into a working mine. As no plans of 'ancient' workings had at that time been made there was no certainty to their location. This led to the legislation that required all working coalmines in England and Wales to be regularly surveyed and on abandonment the surveys were to be lodged with the state.

These mine workings still influence the lives of the people living close by in Workington today as there are still some abandoned ventilation shafts that vent methane or draw air into the long closed mine system with the rise and fall of the tide. The UK Coal Authority has the liability to monitor these twice daily events into the future.

Chapter 14

Changes

Since the 1990s the mining industry has changed dramatically. The major companies that have been the main operators across the world, in some cases for more than 100 years made a conscious decision to develop a more open and responsible attitude towards the communities and environments in which they operate. This in many ways mirrored major world political events such as the breakup of the Soviet Union, the democratisation of South Africa, western intervention in Afghanistan and much else. The green lobby was finding its voice was being listened to and an acceptable place in many nations' politics.

This was marked by an international initiative, Minerals 98, which outlined the need for stakeholder involvement, consultation and explanation. This was the mood of the conference in London that wanted to demonstrate the needs of everyday life and its dependence on minerals. This was also to address public developing awareness of the environment and peoples universally demanding an unpolluted environment. In the years prior to this development the numbers of accidents and catastrophic events worldwide appeared to have escalated and not just those associated with mining. Oil tankers appeared to be grounding and shedding their loads of sticky and pernicious pollution about the coasts of the world on a rather too regular basis.

This set of events that had allowed the various extractive industries to be seen by the public as inconsiderate and uncaring. In some cases, the term 'conniving with governments' was used. The, in most cases, unsubstantiated charges of governments in Africa and around the world being toppled by mercenary led troops in the pay of mining companies added to the negative public perception of the industry.

The old companies have developed a long way over the thirteen years, with some being at the forefront of community development and education initiatives. If it was not for mining companies taking the lead in the battle against HIV/aids much of southern Africa and South America would still be coming to terms with the principles and not tackling the epidemic. The same is true about water. Both the scarcity of it in arid regions and the operational and post mining pollutions would be the norm in many parts of the world. The active involvement of major companies has led many developing countries to originate legislation regarding water, wildlife and community care.

This cannot continue as a eulogy to the mining industry. Since Minerals 98 there many new companies have developed in states and regions that are now able to operate with private and public investment; many are the privatised old nationalised industries. Their old methods of being secretive and cautious in their involvement with stakeholders have continued. These new conglomerates have been joined by some of the companies of the old school whose enthusiasm for the new openness has only apparently been ‘lip service’.

As the world is developing new regulation, many communities are becoming less grateful for the jobs that many mining companies are offering. These same communities are learning how to use their political systems, for the first time in many cases, to protect their rights to environmental security. As reforms come about, the evolution of these less far sited companies will inevitably develop or founder, as many have in the past. The financial markets have an interest in protecting investments and law suits are not good for share prices or dividend payments.

Chapter 15

Potential Future Catastrophe

The world has become aware of the possible repercussions of mineral and minewater mismanagement. It is also more at ease with natural seismic events and, though not as yet accepting of such phenomena as tsunamis, is more scientific in its acceptance. There are, though, issues which need to be considered and reacted to before their realisation affects people and the environment.

15.1 SOUTH AFRICA

The potential for damage to surface and ground waters in the area of Johannesburg are being raised by the United Nations as well as by the South African Government and other groups. In the mining areas around the city most of the mineral mining has ceased due to resources being expended. The prospect of contamination from the rapidly rising water table, since cessation of mining in the region, has raised fears for both the vital aquifer that supplies the conurbation with drinking water and contamination with regard to agricultural land. Since mine closures have taken place agriculture is now the main pillar of the local economy.

15.2 UNITED STATES

In the United States there are many future areas for concern. Many mines and other mineral workings are expected to rebound to the natural environment. These mines are not numbered in tens but in their hundreds. The Environment Protection Agency as a federal entity stated that in 2000 there were over 20,000 miles of polluted minewater affected waterways. This number is still not being stabilised by treatment schemes and the financial liability is estimated to run to over one billion dollars.

This situation is developing and will threaten not just the natural environment but human water supply and agricultural use. The future damage, financially, to some of the states' economies could, over time, outstrip that of the estimated reclamation bill.

15.3 EUROPE

Across Europe the closure of much of the coal mining industry has left many areas venerable to flooding from abandoned mine workings. The Silesian coalfield with its many unusual water quality issues, particularly the high loadings of chlorides, is considered by some staff of the European Environment Agency to have the potential to do unspecified, but catastrophic damage.

15.4 RUSSIA AND THE ARCTIC

Russia has mined in the Arctic wastes of the country for some time. The term waste is a reasonable name for how the mining operations in a number of instances have treated the near pristine environments.

The consideration is that these sites are so isolated that no one would wish to visit them so there was little need to show responsibility in the care of water or land. As these sites are now coming to the general attention of the world there are moves to negate some of the worst excesses of poor practice.

The prospecting and development into even more northerly regions and their environmental safety are developing as a major concern.

15.5 NEW DEMOCRACIES, AFRICA

The need for foreign investment and a foreign currency is a driver to allow some of these nations to accept mining activities that are unsatisfactory for the environment and some local communities. The exploitation of some areas prior to the creation of satisfactory governance led, in countries such as Sierra Leone, to water pollution and community poisoning by illegal mining.

Much of this mining was exploiting alluvial gem stones and gold. Other operations used cyanide and mercury in such uncontrolled ways as to damage large areas of land. There are many unconfirmed reports of villages' populations being decimated by such use to liberate gold and copper from host rock.

There are still countries that are not at the stage of secure and democratic governance and illegal mineral exploitation carries on to the detriment of the surrounding areas.

15.6 GLOBALLY

Wherever mining takes place there is always a risk of accident. The notion that methodologies and engineering have improved the situation has only altered the possibilities.

At the same time human kind's perception has developed and altered as to what is acceptable and what might be lived with or endured.

Chapter 16

Minewater Treatment

The treatment of waters from active mines and those from abandoned workings have one major similarity which is that all discharges are unalike and that each needs to be treated individually.

