Coal mine site reclamation

Lesley Sloss

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Abstract

Coal mine sites can have significant effects on local environments. In addition to the physical disruption of land forms and ecosystems, mining can also leave behind a legacy of secondary detrimental effects due to leaching of acid and trace elements from discarded materials. This report looks at the remediation of both deep mine and opencast mine sites, covering reclamation methods, back-filling issues, drainage and restoration. Examples of national variations in the applicable legislation and in the definition of rehabilitation are compared.

Ultimately, mine site rehabilitation should return sites to conditions where land forms, soils, hydrology, and flora and fauna are self-sustaining and compatible with surrounding land uses. Case studies are given to show what can be achieved and how some landscapes can actually be improved as a result of mining activity.

Acronyms and abbreviations

AGDRET	Australian Government, Department of Resources, Energy and Tourism
AMD	acid mine discharge
AOC	approximate original contour
ARD	acid rock drainage
BAT	best available techniques
CAA	Clean Air Act, USA
CAP	Central Appalachian Plateau, USA
CCB	coal combustion by-product
CEPA	Canadian Environmental Protection Act
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act, USA
CFBC	circulating fluidised bed combustion
CWA	Clean Water Act, USA
DDNM	dual density natural medium process
DEFRA	Department of the Environment, Food and Rural Affairs, UK
DWEA	Department of Water and Environmental Affairs, South Africa
EMOS	Environmental Management Overview Strategy
EPFL	Establissment Public Foncier de Lorraine, France
ESA	Endangered Species Act, USA
EC	European Commission
EU	European Union
FBC	fluidised bed combustion
FFI	Fauna and Flora International
FGD	flue gas desulphurisation
FRA	forest reclamation approach
HSPF	hydrologic simulation program-Fortran
IBAT	Integrated Biodiversity Assessment Tool for Business
ICMM	International Council on Mining and Metals
ICP	IndoMet Coal Project, Borneo
KDSMRE	Kentucky Department of Surface Mining and Enforcement, USA
LMBV	Lausitzer und Mitteldeutsche Bergbau-verwaltungsgesellschaft mbH
LULC	land use and land cover
MCA	Mineral Council of Australia
MCMPR	Ministerial Council on Mineral and Petroleum Resources, Australia
MIBRAG	Mitteldeutsche Braunkohlengesellschaft mbH, Germany
MWLP	mine water leaching procedure
NEPA	National Environmental Policy Act, USA
NGO	non-governmental organisation
NOAMI	National Orphaned/Abandoned Mines Initiative, Canada
NPI	net positive impact
NSE	Nova Scotia Environment, Canada
NVDI	normalised difference vegetation index
NWA	National Water Act, South Africa
OSM	Office of Surface Mines, USA
PAF	potentially acid-forming rock
RCRA	Resources Conservation and Recovery Act, USA
SCS-CN	Natural Resource Conservation Service Curve Number Method, USA
SDWA	Safe Drinking Water Act, USA
SMCRA	Surface Mining Control and Reclamation Act, USA
SWDA	Solid Waste Disposal Act, USA
TDS	total dissolved solids

TMF	tailings management facility
TSCA	Toxic Substances Control Act, USA
TVCM	township and village coal mine, China
US EPA	United States Environmental Protection Agency
WDCS	Waste Discharge Charge System, South Africa
WVDCH	West Virginia Division of Culture and History, USA
WVDEP	West Virginia Department of Environmental Protection, USA
WVDNR	West Virginia Division of Natural Resources, USA

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1 Introduction

Remediation, reclamation or rehabilitation is the process of repairing any negative effects of mining activities on the environment. This can be simply returning the site to a safe and stable condition, restoring pre-mining conditions as closely as possible to support the future sustainability of the site, or improving the landscape with new features. In the 20 years since the last IEA CCC report on mine land reclamation and remediation, the whole ethos of the practice seems to have changed. Whilst in the past, the mined land would be brought up to minimum standards in terms of safety and revegetation, many current projects aim not only to return the land to its former glory but to improve it and leave some form of long-term legacy. Many closed mines have become forests, farm lands and even nature reserves and art installations.

Figure 1 shows the lifetime of a mine project. Following a few years of exploration and site design and construction, the life of the mine is usually somewhere between 2 and 100 years. The decommissioning period can be short, at under five years, but the post-closure management of the site can vary from a decade to perpetuity, depending on the ownership and use of the land. How a mine site evolves following closure of mines varies according to location and local requirements. In the European Union (EU), of the mined lands that have been reclaimed, over 50% are reclaimed as forests or grasslands whereas in China, more than 70% are reclaimed for agricultural purposes. China has a large population and a shortage of farmlands and so useful land is a valuable commodity (Bian and others, 2010).

Figure 2 shows the environmental impact that surface mining can have on different sectors, from contamination effects on water bodies, through effects on soil, plants and animals, to changes in land use and sociological effects on the local community (Dogan and Kahriman, 2008). Clearly there are many issues to be considered when deciding on how best to deal with mined lands.

In the past, shoddy, inconsiderate mining activities in some regions have left a legacy of damaged lands and ugly landscapes. For example, the Santa Catarina coal basin in Brazil has been damaged through 100 years of mining and now ‘extensive remediation is necessary’ to improve water quality in the water sheds in the region (Gomes and others, 2011). There are reported to be around 560,000 abandoned mine sites in the USA alone (Voros, 2006). Fatalities have occurred as a result of badly managed and abandoned mines. But practices are changing and mining practices are far more forward thinking than they used to be. Mine reclamation is expensive – $1.5 million per mine according to some estimates – and this is the main reason why many sites have simply been abandoned in the past (RLCH, 2011).

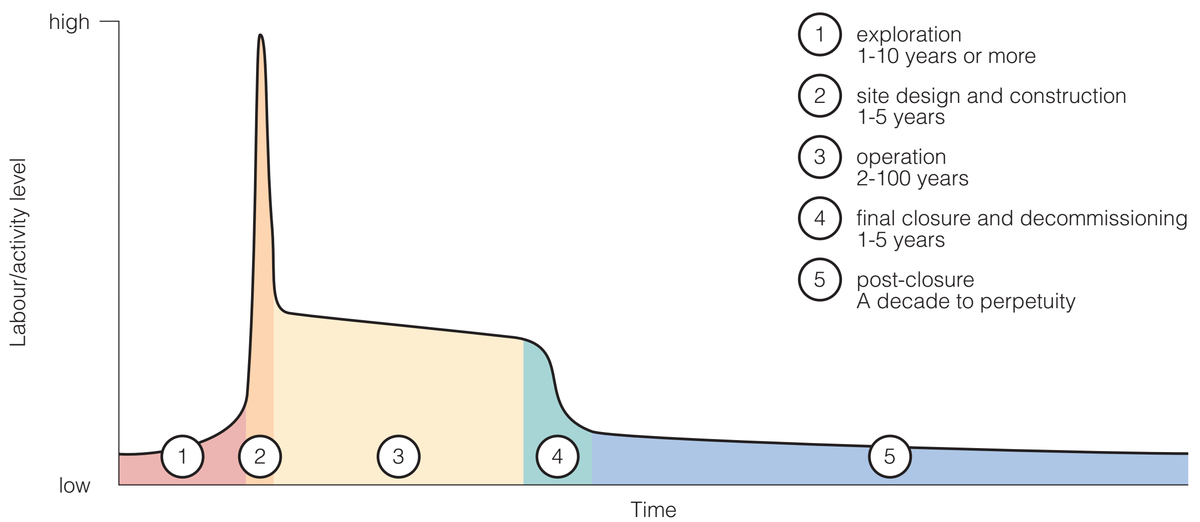

Figure 1 Mine project life cycle (ICMM, 2012b)

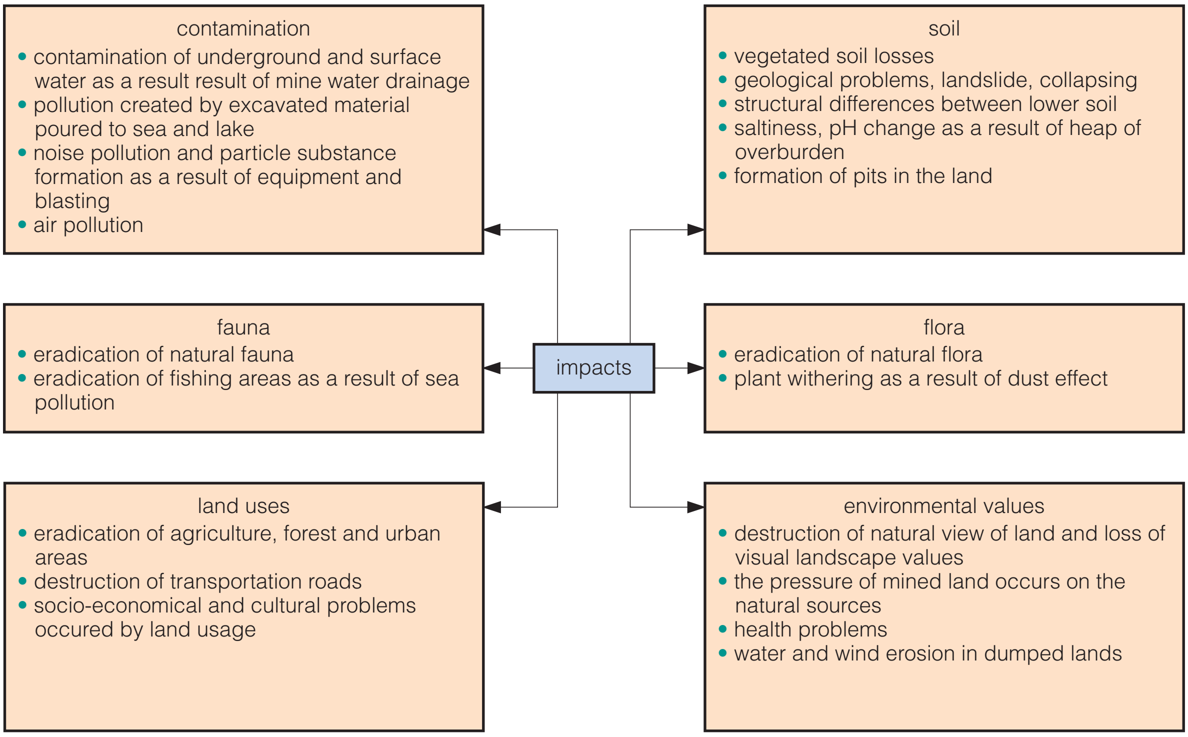

Figure 2 Environmental impacts of surface mining (Dogan and Kahriman, 2008)

Chapter 2 of this report briefly discusses the legislation and regulations which apply to mine reclamation activities around the world. Chapters 3, and 4 then look at the major issues which must be considered when reclaiming mined land – the water and the land structure. Chapter 5 concentrates on methods for reestablishing vegetation and ecosystems and lists several examples demonstrating the different ways in which previously mined land can be returned to having a useful purpose.

2 Legislation

As shown in Table 1, in every other area except China, the majority of coal produced is mined from surface mines. Although coal production is increasing, the number of coal mines in many countries is actually being reduced. This is largely due to the improvement in mining efficiency – technologies are improving so that more coal can be extracted from each individual mine – and to the increasing size of single mines. For example, in 2007 the Shengdong Coal Mining Company in China produced over 20 Mt of coal from only two long-wall work faces. Coal production in China increased from 1.38 Gt in 2001 to 2.3 Gt in 2006, a 66% increase. However, during the same period the number of mines was reduced by 50%. The same has happened in the USA where, in 1993, there were 2475 coal mines producing over 940 kt/y of coal but only 1438 mines producing a total of over 1.16 Mt/y in 2006. Conversely, coal mining activities are being reduced significantly in Europe – France had closed all national mines by 2004, the UK has very few remaining working mines and the German government plans to phase out subsidies for coal production (Bian and others, 2010). Subsidies for coal mining in Europe have been extended to 2018 – this is discussed more in Section2.1.