The treatment of minewater came to the fore in the UK in the early 1990s when the government of the day and the nationalised industry announced the closure of 80% of the already shrunken coal mining industry; this was announced within months of the Wheal Jane minewater rebound event in Cornwall. Within a further few months the Government announced that the rump of coal mining operations in the UK would be denationalised. Simultaneously the Government allowed a research document from the House of Commons library to be published. This report outlined the national disaster which was that minewater pollution was taking place across large tracts of the country and the deepening crisis of further potential major pollution incidents from the large number of recently closed mines and corresponding coalfields.

This interest in minewater escalated in the UK due to the political relationship between mine closure and the growing pollution liability that looked certain to be shouldered by the nation though the 'good offices' of the Coal Authority and the National Rivers Authority (the forerunner to the present Environment Agency). Both organisations have had to spend large sums of public money over the last 20 years to safeguard the inland watercourses of the UK. This multimillion-pound investment has had a major impact on the longstanding contamination of rivers in the UK but there are many further minewater contaminations to be remedied to keep abreast of the still growing number of minewater issues. This is well known to the practitioners at both agencies but the present financial strictures are now holding up any further major remedial works. This lays the UK Government open to failing to meet European

Water Quality objectives and the prospect of being fined in the courts for this lack of compliance.

In the UK the Government in the form of the Department for Environment Food and Rural Affairs (Defra) is looking at new models for the development of having contaminations remediated under the ‘Big Society’ banner where communities take responsibility for their environments, including the funding and organisation of cleaning up historic pollutions from mines. This option further requires that communities have to decide on how clean their community wishes their environment to be. If a minewater discharge is to become a community liability the group would need the agreement of the state to manage the site after remedial works have been undertaken, or else that community will be tied to an open ended agreement to which no community group should ethically be made to subscribe.

In the US similar actions are taking place and the groups that are involved in projects such as this have the ability to refer the completed works for adoption by such organisations as the Tennessee Valley Authority or the various state environment protection offices. Most states have remediation projects in place at many abandoned mining areas and have agendas for future remediation.

In the state of Pennsylvania there were, in 1966, over 2000 miles of mine-polluted rivers and streams. In that year a fund of US $200 million was put together to rectify the problems that were the cause of these pollutions but by the 1980s the money was used up and the works that had been put in place to combat the discharges had been found too costly to run indefinitely. These operations had been the standard minewater treatments used by the industry at working mines. These used chemical dosing techniques to raise acidic water pH levels, flocculate out metals and otherwise make water fit for discharge. These unsustainable operations had to close due to the lack of funding for the long-term.

This was not the only state in the Union with these issues to contend with. The US Bureau of Mines and other interested parties began to look to other ways of managing mine-polluted water. In the 1980s there was much experiment in the use of reed bed and wetland methods of treatment with much investment from states and federal sources. Some passive systems were put in place in attempts to mirror natural systems that had been observed to limit environmental damage at mines where water was accidently leaking on site.

There are many accounts (mostly apocryphal) of sphagnum mosses and similar flora being noted to thrive on acidic metal rich waters from mines. Experiments were carried out on such plant life and it was shown that they did thrive, but then died. These flora showed a propensity for over accumulation of metals by the plants choking their metabolism and disallowing their take up of nutrients.

Throughout the 1980s and early 1990s the schemes that were put in place were found to treat some parts of the problem, pH and iron suspended solids, but there was little true understanding of the mechanisms that were being attempted to utilise. This is still true today though the science has moved on considerably.

Across much of the Appalachian coalfields there was an investment in 1999 for a five year period of around US $1000 million (Pennsylvania Environment Department 2011) to rectify some of the worst polluted areas. Over the five years 19 treatment sites were constructed. This was a remarkable building programme with huge funding but contrasted to the estimates for the remediation of Pennsylvania alone of US $5 billion.

16.1 ACTIVE TREATMENTS

Active treatments are, as has been noted above, a normally high cost set of options. The issue, though, is that it may be desirable to consider if the problem is compelling enough or a site is too small to be able to locate another form of treatment option.

The active treatment technologies can be generally subdivided into:

- pH modification
- ion exchange
- biology-based treatments
- other adsorption treatment
- electrochemical treatment
- physical process technology

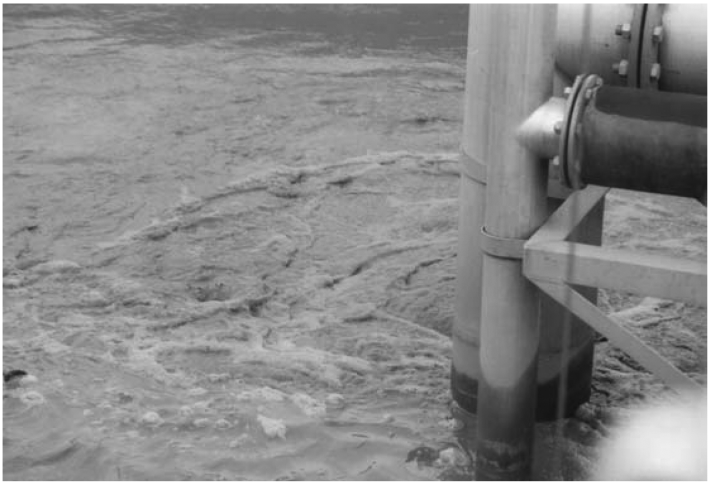
16.1.1 pH Modifications

The conventional active treatment of contaminated minewater is that comprising neutralisation and precipitation. Materials used to achieve this neutralisation are most commonly lime, limestone, caustic soda or sodium carbonate; other chemicals can also be used.

The basis of pH modification treatment is to raise the pH of the acid mine drainage (AMD) causing first iron and then other metals to precipitate out of solution. The minimum pH values required to remove metal ions as hydroxides span the range 4.2 to 10.6 for Sn to Mn.

The use of waste products is an attractive proposition as an alternative to virgin material to raise the pH of waste water, thus solving two waste disposal environmental problems at once. The reliability of such wastes is, though, a consideration. Volume and composition variation are important factors.