Table 1 Percentage of coal production by mining method in the main coal producing countries, 2006 (Bian and others, 2010)

Country	Underground mining, %	Surface mining, %	Total, Mt
China	95	5	2380.0
USA	30.9	69.1	1503.6
India	19	81	447.0
Australia	22	78	405.1

The approval process for initiating mining activities in many countries can be a long and difficult process. This report considers only the legislation associated with the remediation and rehabilitation of coal mines following closure. However, it is important to note that the requirements for mine remediation will, in most cases, form an integral part of any mining permit application and must be considered before the mine can even begin operation.

It is not possible to summarise in detail the legal requirements for mine rehabilitation around the world as these vary significantly from site to site depending on the local conditions. For example, Table 2 gives an indication of the number of different laws and regulations which are appropriate to mining activities in China alone. Many countries have Environment Acts and/or Mineral Resources Acts and similar legislation which will include minimum considerations for permits for new mining activities and the subsequent rehabilitation of the land. Erickson (1995) published a review of international policies for coal mine planning and reclamation which is still being cited today. Relevant information from this review is cited below.

The requirements for the rehabilitation of the land following closure of the mine will commonly be included in the initial planning permit for the site but will be site-specific – the standards to be met with respect to effluents, soil quality and so on will all vary from location to location and with the specific geographical and geological characteristics of the mine location. Prior to 1970, reclamation policy tended to concentrate on post-mining health and safety rather than the environment and reclamation. However, more recent policies concentrate on remediation and work towards sustainability of new land uses, with significant community involvement. The International Council on Mining and Metals (ICMM) defines sustainable development in the mining industry as development which is technically appropriate, environmentally sound, financially profitable and

Table 2 Law, regulations and measures relating to the rights to mineral resources, mining, and environmental protection in China (Andrews-Speed and Xia, 2003)

Name of Instrument	Year
Mineral Resources	
Mineral Resources Law, amended	1986,1996
Rules for the Implementation of Mineral Resources Law	1994
Regulations for Registering to Explore for Mineral Resources using the Block System	1998
Regulations for Registering to Mine Mineral Resources	1998
Regulations for Transferring Exploration Rights and Mining Rights	1998
Mine Operation	
Law on the Coal Industry	1996
Administrative Measures for Coal Production Licences	1994
Implementation Rules for the Management of Coal Production Licences	1995
Regulations for Coal Businesses and Operations	1996
Law on Safety in Mines	1992
Regulations for Coal Safety Supervision	2000
Environmental Protection	
Law on Water	1988
Law on Environmental Protection	1989
Temporary measures for the Management of Environmental Protection in the Coal Industry	1994
Law on Water and Soil Conservation	1991
Law on Prevention and Control of Water pollution, revised	1986,1998
Law on Land Administration, amended	1998
Implementation Provisions for Law on Land Administration	1998
Regulations on Land Reclamation	1988
Implementation Measures for Regulations on Land Reclamation	1998
Township and village mines	
Circular of the State Council on the Implementation of Industrial Management of Township and Village Enterprise mines	1986
Administrative Measures for the Township and Village Enterprise Mines in the Shanxi Province	1986
Measures for Reorganisation of Township and Village Enterprise Mines in Shanxi Province	1986
Administrative Regulations for Township and Village Coal Mines	1994
Implementation Measures for the Administrative Regulations for Township and Village Coal Mines	1994
Regulations for Small Coal Mine Safety	1996
Law on Township Enterprises	1996

socially responsible (AGDRET, 2006). Although many mines may now follow this ethical approach, this has not always been the case. However, legislation is evolving in many countries to ensure that mining does not cause the environmental issues it has in the past.

Since there are significant amounts of legislation associated with the mining activities themselves and standards to be met during mining and upon mine closure, countries and regions tend to produce guidelines and manuals which present the most important issues that should be considered when establishing new coal mining activities. For example, the Environmental Assessment Branch of Nova Scotia Environment (NSE), Canada, has published the *Guide for surface coal mine reclamation plans* which outlines the different responsibilities of the operating company when planning a mine reclamation project (NSE, 2009). Similarly, the Australian Government has developed a *Leading Practice Sustainable Development in Mining* handbook series which covers environmental, economic and social aspects of mineral mining. 'Leading practice' is defined as the best way to do things at a given time and is therefore a flexible approach which allows for developments and advancements in methods and technologies. It also includes the concept of 'adaptive management', based on 'learning by doing' and the application of best approaches through trial and testing (AGDRET, 2006).

The majority of mining permits will include elements of the following which relate to minimum requirements for reclamation (AGDRET, 2006):
- rehabilitation of land disturbed or occupied in operations;
- consultation with stakeholders to develop a closure plan;
- where possible, rehabilitate progressively through the operation life of the mine;
- monitor success criteria with stakeholders;
- undertake and support research into land and water rehabilitation practices;
- use of appropriate technologies to reduce negative environmental impacts and improve site rehabilitation techniques;
- manage and, where appropriate, rehabilitate historical disturbances to an appropriate standard.

The following sections briefly review reclamation standards and practices in certain regions of the world.

2.1 European Union

In 2010, the European Commission (EC) proposed a rule that member states must stop granting subsidies to loss-making coal mines by the end of 2014. In 2008, European governments paid out €3.2 billion in subsidies to coal. The new rules would only have allowed governments to give operating aid to loss-making coal mines if closure plans are in place and if they are scheduled to be shut down by 2014 (Sourcewatch.org, 2012). However, despite action by several environmental groups, the rule was thrown out and Germany, Spain and other coal producing states won an extension on the subsidies until at least 2018 (Reuters, 2010). Mining reclamation issues are therefore likely to continue for many years yet in the EU.

The EC has several directives and guidance documents which relate to mining activities and reclamation. These include the guidance document outlining best available techniques (BAT) for the management of tailings and waste rock from mining activities, which can be downloaded from the EC website (EC, 2009). The following paragraphs summarise the most relevant information in the EC BAT with respect to coal mining. For the most part, the EC document concentrates on metals mining. However, coal is included when it is processed and there are tailings produced. Generally, this means that hard coal (or rock coal or black coal) is covered, whereas lignite (or brown coal), which is usually not processed, is not covered. For all mining activities, the EC guidance requires complete management of issues through the lifetime of the mine. Figure 3 shows a flow diagram outlining the main considerations when planning for mine closure. These include baseline studies to determine the status of the land with respect to rocks, tailings and waste and combining these with current

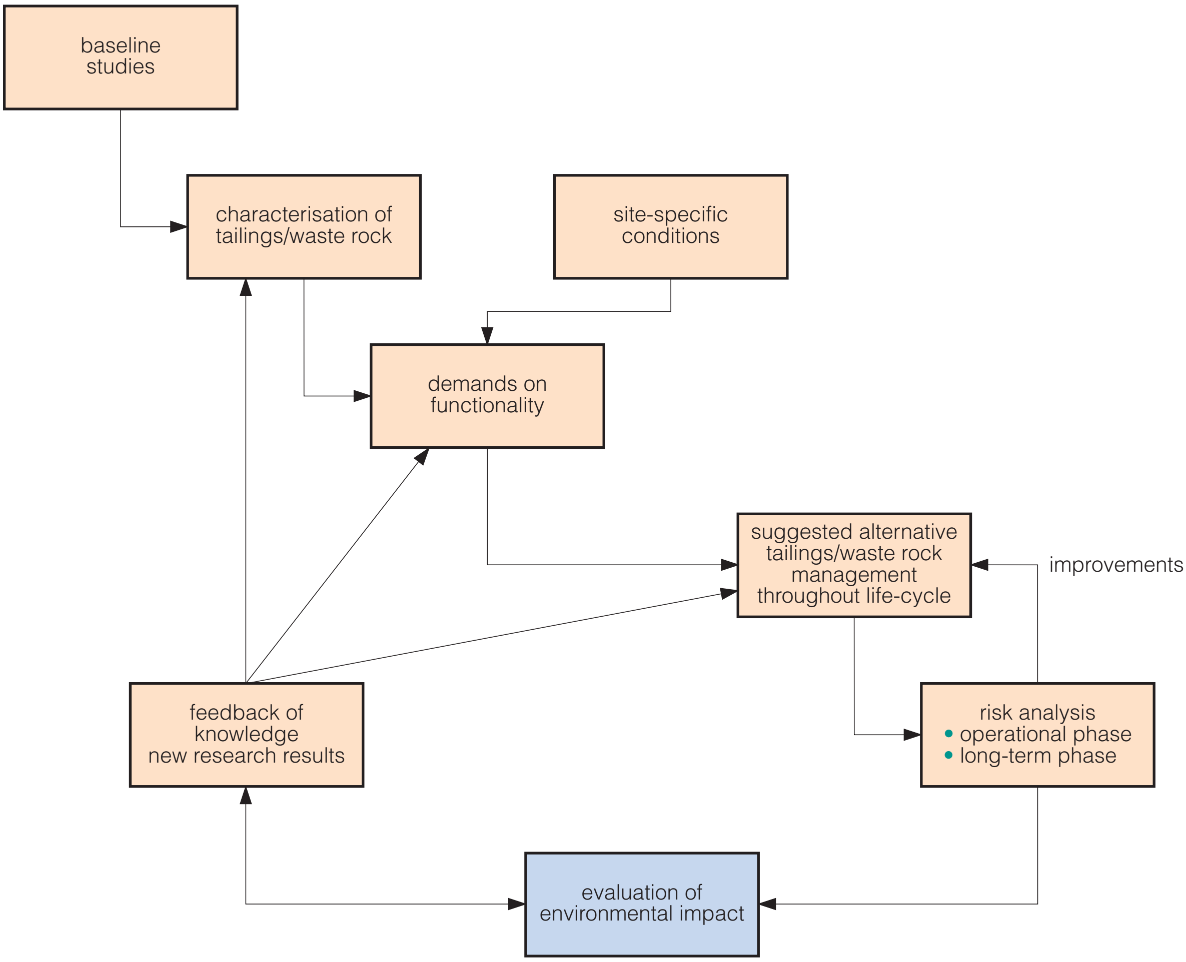

Figure 3 Illustration of the information flow for a 'design of closure' (EC, 2009)

knowledge and new research on how best to improve the situation in the long term, resulting in an overall environmental impact assessment. More details of the EC guidelines are given in Chapter 4.

The EC BAT for mining activities require that mine plans must also include consideration of:
- reagent consumption;
- water erosion;
- dusting;
- water balance and a water management plan;
- manage groundwater around all tailings and waste-rock areas.

The EC (2009) document has many examples of best practice in mine management and reclamation. Although much of the document relates to metal ore mining, many of the details included are relevant for coal mining sites. For example, in addition to these generic measures for all mining activities, coal sites, must also prevent seepage and dewater fine tailings from flotation.