Lime has much to recommend its use; it is tried and tested, capable of treating highly acidic wastes and largely unaffected by seasonable temperature change. Lime requires straight forward plant and operation to dose the waste water, and waters can be discharged to receiving waters with little worry. Any change in water composition can also be easily and quickly accommodated.



pH adjustment at Wheal Jane, UK 2006

The drawbacks to be recorded are that if high pH is required to remove metals such as manganese the chemical reaction may remobilise other metal hydroxides such as aluminium. Sludges from the treatment methods are complex and have issues to do with ultimate disposal. Sludges are low density and gelatinous and the resulting large volumes are difficult to handle and dispose of. They have no commercial value.

The four best known additives to raise pH as stated are lime, limestone, sodium carbonate and caustic soda and these can be considered by comparison. The issues for and against calcium and sodium are various.

The calcium compounds are less expensive than sodium, but they have low solubility in water, so making reaction rates slow. Calcium is, for this reason, more suitable to be used in larger treatment schemes where there are mechanical methods of blending the lime as a slurry with the minewater to be treated. Even then if sulphate concentrations are elevated the resultant waste can clog and scale the pipes and mixing vessel. This method further produces a far harder water effluent than sodium compounds. The addition of magnesium at this stage can also help iron precipitate out as a denser sludge.

As already said, choice is dependent on which metals require removal. The addition of carbonates can elevate AMD to a pH of 8 whilst hydroxides can raise pH to above 10. An assessment should be made as to which reagent is necessary. If ferric iron is the main constituent of the waste stream it will be acceptable to use a carbonate material addition. If the metal was manganese a higher pH, above 10, would be required and a hydroxide material would be the desired addition.

Ammonia has been used as an addition to AMD to remove manganese, to raise pH. There are though, several issues of concern with regard to this. There is the possible risk in its handling and potential harmful effects on the environment if strict controls are not ensured.

The decision on what chemical to use for pH modification is a matter of considering the chemistry of each individual water that is to be treated. In some instances a mix of several additions may be required to achieve the optimum treatment in terms of both value for money and reliability.

16.1.1.1 Aeration

In most cases the need for oxygenation of AMD is necessary to help lift the pH level. It is also critical for metals removal from solution. This is an area of importance to both active and passive treatment methods. Oxidation may be achieved by passive physical means such as a cascade. However, if there is insufficient space or head to achieve the desired flows or if the metal content is so high that cascading alone is not sufficient, other methods need to be employed. These may include the addition of oxidants, peroxide ozone, chloride compounds or potassium permanganate. Other methods may include passing the stream through a bio-reactor exposing the AMD to micro-organisms.

It is also possible to force oxidation by artificially pumping oxygen or if space allows using renewable means such as aerating windmills (US Environmental Protection Agency) or paddle island mixing. These methods have an added effect of degassing the effluent, removing carbon dioxide from the water. This also raises pH and by so doing increases the oxidisation and thus the removal of iron from solution.

16.1.1.2 Artificial Removal

The waste sludges that are formed by alkaline addition are usually of a low density with a solids proportion of as little as 2%. It is a high volume, bulky waste that is hard to dispose of. Further, the hydroxide precipitates tend to have a small particle size and for this reason need considerable amounts of time to settle out in settlement tanks or tailings dams.

The precipitates' settlement characteristics may be improved by the use of chemical flocculants and coagulants to improve this settlement process. The coagulants promote consolidation, the flocculants aggregate or combine the small particles by bridging them with chemical addition. This allows for the formation of larger particles that will settle more readily than the original particles. The problem of the paucity of sludge density may be addressed by using a proprietary process to increase particle size or the alteration of the sludge consistency, otherwise physical or mechanical dewatering of the sludge by centrifuge or filter press may be considered.

The development of an added stage to the coagulation and flocculation processes, which includes the recycling of the treated waste stream back into the untreated waste water, increases the ability of the same quantities of chemical reagents to increase their efficiency. This method is known as the high density sludge process. There have been several proprietary processes that have been developed over recent years. All require reconfiguration to see that each particular minewater is treated as a unique issue in its own right. These reconfigurations can be time consuming and can lead to configurations that need re-jigging if a water quality alters, which is not uncommon. If this possibility is not wanted to be expected or the specification for tender does not allow for such eventuality there may be the temptation to over engineer or overdose the chemical addition to compensate. This may lead to environmental issues arising in the future or, at the other end of the equation, increase running costs. The need to be able to alter the management of individual water feed's treatment to echo its possible variations should be factored into any tendering process for remedial works.

The over treatment of trial waste streams led to the development of another group of methodologies involving the neutralisation, by steps, of the level of supersaturation of metals during precipitation. The processes require reactor vessels in sequence; some dosed with pre-treated waste others with lime slurries. It does reduce the lime dosing volume but requires several more reactor vessels.

The power requirements are high for many of these methodologies. The viability of some may be questioned as they could not be used in more remote locations. One trial has, though, been powered using the power generated by a waterwheel.

16.1.1.3 Waste and Bio-reactors

Bio-reactors have had a long history of competency in environmental clean-up options. They function via the washing of contaminated soils and the use of selected bacteria to 'eat' the contaminants of many different waste streams. There are similarities in their nature and type to several that occur in passive treatment schemes. There are also several areas where their development in tandem with passive systems may be critical and considered a preferred option.

Some of the reactors consider the use of sulphate reducing bacteria as the active causation of change and decontamination. In brief, these bacteria are a diverse group of anaerobic, heterotrophic micro-organisms that reduce sulphate levels which act as oxidising agents for the dissimilation of organic materials, as does oxygen in conventional respiration. A small amount of sulphur is assimilated by the organism but virtually all is released into the external environment as the sulphide ion, usually greatly hydrolysed to allow hydrogen-sulphide gas to be liberated. If this end product encounters metals, precipitation of metal sulphides will occur. The drawback is that the hydrogen sulphide can be toxic to the micro-organisms.

There have been many technologies that have been based around the bio-reactor and similar waste reactor systems. Many though have fallen by the wayside due to cost of developing the right bacterial growth to suit the specific contaminant loadings. In several cases the reactions could not be controlled over prolonged time periods or the effluent chemistry altered and the active material succumbed to toxic shock.

These reactors have been designed to work on wastes that have a neutral pH. There has been a considerable amount of work with the use of acidophilic bacteria as well. The work involves the use of naturally occurring acid, metal tolerant bacteria species. The data, though, demonstrated that the reactors' efficiencies were not as great as the more pH neutral operations.

These reactors removed oxygen from the treatment system though some reactors have been aerobic. The system has been piloted and is now used at the Nickel Plate Mine in British Columbia as a part of a composite system. This project has shown that the system can remove some difficult, environmentally challenging materials such as cyanide.

The cyanide step in the removal process has been shrouded by legal patents that have stopped any other company or the environment gaining from this knowledge. However, work has been carried out independently in this area and is being considered for the treatment of similar waste streams in Europe.

Waste materials are well known in their make-ups, and in many cases have the enviable property of being readily available. There are, though, other issues that have made them almost unusable, one being that they are recognised as waste and are regulated as such and not as a recycled product. This is particularly true of mineral waste. One instance that illustrates this issue graphically is the substance marketed as Bauxsol.

The use of waste, as already noted, is a far sighted development in the treatment of AMD, as is the use of waste from the aluminium smelting process which produces large volumes of 'red muds' that are a considerable liability to the bauxite industry. The red mud spill from the tailings impoundment at Devecser aluminium processing works, which engulfed its village and a large tract of surrounding agricultural land in Hungary in October 2010, was made up of this material. The highly corrosive nature of the waste and its lack of value has been a developing problem not just in Europe but around the world. The refining of aluminium from bauxite is a global industry and its wastes are of international concern.

The process was developed from Australian academic research into the properties of the bauxite wastes which are a problem in parts of Australia, where there have been concerns regarding similar events to that which happened in 2010 in Hungary. The waste is chemically and physically altered from the base waste mud residue that is the resultant waste of the Bayer process of refining the Alumina.

The proprietary material is a dry red solid that consists of a complex cocktail of minerals including hematite, boehmite, gibbsite, sodalite, quartz and cancrinite (McConchie 2001). It also fields many other trace materials including gypsum. The exact composition of the material depends on the original source of the bauxite, which varies with each source location. The end product that is manufactured from the waste is environmentally benign but has proved to have huge potential and has now proven its capabilities on many waste streams. The issue was that in the UK and in Europe the material was considered as a hazardous waste, even after its benign state was manufactured, due its original classification as a special waste.

The environment regulators both in the UK and Europe took a long time to come to an agreement that the material was marketable and not just a remarkable and interesting research material to be confined to bench scale testing. Many similar materials may have not fared so well in this form of regulatory lottery.

The substance has some exceptional characteristic abilities and even at the end of its active life can be reused in other areas including building aggregate without consideration of concerns regarding contamination of other material that it may come into contact with.

Its natural abilities include a high acid neutralising ability and a high capacity for trapping metals and phosphates. This far out competes such materials as lime or limestone in that the material does not armour itself and through its chemical characteristics recruits the metals it collects to share in the task of further metal and phosphate decontamination. It also binds the contaminants to itself in a non leachable form making the handling and transportation of used material a safe and simple inert waste issue.

From long experience of this and other technologies it is not, as are no others, a stand-alone solution in most locations, but the company that supplies Bauxsol (Virotec) has a record of looking to develop synergies with other technologies to partner their technology.

Many active treatment companies have outlined that their particular process technologies are not cheap, but have suggested much of the costs may be offset or regained by the recycling of the more valuable or abundant minerals that may be removed from the waste stream by their processes. This has yet to be proved to the minerals industry.

16.2 PASSIVE TREATMENTS

Passive systems of treating minewater have a philosophical as well as practical aspect that is appealing on many levels. The thought of treatment systems that come some way to managing themselves while being of low capital and maintenance cost adds to the attractiveness.

The realities are somewhat less romantic and more workaday. The majority of passive systems are formed from two main tenants of remediation: the reed bed or wetland and the settlement lagoon with aeration. These basic parts have been experimented with over several years and have proved to have many satisfactory configurations.

The most notable need in the use of wetland methods for remediating many minewaters is the need for areas of land suitable for their construction.

16.2.1 Background

The background to the use of wetland methods was said to have come from the observation of natural plant/pollution contacts. The observation was made that some bog mosses appeared to thrive when in contact with contaminated waters at certain mines that observant engineers were involved in. This natural liking of polluted waters was considered worthy of continued observation and examination. The mosses took up pollutants within their metabolisms, appearing to remove them from the water environment. This exciting observation was rewarded further with the continued study it received. This led to the observation that the mosses died swiftly and decomposed releasing their pollutants back into the environment.

This remarkable finding that there were plants that could take up or at least absorb some forms of pollutants from minewater fostered further investigation. The mosses had evidently satiated themselves on this waste stream and in so doing had overdosed or over imbibed. The answer was to consider the ecology of what appeared to grow satisfactorily within a matrix of contamination. The studies involved the enquiring into the flora of the areas of known contaminations and their similarities.

Typha latifolia

In the United States this led to the development of the use of cat tail, or in the UK the mis-named bull rush, best referred to as Typha latifolia (Great Reed Mace). In many instances this plant was considered the universal panacea for treating mild minewater pollution discharges, with many large monocultural stands of these plants being put in place. In the UK a similar reliance on Phragmites australis (commonis) or Great Reed developed. Both these plantings were being developed in the mid 1970s.

Phragmites australis flower

Phragmites australis

The true knowledge of these developments in the use of marginal flora was commencing well ahead of the science. There was little understanding of what was actually taking place within their sphere of influence, namely their rhizome sphere or root space. What is certain is that the natural accretion of bacteria within the root spaces, the general substrate and the minewater itself, were remarkable; particularly for their specific preferences or tolerances of specific aquatic conditions.

By the 1980s much work had been carried out using reed beds, rather than wetlands, to bring sewage treatment facility discharges up to higher standards of tertiary treatment. The use of the vegetation was in this case considered more aesthetic and in many engineers' views gravel beds would be equally satisfactory. There is still some debate regarding these opinions today.

Into the 1990s research developed into the reed bed and the actual mechanisms that were taking place within its active areas, the rhizome sphere, the area that was in contact with the pollutants, and the chemistry that was taking place. The realisation came that it was not just the plants, substrate or their conjunction but the added elements that allowed the sites to work better over time. This realisation allowed for a development of interest in the litter of the plants, the accrual of waste matter that develops as perennial plants die back and regenerate over time. These layers of waste allow bacteria to develop and find niches which in the newly planted systems there were none of. At the same time the realisation that monocultures of aquatic marginal plants were unnatural and that a more diverse planting regime may have benefits was put forward and slowly accepted as desirable.