Within the EU there are many organisations who provide information and support on coal mine reclamation practices. These include:
- www.commonforum.eu – a network of contaminated land policy makers, regulators and technical advisors from Environment Authorities in European Union member states and European Free Trade Association countries;
- http://www.nicole.org/ – a leading forum on contaminated land management in Europe, promoting co-operation between industry, academia and service providers on the development and application of sustainable technologies;

- http://www.cabernet.org.uk (Concerted Action on Brownfield and Economic Regeneration Network) – the European Expert Network addressing the complex multi-stakeholder issues that are raised by brownfileld regeneration;
- http://www.iccl.ch/ – the International Committee on Contaminated Land;
- http://www.rescue-europe.com/ (RESCUE) – intends to improve the quality of derelict land recycling in terms of the sustainability of the build environment and the quality of urban life. It does so by developing tools for the practical work of real estate owners, planners, architects, engineers and public authorities involved in the complex processes of brownfield regeneration projects;
- http://www.zerobrownfields.eu/index.aspx (HOMBRE) – aims to create a paradigm shift to 'Zero Brownfields' where brownfields become areas of opportunity that deliver useful services for society, instead of derelict areas that are considered useless;
- TIMBRE – a EC FP7 project for the tailored improvement of brownfield regeneration in Europe. More details on the project can be found online (*see* Bartke, 2012*);*
- SUMATEC – the SNOWMAN (Sustainable management of soil and groundwater under the pressure of soil pollution and soil contamination) project on Sustainable management of trace element contaminated soils – development of a decision tool system and its evaluation (Snowman, 2012);
- CLARINET – the Contaminated Land Rehabilitation Network for Environmental Technologies which is funded by the European Commission, DG Research, under the Environment and Climate Programme and co-ordinated by the Austrian Federal Environment Agency (Clarinet, 2002).

The following sections include examples of mining reclamation requirements or activities within selected EC member states.

2.1.1 Belgium

In 1991 SPAQUE was formed to deal with rehabilitation of landfills and polluted brownfield sites in Wallonia. The association has an inventory of contaminated sites in the area and assists in the development of projects in alternative energy (wind, solar, hydro, biomass). Through its subsidiaries, SPAQUE is a major factor in the collection, treatment and recycling of inert waste and construction www.spaque.be.

2.1.2 Germany

Germany has seen a significant amount of coal mining activity over many centuries. One of the first ever published pieces of legislation relating to the treatment of mined land was the 1966 decree from Rheinland which required that abandoned mines be planted with alder trees. In 2007, Germany produced 180 t of brown coal, over twice as much as the next highest producing nations – Australia (72.3 t), Russia (71.3 t) and the USA (71.2 t) (Lotgers, 2004).

Some confusion can occur when studying German reports on mine reclamation due to the different terms used. 'Recultivation' is used in the same manner as reclamation. Germany also uses the term 'Immission' which is not used elsewhere, as a measure of exposure of the natural environment to emissions of pollutants. Figure 4 summarises the different laws in Germany which relate to the approval process for any new mining activity. These include forest laws, water rights, waste laws and nature conservation laws (Milojcic, 2011).

The UN has also produced a summary of policy and regulations relating to mining in Germany (UN, 2012). The most relevant of these is the legislation pertaining to 'rehabilitation of affected communities and life-supporting ecosystems, including mine-site decommissioning'. The German Federal Mining Act recognises that mining activities do not end with mine closure and therefore

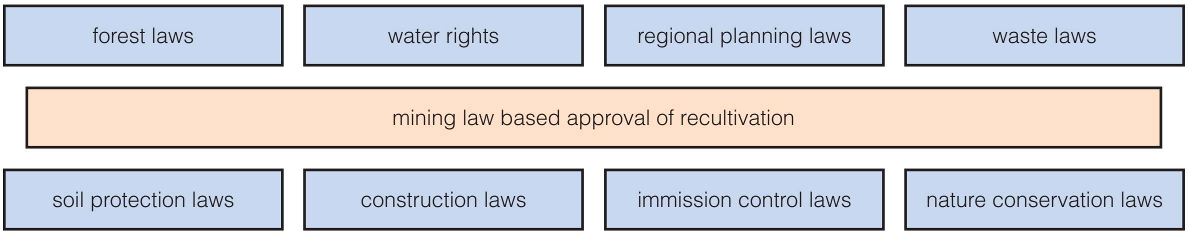

Figure 4 Legal fields associated with mining approval in Germany (Milojcic, 2011)

requires that worked out sites are rehabilitated. For lignite, which is an important portion of the fuel mined in Germany, there is a specific lignite extraction plan which is co-ordinated by a committee. The committee includes elected members from communities involved in lignite mining regions. The lignite extraction plan must define work boundaries, co-ordinate changes in infrastructure required by the mine, find resettlement territories and state basic rehabilitation measures. There is also legislation relating to 'mine closure planning (land use plans and site rehabilitation, site safety, decommissioning, waste dumps and tailings, site water management, off-site infrastructure, community socio-economic programmes and employees)'. The Federal Mining Act and relevant mining ordinances in Germany outline requirements for mine closure planning including rehabilitation.

Mining activity was significant during the 1970s and 1980s leaving a large amount of derelict land across Germany. Unplanned mine closure after reunification of East and West Germany also left significant areas of devastation. Local governments of brown coal producing states and the Federal Ministries for Environment, Labour, Economy and Finance undertook a joint programme to deal with this legacy. German Federal Mining Law now includes the requirement for a special abandonment plan which must be approved by the Mining Authority before a permit to mine is released (Andrews-Speed and Xia, 2003). For lignite mining there is the Administrative Agreement (VAI) of 1992 between the Federal Republic of Germany and the Länder Berlin, Brandenburg, Mecklenburg-Western Pomeriania, Saxony Anhalt, Thuringia and the Free State of Saxony on the financing of contaminated site remediation. The agreement is divided into three levels (Frauenstein, 2009):

1 Secretariat of the Steering and Budget Committee – steering and control for lignite mine remediation, involving Federal Government and Lander Representatives;
2 Regional Advisory Councils for Remediation – project management by LMBV (Lausitzer und Mitteldeutsche Bergbau-verwaltungsgesellschaft mbH);
3 Remediation companies established by lignite mining companies – for the implementation of the remediation projects.

Overall there are over 5000 suspected contaminated sites covered by the agreement of which 159 are closed opencast mines, 122 tailings with ash or lignite, 120 sedimentation facilities (inert overburden), and nine thermal upgrading plants. Over €8.2 billion had been spent on lignite remediation by 2008 and for the current period, 2008-12, a further €1 billion is provided with 75% of this coming from the Federal Government and 25% from the 'Länder' (Frauenstein, 2009).

2.1.3 France

In France, 'brownfields' are considered different from contaminated sites in that they are 'previously developed land (agriculture, harbour, industry, service, ore processing, military/defence, storage or transport) that has been temporarily or permanently abandoned following the cessation of activity and must be reclaimed for a future use.' Brownfields are located in areas such as former industrial French region, for example Lorraine and Nord-Pas de Calais. Inventories of brownfield sites have been created by EPFL (Establissment Public Foncier de Lorraine) along with evaluation of the suitability of sites for future use. About 200,000 former industrial and service sites (around 20,000 ha), and about

200 former mines are now brownfields. The number of brownfield sites has not decreased in the last decade, despite active reclamation. Legal aspects of brownfield reclamation are covered by several laws and regulations, including (EUGRIS, 2012):

- Law on environmental permits for industrial sites;
- Mining Code, for former mines (Mining Code recently modified to take into account the cessation of mining activity and the closure of mines);
- Civil Law Code (liability of property owners for harm caused), Urban Planning Act for the redevelopment of brownfield sites, in the urban context;
- specific regulations concerning historical building preservation and new qualification.

In 1995 a new tax was created on special industrial waste to finance the remediation of 'orphan' sites or sites whose owners are insolvent.

2.1.4 Spain

Spain saw a boom in surface mining during the 1980s, largely in the River Martin watershed area, with 17 mines in a 2500 ha area. Mining activity has decreased to leave only three operating mines and, with the EU subsidies being phased out, this is expected to continue to decline. The closed mines in the River Martin watershed are regarded as restored in they have more than 40% plant coverage. However, at the moment, only eight of the seventeen mines are regarded as being restored to a 'good' ecological status (Comin and others, 2009).

2.1.5 UK

In the UK, coal mining activities fall under the remit of several distinct regulations and laws relating to contaminated land, planning, water pollution, environmental protection, waste management, common law, statutory nuisance and health and safety. In 2004 DEFRA (Department of the Environment, Food and Rural Affairs) produced *Guidance for successful reclamation of mineral and waste sites*. The document is a form to be completed which the user follows through to determine areas and topics which must be covered in any application for mine reclamation.

The site application must take into account planning considerations, overall restoration proposals, soil, the method of working (of the mine), soil handling equipment used, current soil storage, an outline of the after care issues and any effects on local farming. The site working section of the guidance then concentrates on procedural matters, equipment, monitoring, and so on. The restoration section deals with land forming, soil replacement, remedial issues and drainage. There is then a final section on aftercare, such as continuing soil analysis, drainage and post-site actions required (DEFRA, 2004).

The Land Trust is an independent Charitable Trust in the UK which manages open spaces on behalf of and in partnership with local communities (LRT, 2012). There is also a company www.recycoal.com which actively invests in site reclamation of old coal spoil heaps in the UK to return the land to an uncontaminated state while recovering usable fuel. RecyCoal projects are discussed in more detail later in this report.

2.2 North America

Both Canada and the USA have seen a significant amount of mining activity in recent decades and many of these sites now need to be recovered to usable areas of land.

2.2.1 Canada

In the 1995 review, Erickson noted that, by the early 1980s, around 240,000 ha of land had been disturbed for mining in Canada and yet less than 30,000 ha had been reclaimed. As is the case in Australia (*see* Section 2.3), the requirements for mine reclamation are left to the local authorities or to the mining companies themselves, with little regulation at the national level. Alberta has what may be the most established legislation of any province in Canada with its Land Surface Conservation and Reclamation Act (1973). Reclamation must ensure that '*the ability of the land to support various land uses after reclamation is similar to the ability that existed prior to any activity being conducted on the land, but the ability to support individual land uses will not necessarily be equal after reclamation*'. The Canadian system is arguably more flexible and open to provincial discretion than the system in the USA (*see* Section 2.2.2). The Canadian Environmental Protection Act (CEPA, 1989) was based on environmental impact assessments which include social as well as physical and biological impacts of mining (Erickson, 1995).

In 2010, the National Orphaned/Abandoned Mines Initiative (NOAMI) published the *Policy Framework in Canada for Mine Closure and Management of Long-term Liabilities: a guidance document*.

2.2.2 USA

The Surface Mining Control and Reclamation Act (SMCRA) of 1977 requires the coal mining areas to be restored to '*a condition capable of supporting the uses which is was capable of supporting prior to any mining, or higher or better uses*'. The definition of '*higher or better uses*' is open to interpretation within each permit or plan. SMCRA established permitting guidelines for existing and future mines as well as a trust fund to finance the reclamation of abandoned mines. SMCRA requires mine operators to provide a reclamation plan prior to the release of any permit to commence mining. Operators must also post a performance bond to ensure that funding will be available to complete the reclamation. This will ensure the reclamation is completed even if the operator goes out of business prior to finishing the reclamation or is otherwise unable to complete the project. The bond is not released to the operator until after the state or federal regulatory office has concluded that the reclamation is successful, which could be over ten years after the reclamation process has been completed.

There are three major types of reclamation bonds (TASM, 2012):
- Corporate surety bond – a guarantee that the contractor will perform the obligation stated in the bond;
- Collateral bond – a short-term debt security (cash, letters of credit, federal, state, or municipal bonds and so on);
- Self bond – legally binding corporate promises available to those who meet certain financial tests. Self-bonds are not allowed in some states.

In some cases, the permit may be granted based on a combination of bond types, assuming that the basic requirements and potential costs are met and/or guaranteed. The minimum value of the bond is determined by the local authority based on an estimate of reclamation costs and what these would cost for a third party to complete the plan in the event of bond forfeiture.

Release of the bond occurs after the regulatory authority has deemed the reclamation work acceptable. This may happen in phases, with parts of the bond being released after completion of each phase (TASM, 2012):
- Phase I – back-filling, regrading, and drainage control;
- Phase II – after topsoil replacement and establishment of revegetation;
- Phase III – meeting the revegetation success standards.