The other aspect of this treatment method was that of the bacteria themselves. The fact that suitable bacteria materialise has concerned the scientific community and much work has been carried out on specific naturally occurring communities in old mines in Wales, the great hot springs at Yellowstone Park in the United States, Rotorua in New Zealand and the Rio Tinto in Spain. All exhibit diverse algal flora and bacteria, some so specific to hostile environments that the US space agency study their nature with the belief that they may hold a key to life on planets elsewhere in the solar system. The reasons for their appearance or how they arrive, though, are still an area for hypotheses. The reason for a colony of bacteria to appear at a trial reed bed at the Wheal Jane mine water trial site, in Cornwall UK, that has only been found in the Yellowstone Park in the United States before 2002, may be that it is perhaps widely spread globally but as no one has been interested enough they have not looked and found it elsewhere before.

The development over the last fifteen years of laboratories selecting bacteria and then patenting or, by other means, protecting their investment before marketing the patent panacea is a concern if these bacteria spore or otherwise colonise away from where they have been inoculated into treatment systems, as it is not known what impact they may have on other locally valid and suitable bacteria. Their presence may have legal implications in sites in areas such as Pennsylvania where such organisms (Pyrolustite®) have been employed.

16.2.2 Wetlands

Wetlands are now a more acceptable term and a more desirable alternative to the monoculture of reed beds. Their nature and aesthetic are both functional and attractive and not just to the eye.

There are three particular methods of using, and as such three methods of engineering, the sites to perform their function. These are subsurface flow, surface flow and vertical flow. All have their adherents and all have their place in the schemes that they may be considered for in the future.

16.2.2.1 Subsurface Flow

This method, as its name would suggest, allows the treatment water to pass through the rhizome sphere and planting medium with no water standing or flowing on top of the system. Its initial development was the use in tertiary treatment of sewage, for which it was very successful.

The design of a subsurface bed is important so that it is adequate for the flow rate through the system and that the substrate, usually gravels and course nutrient rich media, is kept moist and does not develop dry islands or develop flow channels through the substrate. This will limit retention times within the wetland and negate, to some extent, the biological remediation that is meant to be taking place.

One issue that needs to be addressed is the loading of metals, particularly iron as the ferric content is likely to precipitate out rapidly and course clogging within the first part of the bed system due to oxidation and/or pure precipitation.

This has been a major problem at one site in the United States, where, due to very acid water being put through a system, limestone was incorporated within the media. All worked satisfactorily for a short time, but even with, or despite, inoculation with specialist bacteria the system became clogged up with iron precipitates and the scheme had to be rethought. This was not a trial site, but one of many hectares and, with the introduction of bacteria that were of a specialist nature, the whole site became a specialist waste for disposal.

The use of subsurface beds is very effective if the main determinants that need addressing are small loadings of specific metals that can be sent through small beds tailored to specific requirements. These may be developed as chains of small beds that can be designed to vary pH or other required environment.

16.2.2.2 Surface Flow

Surface flow wetland systems are similar to the subsurface systems in their ability to choke up on iron precipitates and cease working. Apart from this consideration they are easier to operate and manage water flow rates. Again these systems were originally developed as part of a range of tertiary sewage treatment methods.

Wetland Vegetative Litter

In surface flow schemes the development of the system is ongoing and may be considered to be a system that can improve with age. The litter build-up, apart from developing a nutrient bank for the plants also develops to cater as environments for bacteria. This was noted at the Wheal Jane minewater trials site in Cornwall, UK where the development of the bacterial communities were studied in more depth than most places of a similar nature on earth.

Also, as found at the wetland trial site at Wheal Jane, there was the need to ensure that the substrates were high in nutrient as this allows the plants to establish. At Wheal Jane this was not done, instead inert tailings were used and within a few months the plants were noticeably stressed due to lack of, particularly, magnesium and an artificial fertiliser had to be applied. This problem is not usual in sewage treatment due to the nature of the waste waters.

16.2.2.3 Vertical Flow

These systems have been used extensively in the historic Pennsylvanian coalfields. They have proved to be, in many cases, very successful, particularly where iron loadings have been modest.

The principle of these systems is that the influent water containing oxygen is passed through composting material to deoxygenate the waste and at the same time remove the ferric iron. The anaerobic waste then passes through a layer of limestone upwards, vertically, so as to limit the armouring of the limestone and allowing some alkalinity to be picked up by the acid minewaters. At this stage further alkalinity can be added in the form of slurries of lime or other methods. The water is then passed through the wetland substrate where it meets the bacteria. The whole water system then flows through the wetland system.

In many sites these systems have been constructed where limited space has been available. The need to add flocculants or for major pH adjustment has needed to be linked to the system, which negates them being a pure wetland system.

16.2.2.4 Plant Establishment and Nutrients

As has been mentioned earlier, the need to make sure that wetland plants establish themselves in the planting schemes is imperative. The wetland may be functioning satisfactorily due to bacterial action, but the aquatic vegetation dying back or exhibiting stress does not bestow confidence in the system. The long-term well-being of the plants can only be assured by a nutrient base in the wetland. This will over a period of time develop a naturally regenerating regime of nutrient replenishment; until that age of system is achieved the nutrient levels will need to be monitored.

The sourcing of wetland plants is important. The majority of the flora used in such planting schemes are fairly standard and are on the whole widely available. The understandable nature, though, is that some sub-species or bio-types of the plants are more or less tolerant to various aquatic conditions or contaminant loadings.

When designing a planting scheme ideally the observation of local flora types should be considered as of importance. The next and equally important consideration is the development of plants that, though of the same genus one to another, may have different toxicological tolerances. Ideally the development of nursery propagation of plants from the immediate surrounding area may be considered.

Allied to the above, plants that have been procured from various nurseries should be sourced from areas that have similar climactic conditions and are of a chloride or fresh water physiological ancestry, whichever is the more appropriate.