SMCRA has also established a funding process for the reclamation and remediation of abandoned mines. Current coal mine operators must pay a tax of 0.135 $/t for underground mined coal and 0.315 $/t for surfaced mined coal (reduced to 0.12 and 0.28 $/t, respectively, effective 1 October, 2012) to the Abandoned Mine Reclamation Fund. The Office of Surface Mines (OSM) has so far provided more than $7.2 billion to reclaim more than 120 ha of hazardous high-priority abandoned mine sites (TASM, 2012).

For forest land, the performance standards to determine the success of the land reclamation is based, amongst other things, on the growth of the planted trees. The final bonds will only be released once minimum criteria have been met. However, according to Sullivan and Amacher (2010) the performance standards used for releasing bonds differ between states ‘for no apparent reason’ and this can lead to some states having to meet stricter requirements than others. For example, in Virginia, the requirement for 90% ground cover (vegetative or tree growth) was tougher than any other state in the Appalachian coal region. However, this requirement has since been relaxed.

Sullivan and Amacher (2010) argue that the differences in state requirements place an ‘avoidable burden’ on some mine operators in the form of a private cost to meet the performance standards. The cost of meeting a 90% ground cover standard as opposed to a 70% standard could be more than 700 $/ha. A strict tree survival standard of 1235 trees/ha could cost more than 200 $/ha more than a 1087 trees/ha standard. On the other hand, Sullivan and Amacher (2009) note that the requirement of SMCRA to return mining land to minimum requirements means that operators are not necessarily obliged to make the most appropriate decisions on reclamation strategies. The mine operators are free to bring the land back to minimum standards of regrowth and vegetation but do not have to take into account the potentially most profitable use of the land following reclamation. For example, the operator may return the land to grassland which is less valuable to a farmer than forest land.

Figure 5 shows the cumulative area reclaimed under SMCRA in the Appalachian region between 1978 and 2009. At the end of 2009 a further 50,000 ha was partially reclaimed but not released as complete (Zipper and others, 2011).

In addition to SMCRA, mining operations must abide by a number of other federal environmental laws including (TASM, 2012):

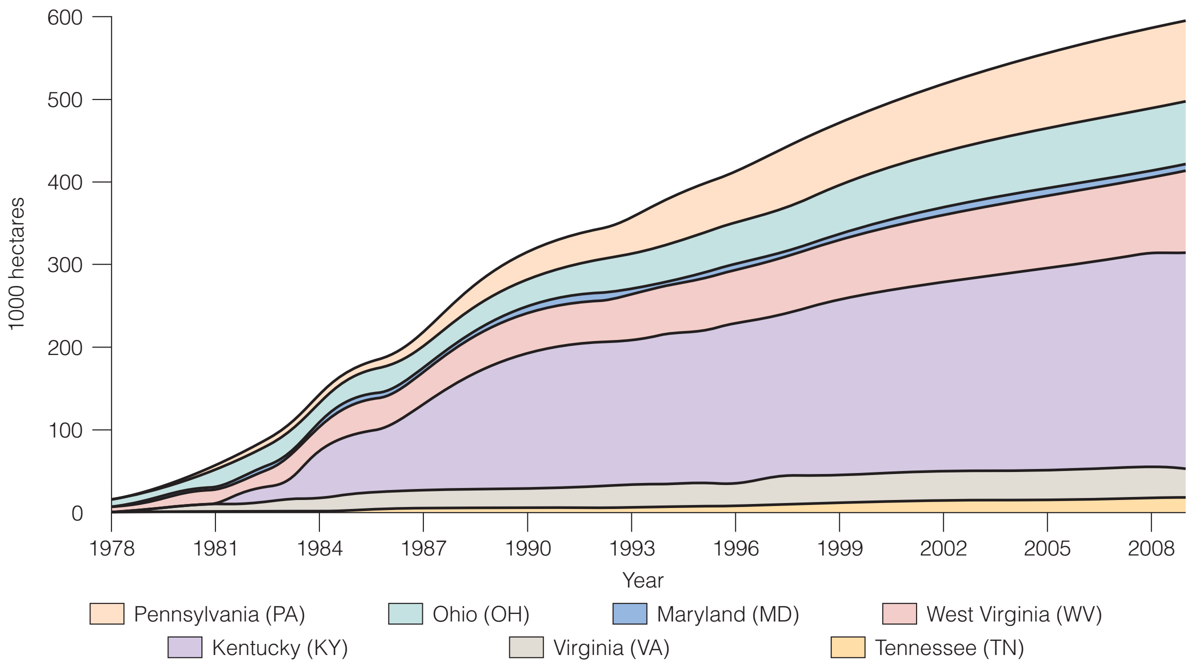

Figure 5 Cumulative Appalachian areas reclaimed under SMCRA (Zipper and others, 2011)

1965: Solid Waste Disposal Act (SWDA)
1969: National Environmental Policy Act (NEPA)
1970: Clean Air Act (CAA)
1972: Clean Water Act (CWA)
1973: Endangered Species Act (ESA)
1974: Safe Drinking Water Act (SDWA)
1976: Toxic Substances Control Act (TSCA)
1976: Resources Conservation and Recovery Act (RCRA)
1980: Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)

Although individual states bear the responsibility of regulating mine reclamation, the OSM has created minimum standards which must be met. The OSM also oversees the state programmes and conducts inspections and evaluations on the behalf of the Department of the Interior. Although most states have developed their own regulatory programmes, two states (Tennessee and Washington) do not have such programmes and are called Federal Program States (TASM, 2012). The federal and state agencies responsible for regulating mining industry vary from state to state. For example, in West Virginia these include the US Office of Surface Mining, the US Army Corps of Engineers, the US EPA, US Fish and Wildlife Service, the West Virginia Department of Environmental Protection (WVDEP), the West Virginia Division of Natural Resources (WVDNR), and the West Virginia Division of Culture and History (WVDCH) (TASM, 2012).

The Pennsylvania Department of Environmental Protection has a Comprehensive Plan for Abandoned Mine Reclamation which was established in 2000. One component of this is the Eastern Pennsylvania Coalition for Abandoned Mine Reclamation (EPCAMR), a non-profit organisation set up in 1996 to help reclaim and remediate mine land in the area. EPCAMR is mostly funded by the US EPA with over $635 million spent since 1967 on reclamation and over $15 billion worth of reclamation still to be completed. It is estimated that this will take around 105 years to complete. As part of their work, EPCAMR have completed many efforts including (EPCAMR, 2012):

- restoring 80 km of stream channel;
- restored 7135 ha of abandoned mine land,
- eliminated over 201 km of dangerous highwalls;
- reduced the subsidence risk to around 937 ha of land.

It is sometimes the case that legislation faces criticism for the stringency of requirements set. For example, the US EPA has set guidance stipulating that water discharging from central Appalachian mining activities must be <500 micro Siemens per centimeter (µS/cm, a unit of measurement of conductivity). In some situations >300 µS/cm could be cause for reconsideration of a mining permit. TASM (2012) argues that these values are extremely low and difficult to achieve, thus effectively eliminating mining in that region. They argue that the US EPA established these low values based solely on the inconclusive data on mayfly populations whilst ignoring other parameters of the streams which may be just as important, if not more so (TASM, 2012).

2.3 Australia and New Zealand

Individual **Australian** state and territory governments are responsible for the majority of mining rehabilitation legislation within their jurisdictions. The national Commonwealth government considers any issues of national significance such as issues which fall within the scope of the Environmental Protection and Bio-diversity Conservation Act (AGDRET, 2006). Mining activities are strictly controlled, with mines requiring to provide a detailed rehabilitation plan and often payment of a bond before any mining can commence. For example, Queensland provides fact and information sheets as well as guidance and forms online, which allows operators as well as the public to understand the issues associated with mining through from the initial application and impact assessment to reclamation and reuse of the site: http://www.ehp.qld.gov.au/land/mining/index.html.

The state of Victoria has mostly brown coal and surface mines. The state government of Victoria has provided an extremely useful website which gives information on all aspects of mining and rehabilitation in the region http://www.dpi.vic.gov.au/earth-resources/minerals/environmental-guidelines/rehabilitation-and-environmental-aspects-of-mining-and-extractive-work-plans

The site includes a link to a bond calculator to provide an estimate for rehabilitation costs for extractive, exploration and mining operations in the region. The calculator is also recommended as a useful planning tool to help in the design of mining operations – to minimise the area disturbed and to maximise progressive rehabilitation. Under the Mineral Resources Sustainable Development Act, the mine operators must submit a bank guarantee of the estimated rehabilitation costs prior to the commencement of any works. The rehabilitation liability is estimated based on external contractor rates to cover the cost of site rehabilitation should the site operator default on their licence requirements.

The 'Mine rehabilitation' guide produced by the Australian Government's Department of Industry Tourism and Management is an excellent guide, not only to the best practices for mine reclamation but also to the wider issue of considering more than just the mining land, but the surrounding environment, ecosystems, peoples and heritage (AGDRET, 2006). Because of the large amount of land area and the low population growth, **Australia** does not have some of the space issues that many other countries have with respect to mining land. New mines rarely coincide with the location of existing industry or with established residential areas. However, there are often competing land uses such as agriculture and recreation. It is also the case that around 60% of the mining activities in Australia are on land where there are neighboring indigenous communities. In practice, operators in Australia tend to work very closely with these communities before, during and after mining.

Although there are 'thousands' of abandoned mine sites in Australia, the majority of these are metal mines. The responsibility for abandoned mines lies with local governments, state and territory governments and sometimes with private land owners and industry. In 2011 the Ministerial Council on Mineral and Petroleum Resources (MCMPR) and the Mineral Council of Australia (MCA) produced a 'Strategic Framework for Managing Abandoned Mines in the Minerals Industry' (MCMPR, 2010). A trust fund for mine regeneration has been established in Tasmania. In 1999, the Geological Survey of Western Australia initiated a programme to document abandoned mines throughout the state – by 2010 there were 11,411 historic sites on the database. However, again, only a fraction of these mines are coal mines (MCMPR, 2010). The Australian Government's Department of Resources, Energy and Tourism provides a wealth of knowledge on all mining activities and includes a useful glossary of potential reading for the interested reader: http://www.ret.gov.au.

Both coal and gold mining have been carried since the mid-1860s in **New Zealand** and the practices continue. Several planning requirements must be met before mining can commence. These are (Cavanagh and others, 2010):

- permit or licence granted under the Crown Minerals Act;
- an access arrangement negotiated with all landowners and occupiers (this may include individuals or government departments);
- resource consent (such as use of land and water, discharges to water and air). These will be negotiated with the district and regional councils.

A guidebook has been produced to advise authorities, regulators, mining companies and the local community on best practice for managing the effect of mining activities on streams (Cavanagh and others, 2010).

2.4 Asia

Andrews-Speed and Xia (2003) reviewed the legal frameworks relating to mine reclamation in **China**.

Much of China's coal production (45%, or more than 650 Mt, in the 1990s) came from 75,000–80,000 township and village coal mines (TVCMs). During the energy supply crisis of the early 1980s, any laws and regulations relating to the maintenance and rehabilitation of mine sites were ignored in favour of fast and cheap coal production. Coal demand dropped dramatically in the last 1990s and many mines were abandoned under the government's TVCM closure plan, which targeted illegal mines. The estimate for the total area of land affected by coal mine subsidence in 1994 was around 400,000 ha with an annual increase of 32,000 ha/y. There were also over 1000 coal waste dumps occupying over 10,000 ha of farming land.

China set the Regulations on Land Reclamation in 1988 which defines reclamation as '*the activities in which the land destroyed by extracting, subsidence and re-occupation . . . during the process of production and construction is restored to a utilisable state.*' The regulations also specify the obligations for those involved (industrial authorities, mining companies and so on) as well as the funding sources. Other relevant laws have been established such as the Water Resources Law, Soil Conservation Law and Forrest Law which relate to the various criteria to be met during restoration of a site. The different regulations and laws relating to mining activity in China were summarised in Table 2 on page 8.