16.2.2.5 Additions: Anoxic and Otherwise

In many instances the treatment by wetlands has been allied with the use of limestone drains and other methods of lime dosing and filtration. In many instances limestone has proved to become armoured by iron accretions that make the mineral redundant and unusable. In the case where limestone has been used in anaerobic conditions the treatment of acidity in minewater has been highly successful. As oxygen is excluded the iron accretion to the limestone and its armouring does not occur.

There are though other problems that may occur, particularly the development of anaerobic bacteria in such quantities that they can block the system to the point of totally choking it so that it cannot function. This has, in at least one treatment site in the United States, led to the use of a bactericide. The problem with this approach was that it had an unexpected but logical effect on the bacteria in the wetland downstream of the anoxic limestone drain.

The most valuable front end aid to wetland systems' longevity and functionality is the oxygenation of the minewater on coming from the ground. Cascades, forced oxygenation or any other form of aeration allows the ferric irons to leave the waters faster. In areas where they do not remove as much iron as possible it may often result in problematic effects on any wetland treatment. In areas where space is not restricted or the geography of a site naturally allows for them, these methods may be considered highly desirable.

Where iron hydroxides are allowed to accumulate in wetland systems the finest parts become choked and soon begin to fail in their treatment task. Once this happens it becomes an issue of waste removal and re-engineering the system.

As all wetland systems should be, as any treatment for minewater remediation, a bespoke solution, the arrangement of oxygenation and treatment lagoons will be unique. The idea that wetlands need to be placed on level areas of ground is now no longer a necessity. The establishment of terraced structures is an acceptable option, though a more expensive product to install.

16.2.2.6 Other Benefits and Drawbacks

The main benefit of wetland treatments, which was quoted from the 1980s, was that they could be considered as walk away methods of remediation. This has been shown over time to have been wishful thinking. At best the wetland remediation system needs attention from a gardener/maintenance person with the distant support of a biologist rather than a process engineer. This, though, is only accurate if the system is functioning correctly and does not fail due to design faults. It is important that parts that are used within distribution mechanisms do not block up or become so mired in precipitates that their functions cease.

Ferrous accretion on distributer head

One area of great benefit for using wetlands as a treatment method is the remarkable attraction they have for wildlife and they may rapidly become species rich in not just common species; the unusual, and at times rare, can appear as if out of the blue. The fact that to all intents and purposes the site is an industrial waste disposal mechanism does not detract from its ability to offer secure and valuable habitats that may otherwise have been damaged elsewhere locally or the fact that the wetland is providing a niche that is unique in the area's biota and ecology.

A case in point is the minewater treatment facility that operated at Wheal Jane for several years in Cornwall, UK, where, over the five years of study, it was found that the site's macro and invertebrate fauna developed swiftly after the first three years of establishment. Damsel and dragon flies hunted not just the wetlands but also the substrate, once it developed a litter content, and were breeding and going through their life cycle, including the nymph stage, before maturing in the wetland system.

Some wildlife needs discouragement so as to avoid wetlands, especially during the establishment of systems. Particular creatures to discourage include wild boar and feral pig populations who will decimate the planting and devour plant rhizomes which could certainly muddy the water downstream.

Management, as stated, should need to be minimal but regular analysis of influent and effluent streams will need monitoring on a regular basis, not just to be sure of present working mechanisms, but to be aware of what may be happening in the subterranean environment of the abandoned mine. Mines are dynamic voids in their own right and never cease moving and destroying themselves. Roadways and other tunnels can undergo heave or subsidence; old dams can be breached and stopping may unstop. A running source of water can fail leaving a treatment site with nothing to treat.

16.3 COMPOSITE SYSTEMS

The use of passive systems with the addition of some forms of active technology can prove to be considerably more efficient than a pure passive installation. Much consideration, over the last eight years, has gone into the issues of sustainability and long-term viability. The realisation that most passive systems are not walk away solutions and need much more active management and removal of some waste and, notably, iron hydroxides has focused the attention of treatment design on developing systems that take the elements of efficiency from both sets of technologies.

Sets of compatible technologies have been and are being developed using front end treatment of metal rich waters with aluminium refinery waste and the development of sulphide reducing wetlands for sites in Europe and elsewhere. Such configurations are attractive where space is limited or the waters are overloaded with specific metallic compounds. They are also an attractive option on the grounds of long life and ease of maintenance.

16.4 FOO-FOO DUST

Foo-Foo dust well describes many methods of decontamination that rely on ‘special compounds’ that are not explained further than that they achieve their goals. Minewater and its potential to pollute and lay waste to rivers and other water courses have given rise to a plethora of patent methodologies that, if they do work, are still unexplained. The mechanisms by which these ‘miracle’ cures are able to do their task are sadly lacking. The absence of technical background papers or rationale as to the chemistry makes such panaceas unusable.

Some technologies, when first introduced, can sound like foo-foo dust, but on inspection their mechanisms are plainly and openly explained. Many such techniques are, though, underfunded in their trialling and development. This is true not just in the UK but across the globe.

Similar issues arise with the development of patented bacteria as single organisms or cocktail mixes that are 'guaranteed' to achieve faster if not instant results.

16.5 ASPECTS OF TREATMENT CRITERIA

Throughout this section of the book the main advice and the most basic but oft forgotten truth that appertains to minewater treatment is that it is something very close to being a living entity and like all sick things needs to be treated as an individual. No one answer fits all and the treatment methods that are selected for that particular discharge need to be robust enough and flexible to manage some changes in quality, hopefully for the better. If worse, a reconfiguration of the scheme or a return to basic design may be required.

Too often a method has been employed that might have worked elsewhere but fails in total or in part as the system employed has been foisted into a situation for which it was not specifically designed.

All the methods that are alluded to in the above sections have their place in the scheme of things. In the main though, consultants or other designers and contractors are limited by the commissioners of such works who will have cost and space constraints. The answers are all written of above and new methods will appear from other disciplines and areas of future research.

It is though a noticeable reality that the Wheal Jane minewater rebound was a catalyst to the development of and the experimental research for answers to many of the questions as to why and how several methodologies function. The realisation that minewater has been a universal issue had not been fully appreciated except by a few whose lives had been inexorably linked to the mining industry over many years.

Treatment cost constraints will always lead to the lowest cost materials of lime and wetland. The consideration that they may not be the answer is seldom confronted and the need to be aware of ever increasing and more complex legislation needs also to be considered. In the United Kingdom the issues of minewater matter so much that much is being carried out to remedy pollutions. This work is being driven not by the Government or its agencies (the Environment Agency and Scottish Environment Protection Agency) wishing to see pollution free post mining areas but by the spectre of prosecution by the European Union for breach of the European Water Framework Directive. This is the driver. The UK stands at the forefront of obeying such regulation, more so than any other European state.

16.6 DRIVERS OF WETLAND DEVELOPMENT

This almost juvenile observance of the rules has its justification in that as a country the UK had the sobriquet in the 1980s of 'the Dirty Man of Europe' and the embarrassment stuck. It is a sorry criterion for a nation that led the industrial revolution but it is globally a unique driver. No other European country, as a member of the European Union, is having any such blitz on sources of contamination to bring itself into compliance with such legislation. It is noticeable that several nations have as yet not adopted it into their own domestic legislation at all.

The drivers for good environmental practice in the developed world are those that now appear reactive to bad or poor practice. Much that has been removed from the earth had been taken in such quantity that it has literally removed landscapes. Large hills have become voids, areas of productive farmland have been returned to the populace after mineral extraction as open water. These practices may be at the high end of the schemes of mineral winning or exploitation but are eventually agreed to be acceptable actions if nothing untoward results such as pollution of the altered ecosystem or some accidental loss of life through poor restoration, such as drowning in quicksand. This event was not unusual in the past and is quite possible today in working or unrestored sand and stone quarries.

Globally the economically developing world powers are constantly in need of raw materials, from iron to rare earths. These drivers and the investment ‘aid’ and international companies’ wishes to carry on trading and exploiting minerals globally are stronger drivers that see that site remediation needs to be witnessed. As sites are exhausted and new ones are developed, good practice has to be visible. Sites are known to be short-lived but environmental consequences are long-term liabilities that, for the good of future contracts, must be embraced.

The wetland, as part of a restoration of a mineral site, is not just considered to be a cost effective solution for total site reclamation and not just considered for polluted discharges. This strategy has expanded across much of Europe and the United States. In the past mineral voids were considered future landfill sites for wastes, not just mineral but also municipal. Many power generation stations required the sites to dispose of their fly ash wastes from the coal burn systems. Now the utilisation of waste and the undesirability of waste deposition make it impossible to refill all the voids and return them back to productive agriculture.

This situation has made restoration and discharge, drainage, and run-off treatment schemes opportunities for conservation or nature reserve habitat creation. Many mineral rich areas are being developed as future wetland habitat sites. In the UK there has been much investment by mineral companies and government bodies to expand this form of restoration and much more has been spent in a large number of various future, long-term management strategies.

In many parts of the United States the Environment Protection Agency has allowed local communities to take on the long-term treatment of polluted minewater. These same organisations are encouraged to take on other derelict lands and incorporate them into the same operations. This allows the remediation sites to be extended and shifts the responsibility to a landowning entity rather than a long-gone mining company.

In the UK the ‘polluter pays’ principle exists as part of European Union legislation. It has encouraged the handover of many sites to ecological, wildlife and bird associations. This strategy has a long-term set of issues that have, as yet, not been worked out for future changes in legislation or the future interpretation of terms and attitudes. The fiscal and land gifts to charitable organisations to manage and take on restoration and remedial sites are attractive. Such arrangements, if they do work satisfactorily, are a benefit for all sides of the agreement.

Chapter 17
Global Investment and Minewater

Investment and the environmental record of mining companies is a developing area for consideration. The market price of many metals and other mined commodities are standing at record highs on the world metal exchanges, gold reaching around US $1700 an ounce and silver US $40 an ounce. These prices reflect the economic turbulence of our present time in history with stock markets and property values bearing witness to uncertain fiscal times.

The market value of mining stock, particularly that of major developers of the metal or hard rock derivatives, including gold, bauxite and iron ore, is increasingly being watched with concern regarding future liabilities from water related events. The fear in the minds of investors and markets analysts is that since the Gulf of Mexico pollution of 2010, there are concerns that many minerals and mining companies are not reporting the monitoring of water issues to their investors even though many are expressing such interest. This links closely to the whole development of ethical and environmentally credible investment analysis.

Much research has been carried out by investment houses and brokerages in this field over the period of 2010/2011. Some of the findings of that research underscore that the most notable companies operate an open approach to environmental data and welcome scrutiny. Other companies, as would be expected, have proved less open and many still cling to operational confidentiality.

Many of the reports to future investors, private and institutional, raise questions regarding the probity and narrowness of such companies to their apparent disinterest in water issues as the researchers see this as a flaw in many companies' future development and likely future failure in the medium- to long-term.

The general consensus of the research was that the financial community needed information about the local context of a mining company's water use before it may interpret the underlying fiscal risk stemming from water availability and quality concerns. This is especially true in the light of trends such as increasing water scarcity, intensifying competition for water resources, and more stringent water regulations that are affecting many regions of the world. There is a need for localised water footprint and water risk calculations that are complementary to help the financial community to understand mining companies' exposure and response to ambient water risks. A combined risk-adjusted overview could become the basis for assessing an operation's exposure to water risk and it would allow for a ranking of the industry's company rankings of water risk.

To fulfil this development the financial services sector may, it is suggested, develop a water risk index to measure map geographic water risks. This tool could be watershed specific but developed as a global tool. It should include specific data relating to economic, social and governance issues. There could be a predictive capacity to analyse publicly available data and indicators. Establishing such a database and analytical tool would allow the standardisation of reporting issues of interest or note in a standardised form. Thus this scheme could allow the financial community to better evaluate water related risks on a global, as well as local, level.

The proposal is that a scheme such as this would make the financial community take a leading role in encouraging improved water issue disclosure by the industry across the board. The financial sector would see that investors and allied institutions would create a strong incentive to better disclose data and information. It is considered that such information disclosure would improve the financial sector's ability to navigate the complex water risks that are increasingly important as the industry and environmental trends converge, with water becoming a considerable factor affecting growth and profitability globally.

The financial sector's reports that brought about the above recommendations were basic in that they are apparent to those interested in the issues, but they are worth reporting as they are seen by this group of interested parties.