Although many projects have been established since 1995 to reclaim mined land, amounting to over 3.5 million ha between 1987 and 1995, the rate of reclamation is still lower than in other countries – only 6% nationally compared with 80% for the USA and 55% for former West Germany (Andrews-Speed and Xia, 2003).

Andrews-Speed and Xia (2003) looked at the conflicts of interest between those involved in mining activities in China and those who wish to promote rehabilitation of the mines. Figure 6 shows the key issues as seen by different parties involved in small-scale coal mine activities. The figure shows that governments and large-scale coal producers are likely to see small-scale mining activities as too costly to be worth the investment and resources whereas local workers and consumers see these small mines as vitally important to the local community. Figure 7 shows how these local communities are

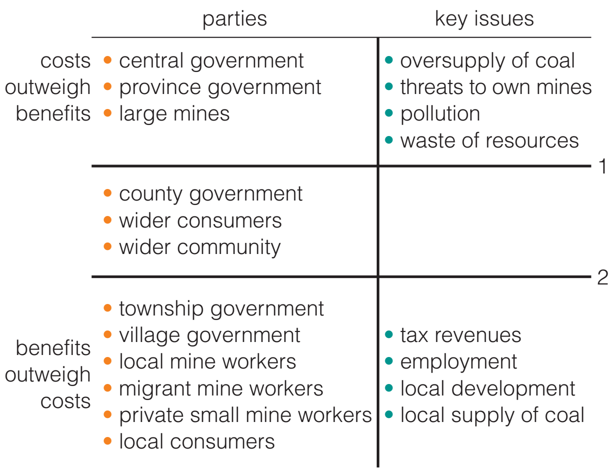

Figure 6 Summary of the key issues as viewed by different parties involved in mining activities (Andrews-Speed and Xia, 2003)

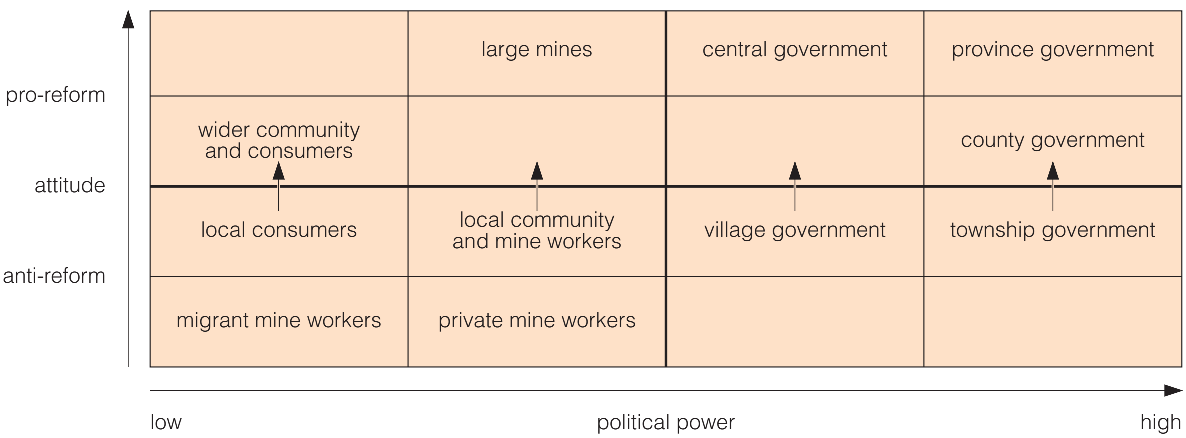

Figure 7 Simplified representation of attitudes towards and power to influence reform of mining regulations (Andrews-Speed and Xia, 2003)

against the reform of the current approach to small-scale mines whereas the Chinese government wish to promote the radical reform of the current approach to mining by moving away from TCVMs. As shown in Table 2 on page 8, there are a significant amount of laws and regulations relating to the operation of the TCVMs.

Andrews-Speed and Xia (2003) argue that the Regulations of Land Reclamation fail to adequately define liabilities and obligations, offers little incentives for reclamation and allows loopholes for corruption and for discretion at different levels of government. All of this serves to hinder those who are willing to reclaim. The revised Land Administration Law (1999) stipulates that '*all users should be responsible for the reclamation of those land attributable to extraction, subsidence, and tailings dumping in accordance with relevant national laws. For those who are unable to reclaim or fail to live up to the reclamation requirements, a land reclamation fee is required, which will be earmarked as a reclamation fund.'* However, Andrews-Speed and Xia (2003) suggest that the regulations are insufficient in their identification of obligations and liabilities of land users and the availability of sources of finance. The matrix of those authorities and bodies involved is described as a 'multi-stranded matrix' which is further complicated by the overlapping nature of responsibilities between the Environmental Protection Bureau, the Environmental Protection Departments of the Coal and Administration Bureaus, the Bureau of Land Administration and the Environment Protection Commissions. Andrews-Speed and Xia (2003) conclude that significant work is required to align the interests of all parties involved in mining in China and to draft new regulations and institutional frameworks which will be effective in ensuring that mine land reclamation becomes effective and sustainable.

In **India**, the extraction of every 1 Mt of coal leads to the damaging of around 4 ha of land. Around 500 ha were rendered 'biologically unproductive' between 1994 and 1995 alone and this rose to 1400 ha by 2000 (Ghose, 2004). More than 73% of the coal production in India in 2006 came from surface operations. There is predicted to be a 'phenomenal' increase in coal production in India over the coming decades with almost the entire land involvement in the power grade coal sector projected to come from opencast mines. Although back-filling and regeneration of mine and is a pre-requisite of post-mining land use, the economics of many mines in India can only support limited remedial action with back-filling possibilities being reduced or forgotten entirely (Mukhopadhyay and Sinha, 2006).

2.5 Other countries

The **Brazilian** Constitution includes requirements that mining companies, being responsible for any environmental damage caused by their activities, are obliged to '*reclaim the degraded environment in accordance with the technical solution demanded by the competent public organisation*'. There has been considerable damage in the Santa Catarina coal basin over the past 100 years of mining. As result, in 2007 the Supreme Federal Court condemned the mining companies and federal government (on behalf of bankrupt companies) for not reclaiming these mined areas. The court demanded that action be taken to remediate the damage at an estimated cost of 20,000–40,000 $/ha. A technical advisory group has been set up to prioritise reclamation and the activities of the mining companies and federal government are being co-ordinated (Gomes and others, 2011).

Currently there are 'no documented national environmental regulations regarding the management of such wastes in **Iran**' (Ardejani and others, 2011). The paper by Dogan and Kahriman (2008) suggests that **Turkish** Mining Laws only require that the land be returned to the user in 'usable condition'.

The first relevant laws for coal mine reclamation in **South Africa** appeared in around 1991 when mines were required to conduct detailed environmental impact assessments and have environment management programmes in place before mining could commence. These new requirements applied to both new sites and to the extension of existing operations. Over and above this, the Department of Water and Environmental Affairs (DWEA) has been implementing a Waste Discharge Charge System

(WDCS) to promote waste reduction. The WDCS is part of a pricing strategy under the National Water Act (NWA) which aims to (Cogho, 2012):

- promote sustainable development and efficient use of water resources;
- promote internalisation of environmental costs by impactors;
- recover some of the costs of managing water quality;
- create financial incentives for dischargers to reduce waste and use water resources in a more optimal way.

The DWEA has developed a water management strategy which is discussed in more detail in Chapter 3.

2.6 Comments

Legislation for mine land reclamation may have been basic or even non-existent when mining activities first started centuries ago. However, legislation has evolved to preserve the different regions of the environment – land, water, ecosystems – and, as a result, mining projects must now comply with an increasing number of different areas of legislation. In most regions such as the EU, North America, Australia and New Zealand, mining permits will only be granted if a full mine plan is provided, covering the cradle-to-grave lifetime of the mine. The mine land will have to be returned to a minimum standard with respect to safety, environmental compatibility (leaching, soil characteristics) and growth potential for future ecosystems. In some cases, mining bonds must be set aside to cover the costs of reclamation and these will not be released until minimum standards are met. In other cases, however, mine sites have been abandoned for so long that the ownership is either not known or no longer valid. In these situations countries must set up their own remediation plans and funding organisations to make amends for previous mistakes and bring brownfield sites back to being useful and beneficial to the local communities.

3 Water

Water is major consideration in mining practices – the position of nearby rivers and water courses can either help or hinder mining activities. Water ecosystems must be protected at all times. As mentioned in Chapter 2, most countries have their own water protection laws which ensure that any discharge from industrial or mining activities do not have any adverse effects on existing water bodies.

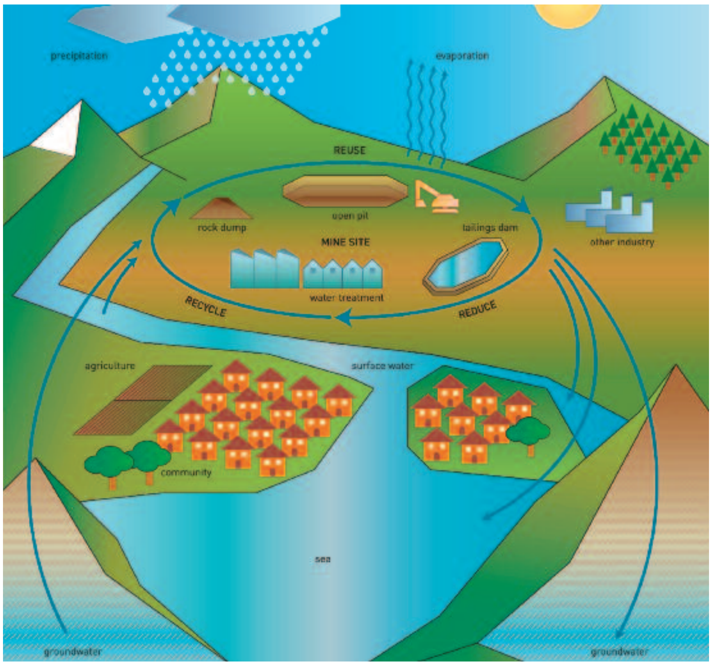

Figure 8 Flows of water to and from a mine site (ICMM, 2012a)

Prior to any mining activity, the local water sources will have been fully analysed. The plan for the mine will take the position of rivers and streams into account as well as the drainage characteristics of the land. In most developed areas, details on the water in the area will be fed into computer modelling systems. Figure 8 shows a simplistic overview of the flows of water to and from a mine site (ICMM, 2012a). Maintaining water features will ensure that local plants and animals within the existing ecosystem will not be adversely affected. Further, upon mine closure, the land will be revegetated and it is important to ensure that there is appropriate site drainage to prevent ponding and water erosion (NSE, 2009).

3.1 Existing water courses

Mine plans must identify existing water courses, water bodies and wetlands and these must be appropriately managed by either returning them to their original location post-mining or seeking approval for relocation or removal. These operations need to take into account the effect on any wildlife, aquatic or otherwise, as well as any effect on local vegetation around the original habitat. Detailed hydrological data must be collected prior to the opening of any new mine and this can take up to a year or more (NSE, 2009).

Cavanagh and others (2010) have produced an excellent guidance document on how to minimise the effects of mining on streams and watercourses. Figure 9 from Cavanagh and others' report shows the decision tree and step by step guide to evaluating the potential effect of mining on local water quality and how best to minimise this. This includes gathering data on local rocks and water chemistry in advance of mining and predicting how this may change as a result of mining activities.