Firstly the environmental harm, for which mining in many areas is responsible, needs to be evaluated. An inventory of the pollutants and the risks that they engender, both environmentally and economically was considered a necessity. It was also felt that the reputational risks needed to be considered.

There was a considerable concern that in areas of poor water supply the lack of process water may be a limiting factor in developing mines in arid or semi-arid regions.

The financial industry reports all underscore that the mining industry was aware or 'conscious' of water risks, and that much was being carried through to lessen or minimise risks and reporting by many companies was carried out. There was criticism that the varied ways of making similar data available was unsatisfactory. It was further noted that corporate disclosure often does not provide a comprehensive picture of water risk. It was also noted that there were no internationally agreed frameworks to guide companies to disclose the full scope of water related risks.

Water quality data was considered to be poorly cared for and seldom available except where there was a statutory need. In many areas there would appear to be no wish by some major companies to make information available to major shareholders. It was noted that there was little information on aspects of how mines impacted on local people and their local water uses. These uses included drinking, agriculture, fisheries and transport.

These reports were unanimous in the belief that the financial community were sadly lacking in information regarding regulatory, social, environmental or other liabilities. In many instances investments were being made with one eye on the commodity price indices and the other on the courts.

Chapter 18

Water Resource

A Royal Commission report into the water supplies of the British Isles reported that in 1888 several towns and villages across the country reported that they used water derived from colliery drainage to supply the domestic households in their areas. Since that time all regions of the United Kingdom have developed other water resources for that of domestic and industrial supply.

Internationally the issues of depleted water availability are focusing the governments and others to look towards water minimisation and recycling options. The lack of fresh water is raising the spectre of conflict or at least enmity between neighbouring states that share water resources in common.

Much work is now underway to identify untapped resources that may feed both national and international consumption need. The availability of minewater is already considered as a resource in several mining regions as a process water and in certain regions of Latin America the excess from particular mines is used for agricultural irrigation.

In the UK at least one minewater source is used to make a high value product that is consumed on a daily basis by tens of thousands of consumers. Sadly it is not considered a marketing tool to state its source publicly. The fact that it has created several hundreds of jobs in an area of chronic unemployment is though, reassuring.

Other sourced minewaters have been found to be satisfactory for passage through cooling towers and cooling power plant facilities for a chemical works. The source was water from an abandoned anhydrite mine in the north of England.

There is, in the UK, an interest in minewater from water utilities and many industrial, governmental and agricultural bodies, but even originating discussions, let alone agreements, with those that have water rights or liabilities, licensing and pollution control are difficult to negotiate. In the UK many millions of cubic metres of minewater are treated to allow it to be discharged to the natural environment and most could take strain away from the over abstracted aquifers around Britain.

Across much of the world, particularly many arid regions, there is a synergy that needs further exploration and development.

Chapter 19

In Conclusion

1 Mining is, has been and always will be, an industry that has major impacts on the natural and human environment. The needs of the world depend on its abilities to deliver the raw materials that each and every one alive today requires for survival, let alone any standard of living.

Catastrophes are a perennial concern. Accidents of huge proportions occur year on year. Pollutions and loss of human life are a constant reminder of the fragile nature of the industry.

The industry is going through many changes including, in the last decade, gaining the realisation that the communities in which they operate are important. There are also pressure groups that have lobbied, and continue to lobby, both the industry itself and the legislatures and planning authorities at local, national and international levels.

The industry still does not show itself in a good light. It believes that its engineers know better; the quoted statement that no non-mining engineer could understand dam engineering beggars belief. When accidents occur, many companies give non-specific excuses. This has been noticeable from Aberfan to the most recent tragedies. The threat of legal action will stop all but the most basic responses from the companies. There are no accepted methods of communication and little that can be done to rectify a horrendous situation.

This is a common state of affairs that is accepted globally. When an accident occurs it is the mine manager and chief surveyor who are sacrificed symbolically by the mine's directors. If the catastrophe involves damage to outside agencies such as local population and property damage, the mine company, which is usually a stand-alone subsidiary of a larger organisation, is now liable to go immediately into liquidation. This has become a regular occurrence after mining accidents in China and in other countries where private or semi-private enterprise mining is presently developing. The managers are prosecuted ruthlessly but the parent companies avoid censure.

In many cases the directors of the larger mining corporations of modern times are not from mining roots. Business schools and corporate financial backgrounds are the main recruiting grounds. The mining engineer seldom finds a way of preferment to the boardroom any longer. That, though, is not unique to the minerals industry but is common to many other organisations and industries. This issue that there is a lack of understanding of the complexities of mining and its allied problems such as water management makes the corporation vulnerable to over eager management of production expectations.

The mining community anywhere in the world feels the loss, devastation and frustration whenever an accident or catastrophic event takes place. The bond between all those involved in the unequal struggle between human will and the ground is a constant reminder of human fallibility, frailty and inadequacy. These are usually found, though not exclusively, in the boardrooms and not the mine manager's office.

2 Accidents and catastrophes involving mines and water will never be a thing of the past unless the industry ceases to exist and nature naturally heals up its scars. The being of mining and the vast works that have been undertaken in past millennia cannot be changed so radically that risk is eradicated.

Around the world there are similar events to those detailed above waiting to happen. Mining engineers have learnt much from the past but there is always something which can be or has been overlooked or an unknown. For example weather and other climactic conditions that have not been factored into mining risk assessments or seismic events that brings about drastic events. Human error or frailty may be the catalyst.

There is a surety that events will always surprise those in the industry and there will always be the external critics who will report after the event that it was an accident waiting to happen.

Predictability is easy for anyone with any knowledge of water. It is not an element that likes confinement; artificially held behind stoppings in a mine or naturally in an aquifer, it will eventually find ways to run free. The difficulty is predicting where it may appear. Once it has appeared its state and nature are equally unpredictable.

3 As technology with regard to minewater treatment is improving the use of that water after treatment bears consideration internationally. The expense of cleaning such quantities as a necessity to protect the environment should not preclude it from other uses; in working mines and processing plants this is already a reality. In the use of abandoned minewater the question of profit and cost recovery are raised as considerations. These are not insurmountable as such, and consider the recourse as large reservoirs that are there for the use of communities that are starting to become aware of water stress.

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Note: f = Figure

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