Surface mining can change the movement of water through a terrain, shifting it from subsurface to surface flow. This can affect rainfall run-off movement and increased frequency and magnitude of flooding. Predicting these changes is not simple but must be attempted to limit any negative effects on the environment (Ferrari and others, 2009). In the USA, the Natural Resource Conservation Service Curve Number Method (SCS-CN) method is used in the design and evaluation of the movement of water in a mined region. The SCS-CN is a model which computes total storm run-off from total storm precipitation depth. The model is based on data from experimental watersheds and, because the model is simple and easy to use, it is popular. However, Eshlemann and McCormick (2009) suggest that the

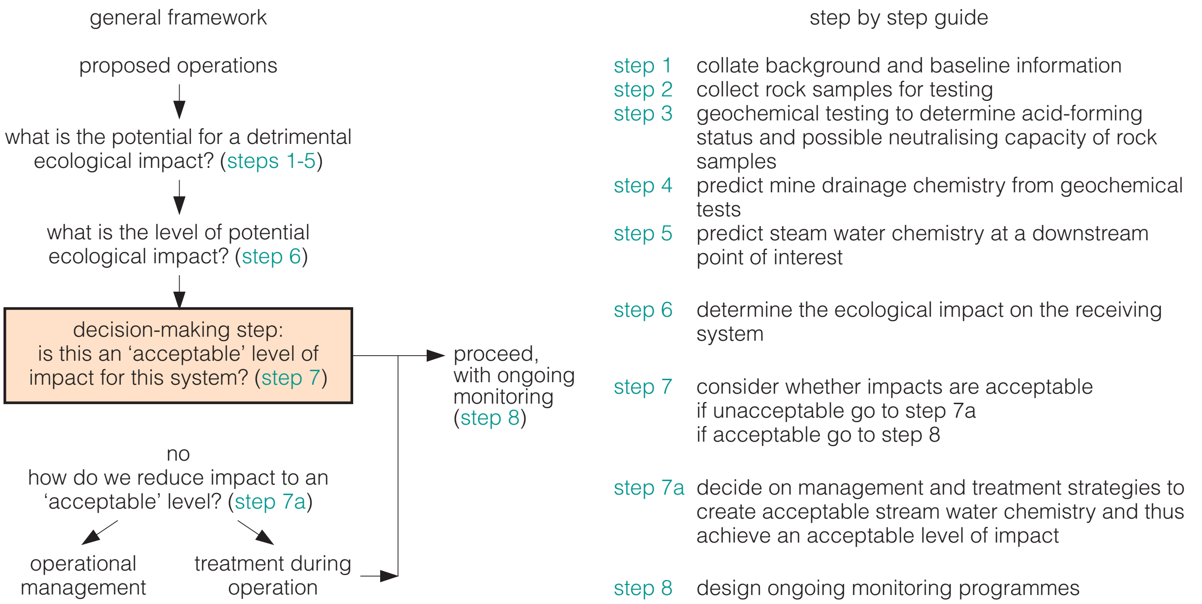

Figure 9 General framework and detailed step-by-step guide for predicting and managing water quality impacts from mining on streams (Cavanagh and others, 2010)

SCS-CN method may underestimate run-off volumes and peal run-off rates in some situations with significant effects downstream.

Comin and others (2009) used a computer model to determine the status of the Martin River Basin area in North East Spain. The study showed that several of the restored mines were still releasing solids into the river network. This was resulting in a combination of erosion in the basin and a negative effect on water flows and natural habitats. Plans were established for restructuring of natural terrain surfaces and the establishment of buffering systems for soil retention and accumulation.

The website www.truthaboutsurfacemining.com gives a good photographic guide to the process of valley filling and the control of water flow through new terrain. A pond is created to capture run-off and then the area is cleared and 'grubbed'. An under drain is then created to direct the water flow down through the valley following the natural drainage path. The drainage path is covered with rock and diversion ditches are created where necessary to guide any side flows of water into the main under drain. Overburden is then applied over the drain and land restored on top. The under drain remains underground to avoid any flooding and erosion from the valley as the land and soils settle.

Table 3 Per cent cover of the Georges Creek Watershed by land use/land cover class (Ferrari and others, 2009)

Land use/Land cover	1996	1987	1999
Urban	3.4	3.7	4.2
Agriculture	10.0	10.8	9.4
Forest	76.3	70.7	70.0
Active mine	5.4	2.1	1.9
Reclaimed mine	4.9	12.8	14.5
Open water	0.01	0.01	0.01

Ferrari and others (2009) used data from the land use and land cover (LULC) classification system in the Central Appalachian Plateau (CAP) of the eastern USA. Between 1975 and 2000 this was an area of significant surface mining of bituminous coal. Over 50 years of data on the area have been collated to determine the effects of the surface mining on the sensitivity of the area to flood damage. Table 3 shows the change in LULC for 1976, 1987 and 1999, showing a decrease in forest use and active mine but an increase in reclaimed mine area. The hydrological data for the watershed area, including the stream flow and atmospheric data, were all input into a simulation model (Hydrologic Simulation

Program-Fortran, HSPF) to predict the changes in the watershed response due to changes in land cover. The program represented a complex matrix of precipitation (rain/snow), infiltration into soil and aquifers, storage in soil types, evaporation and transpiration, deep inactive groundwater, active groundwater storage, stream flow and surface run-off. The study indicated that flood magnitude increases linearly with increasing area of watershed affected by surface mining and subsequent reclamation. This was due largely to the compaction of the soil which affect both soil's water absorptivity as well as plant and tree growth. Impervious ground cover leads to more severe storm events as the rainwater moves over the land rather than being absorbed. The reduced plant and tree growth also leaves a smoother surface for water to move more quickly. Ferrari and others (2009) suggest that more work needs to be done to make reclamation more effective in terms of returning the mined areas to the hydrological state that existed before mining.

In addition to affecting the movement and flow of water, mining activities can also significantly affect the quality and chemistry of water. Water standards exist in most developed countries specifying maximum amounts of detrimental materials. Water quality is tested by a number of different means including conductivity (which varies with the minerals present in the water) and total dissolved solids (TDS) which indicates the quantity of constituents. The natural value of conductivity and TDS varies from water body to water body and also with the different types of minerals and other constituents present. And so, although conductivity and TDS can indicate a pollution problem, natural ranges are great and some naturally high values can be found. This poses problems with fair evaluation of some mine sites and their potential effects on the local water bodies. It is argued that conductivity is an inappropriate parameter for use as a regulatory measure (TASM, 2012).

According to Kite (2009) there have been several cases where intervention with natural streams and rivers have had very negative outcomes, with damage to the water systems and associated ecosystems. Although disrupted water courses can be returned to a 'stable' state, they may not necessarily be returned to a 'natural' state. However, there is a balance to be struck between trying to return a water course back to original status and making it compatible with the new landscape around it. Returning a water course back to its original form may not be appropriate if the surrounding land forms and water flows have changed. Further, it may take years following mining activity to see the whole overall effect of changes in landscape.

During reclamation, soil is commonly replaced as a final layer to the new land topography (*see* Chapter 4). During this replacement, heavy machines such as earthmovers are used and this results in the soil being compacted, increasing soil bulk density and decreasing porosity and infiltration. This can have a significant effect on water movement through the soil, making it harder for plants and trees to grow (Ferrari and others, 2009).

One of the major negative effects of mining on water quality is acidity. Acid mine drainage (AMD) is discussed in more detail in Section 3.2.

3.2 Acid mine drainage (AMD)

The oxidation of pyrite (iron sulphide) uncovered during coal mining leads to acid rock drainage (ARD) or acid mine drainage (AMD). Sulphur bearing minerals are commonly associated with coal seams and these become dissolved in the mine water. Once mine water reaches the surface it comes into contact with the air and the iron present changes from the ferrous to ferric state. This causes small particles of iron (ferric hydroxide) to form in solution, more commonly known as ochre. This gives the water an orange/brown colour. In countries such as the UK, some of the coalfields contain a significant amount of limestone which neutralises much of this acidity, and therefore the term 'mine water' is more appropriate than 'acid mine drainage' in these situations. However, in most situations, the added acidity caused by the pyrite oxidation causes significant acidification of surface waters. Badly AMD affected rivers can immediately be identified, as shown in Figure 10.

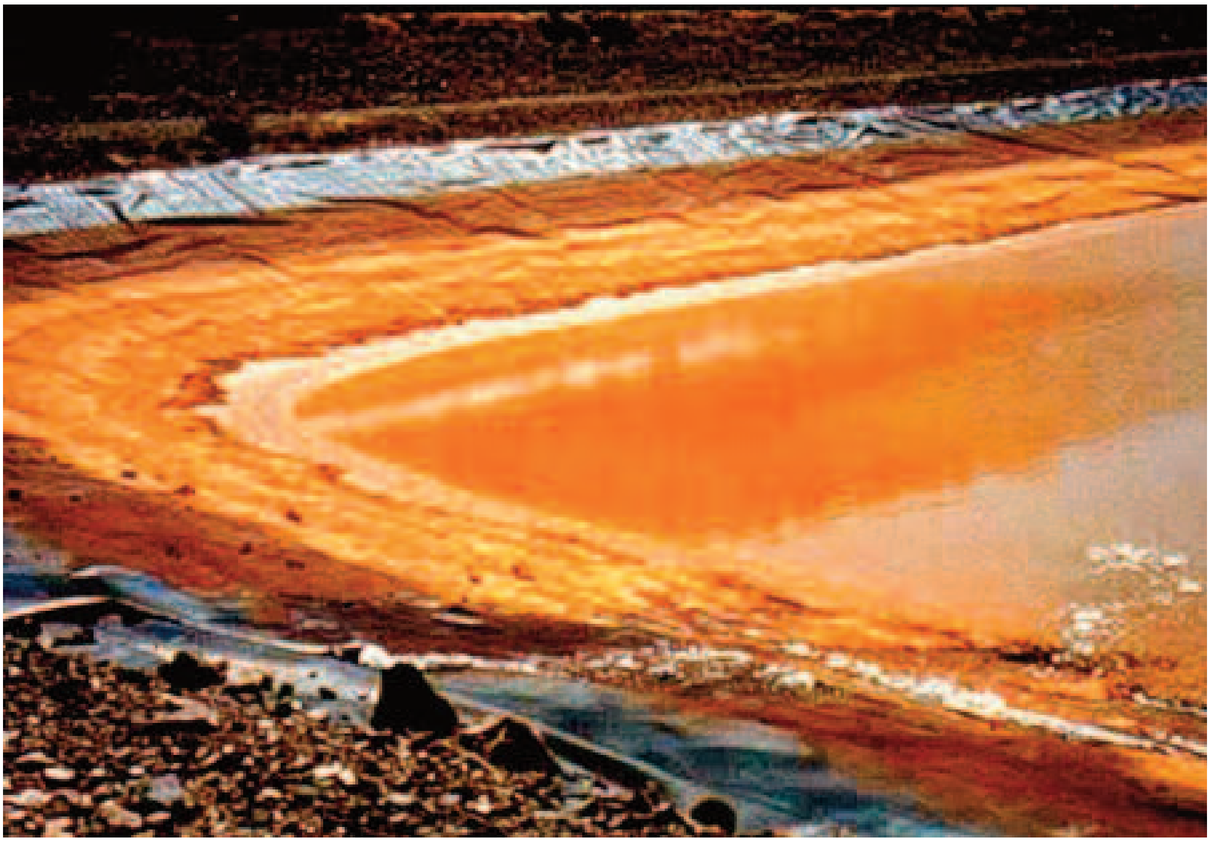

Figure 10 Acid mine drainage (US EPA, 2012)

The chemical reactions can be summarised as follows (Bulusu and others, 2005):

$$FeS_2 + \tfrac{7}{2} O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad (1)$$
$$Fe^{2+} + \tfrac{1}{4} O_2 + H^+ \rightarrow Fe^{3+} + \tfrac{1}{2} H_2O \quad (2)$$
$$Fe^{3+} + 3\,H_2O \rightarrow Fe(OH)_3 + 3H^+ \quad (3)$$
$$FeS_2 + 14\,Fe^{3+} + 8\,H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16\,H^+ \quad (4)$$

The water and air (O_2) are intrinsic to the breaking down of the pyrite into sulphuric acid (equation 1) and free ferrous (iron) ions which then oxidise to ferric ions (equation 2). The reaction in (2) is pH dependent and relatively slow. However, the presence of bacteria (Thiobacillus ferrooxidans) can accelerate the reaction rate by a factor of one million. Equation 3 releases the acidity (H^+) which then increases in reaction 4.

Where AMD is produced, reactions with the surrounding rocks result in a solution which is low in pH (acidic) and concentrated with heavy metals and other toxic elements. AMD can be severely damaging if uncontrolled. In addition to the low pH (<3–4), AMD is also associated with a high redox potential, higher electrical conductivity (due to higher salt concentrations, especially sulphate), increased iron and heavy metal concentrations and deterioration of water quality due to iron precipitation and other metalloid particles (Willscher and others, 2010).

Bian and others (2010) suggest that over 1.1 million surface acres (around 4450 km^2) of abandoned coal mines and over 9000 miles of streams polluted by AMD in the USA, including streams in as many as 44 of Pennsylvannia's 67 counties. Bulusu and others (2005) note that acid mine problems began in Maryland with the first mining in the 1800s, when the AMD from the mines leaked into local streams. Although only around 50 mines in Maryland are now active (of a total of 450), 150 are still releasing AMD.

Hard coal mining has been carried out in the Zwickau region of Germany since 1348 and, due to lack of treatment at these sites, AMD is a major issue. The adjacent creek to the mining area which was closed 50–60 years ago (Zwickauer Mulde) has been contaminated and, as a result, contaminates the River Elbe downstream. The AMD has caused enrichment of Mn, Co, Ni, Zn, As and Cd with groundwater contaminated with up to several mg/L of heavy metals. Seepage waters have mass flows of kg/y up to t/y of some heavy metals and sulphates (Willscher and others, 2009a).

The primary damaging components of AMD and the damage caused are reported to be (Bian and others, 2010):
- pH;
- temperature;
- oxygen content in the water phase;
- degree of water saturation;
- chemical activities of Fe^{+};
- exposed surface area of metal sulphide;
- chemical activation energy required to initiate acid generation and bacterial activity.

The potential for AMD is usually determined as part of the mine planning process. Figure 11 shows the potential water chemistry which will occur as a result of the presence of potential acid forming (PAF) rocks in the area of mining, based on mine type, hydrogeology and mine drainage chemistry.

Gomes and others (2011) report on a computer model to quantify and prioritise mined areas in Brazil's Sangão watershed areas. The model allows the input of parameters such as land use, soil type, topography and hydrology to determine the pollutant load in each area and to prioritise the rehabilitation process accordingly. To date, over 818 abandoned mines have been mapped along with other sources of pollution in the area – the majority of the sites were surface mines, coal waste dumps, waste dumps in open pits and acid dams. Mitigation methods such as confinement, dry covers and vegetation could reduce the AMD significantly and this had to be taken into consideration. The model takes into account the land use, pollutant concentrations, precipitation rate and run-off characteristics. This includes an AMD index covering flow, pH, Fe, Al, Mn and sulphates. The model allows the user to select a watershed from the region and determine how much acid reduction will be needed and then compare the effect of potential remediation strategies. This considers the effect of limestone treatment on the area treated as well as downstream areas. Gomes and others (2011) are continuing to work with the model and will validate the model against measured data.

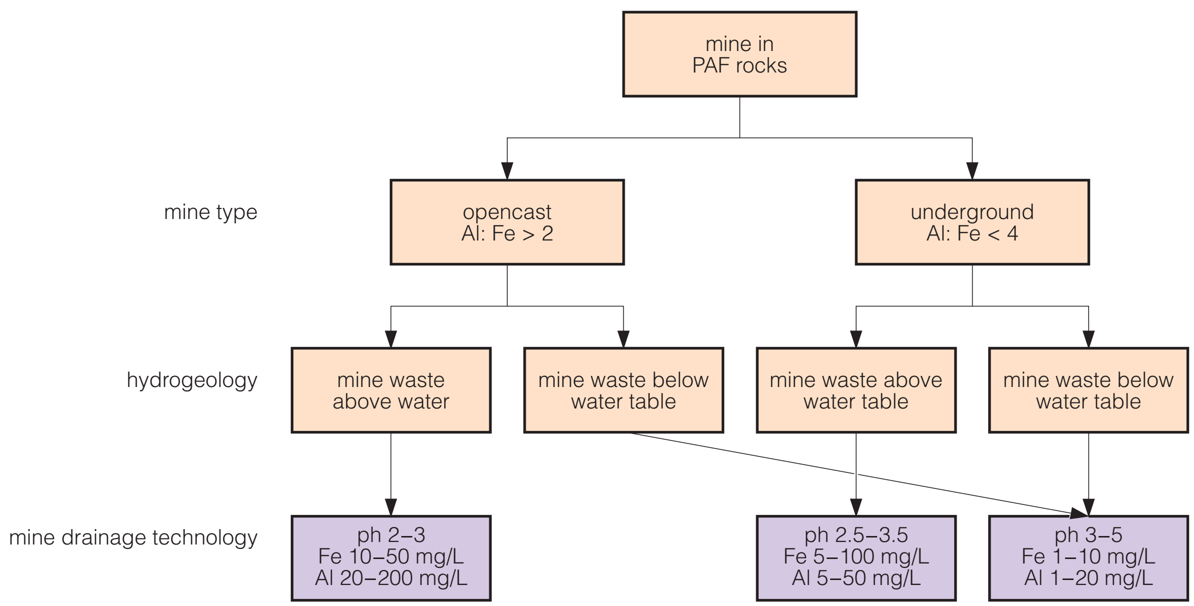

Figure 11 Potential water chemistry from PAF coal measures (Cavanagh and others, 2010)

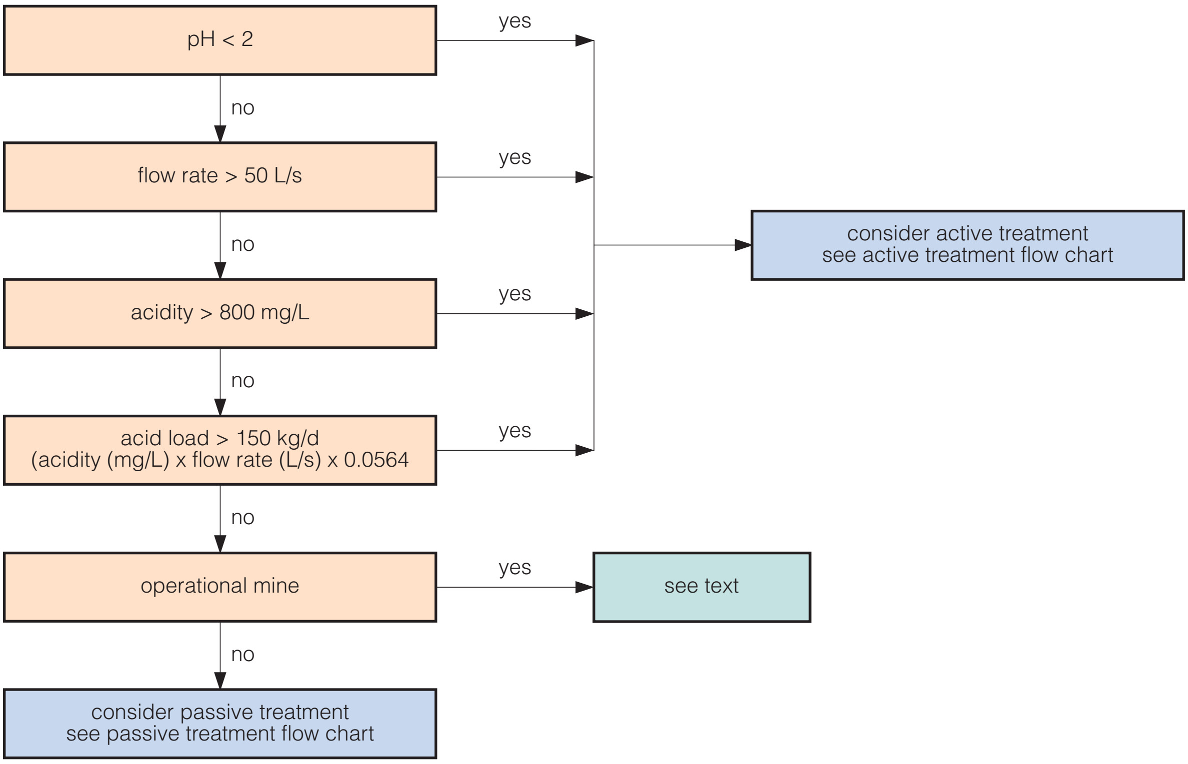

Figure 12 Flow chart to guide selection between active and passive treatment for AMD (Cavanagh and others, 2010)

Methods for dealing with AMD are common in most countries which are familiar with mining. For example, the US EPA has produced several guidance documents which are available for download from their website (US EPA, 2012). According to the EU guidelines on management of mine tailing (EC, 2009) the following techniques are regarded as BAT for treating acid effluents;

- active treatments such as the addition of limestone (calcium carbonate), hydrated lime or quicklime;
- passive treatments such as constructed wetlands, open limestone channels/anoxic limestone drains or diversion wells.

Figure 12 shows the decision tree used to determine whether active or passive treatment is most suitable for each mine site. Active treatments are more suitable for more aggressive AMD conditions and for mines which are still in operation whereas passive treatments are more suitable for closed mines (Cavanagh and others, 2010). Each of these options are discussed in more detail in the sections to follow.

3.2.1 Active treatment

Active AMD treatment systems are intenstive treatment systems involving chemicals and require regular operation and maintenance and, as a result, can be costly. They are most suited for sites where the AMD is severe or ongoing – which tends to be active coal mining sites (Cavanagh and others, 2010).

The most simple method for remediating AMD is the addition of alkaline compounds to raise the pH above the threshold required for iron oxidising bacteria (Bian and others, 2010).

The reactions for AMD neutralisation with lime occur as follows (Bulusu and others, 2005):

$$CaO + CO_2 \rightarrow CaCO_3 \tag{5}$$

$$CaO + H_2O \rightarrow Ca(OH)_2 \quad (6)$$

The calcium oxide (free lime) reacts with carbon dioxide and water to form calcium carbonate and calcium hydroxide. These can react with the sulphuric acid in AMD to neutralise it:

$$Ca(OH)_2 + H_2SO_4 \rightarrow Ca^{2+} + SO_4^{2-} + 2H_2O \quad (7)$$

What happens next depends on the behaviour of the carbon dioxide and the pH of the system. If the pH remains as low as pH5 and the CO_2 formed is releaed into the gas phase then this occurs:

$$FeS_2 + 2CaCO_3 + 3.75\ O_2 + 1.5\ H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 2Ca^{2+} + 2CO_2 \quad (8)$$

If the pH is raised to 6.3 or higher and no CO_2 is released into the gas phase then the following occurs:

$$FeS_2 + 4CaCO_3 + 3.75\ O_2 + 3.5\ H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4Ca^{2+} + 4HCO_3^{-} \quad (9)$$

In most cases the result is a combination of reactions 8 and 9, depending on how open or closed the mine is (for input of O_2 and release of CO_2). Reactions 8 and 9 can be used to calculate the amount of alkalinity ($CaCO_3$) to be added to neutralise the AMD – empirically, the AMD produced by 1 mol of pyrite requires 2 mol of $CaCO_3$ to neutralise it in equation 8. In equation 9, twice as much $CaCO_3$ is required. The exact amount of lime required will depend on the balance between reactions 8 and 9 as they happen in the mine itself. This, of course, assumes no other outside influences such as acidity or alkalinity from other sources in the area. Soils can have significant buffering capacity. The balance for neutralisation will therefore need to be considered on a case by case basis.

Figure 13 from the guidelines by Cavanagh and others (2010) shows the flow chart which can be used to design a site-specific active treatment system for AMD. Selection of the chemicals to be used depend on the different requirements at each site. However, each option has its own advantages:

calcium hydroxide/calcium oxide	low chemical cost and high density sludge produced
ammonia	low volume required
sodium hydroxide/ammonia	fast pH increase and high pH
sodium carbonate	low treatment system cost and no mixing required.

As mentioned earlier, active treatment systems can be costly in terms of chemicals required. According to the report by Cavanagh and others (2010), based on studies in New Zealand, the costs will vary with whether the site has low flow and acidity or high flow and acidity. Sites with low flow and acidity will be looking at costs of around NZ$2.5 million (for calcium oxide; £1.3 million) up to over NZ$20 million (>£10 million) for ammonia gas, over a 20-year treatment period. For a site with a higher flow and greater acidity, more reagents are needed and therefore the costs are significantly more, ranging from around NZ$15 million (£7.7 million) for the calcium oxide option up to almost NZ$120 million (>£60 million) for ammonia gas, over a 20-year treatment period.

AMD can be treated by grouting abandoned mines with alkaline materials. The grout penetrates into the fractures of the pyritic rock, providing structural support to the abandoned mine whilst forming a long-term barrier between the pyrite and the water and air (Bulusu and others, 2005).

Coal combustion by-products such as fluidised bed combustion ash and FGD gypsum are also alkaline in nature. There are numerous IEA CCC reports on coal combustion by-products and their characteristics and potential uses (Smith, 2005; Barnes, 2010 and many more listed at www.iea-coal.org). One of these potential uses is as the alkaline agent for grouting/back-filling abandoned mines to control AMD. These combustion by-products often have excellent structural characteristics and are used in many construction applications. Bulusu and others (2005) tested several coal

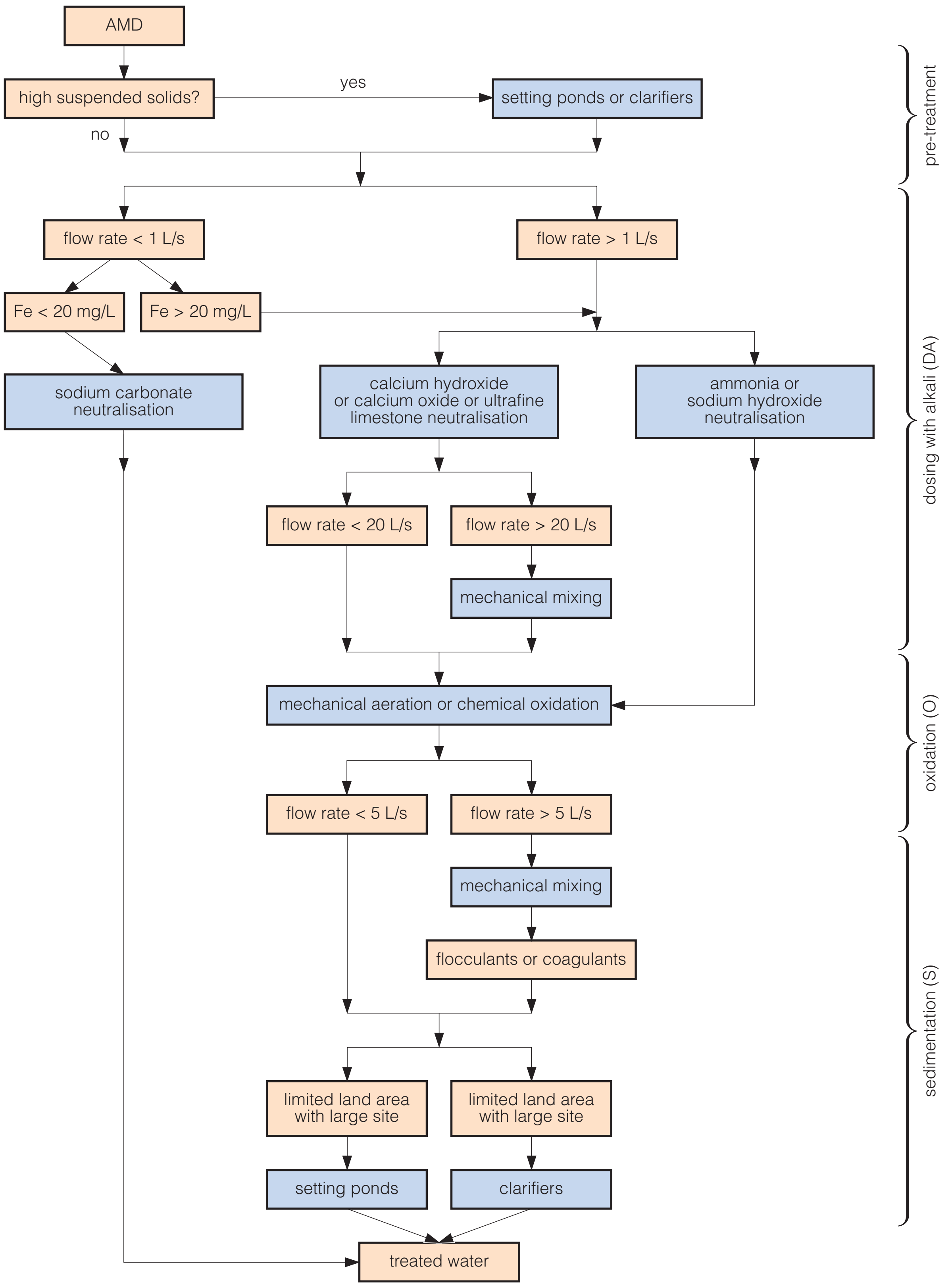

Figure 13 Flow chart to design a site-specific active treatment for AMD (Cavanagh and others, 2010)

combustion by-products to determine their suitability for Frazee, a 4 ha abandoned underground coal mine in Western Maryland, USA. Several products were tested:

- fly ash from the Mount Storm Power Plant in Western Virginia, firing pulverised bituminous coal;

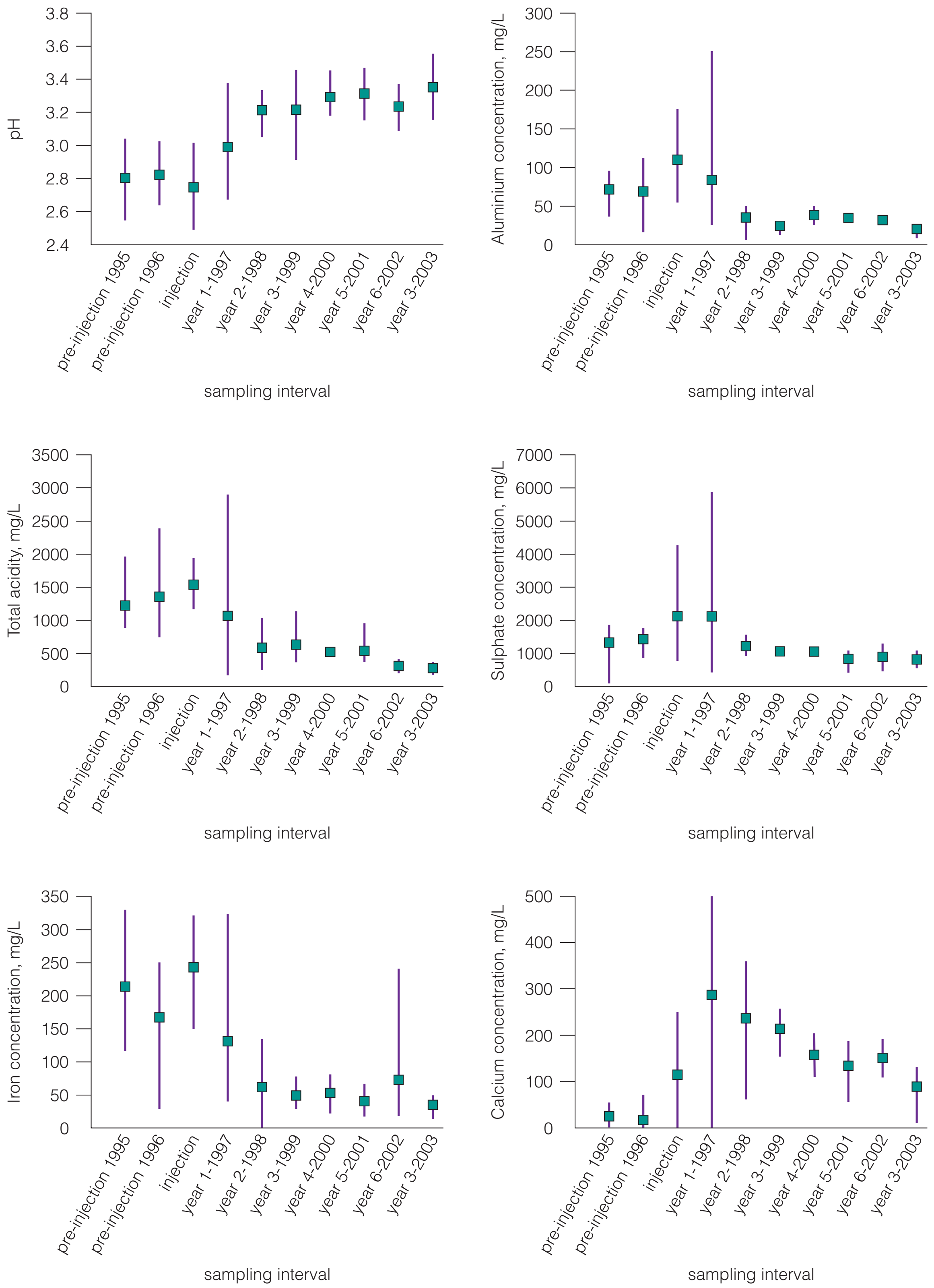

Figure 14 Concentrations of various acid mine drainage parameters before and after placement of the grout (Bulusu and others, 2005)

- flue-gas desulphurisation (FGD) by-product material was obtained from the Mount Storm Power Plant, VA;
- the fluidised bed combustion (FBC) ash was obtained from the Morgantown Energy Associates Power Plant in West Virginia.

Different combinations of fly ash, FGD by-product and FBC by-product were prepared and tested against lime-based mixture which contained fly ash and FGD by-product but no FBC ash. Different sampling locations were selected in the abandoned mine and the sample mixes were injected. The best mix had to take into account the flowability of each of the components, the alkalinity and other relevant parameters. The results were then tested for different measures of AMD after several years. Figure 14 shows the concentrations of various acid mine drainage parameters before and after the placement of grout based on a mixture containing mainly FBC ash. The fluctuating concentrations both during and after the injection of the treatment demonstrates that the mine is 're-equilibrating'. There will also be variation due to the changes in the mixing of waters and rerouting of flows as the grouting mixture fills gaps in the voids within the mine.

Table 4 shows the analysis comparing the cost of using coal combustion by-products versus using lime or lime kiln dust. In an economic sense, using coal combustion by-products is a fraction of the cost of using other raw materials, with the by-products being up to almost an order of magnitude lower in cost. However, the cost will vary with distance of transportation between a mine and the nearest coal-fired power plant and would need to be evaluated on a case-by-case basis (Bulusu and others, 2005).

Table 4 Cost analysis (Bulusu and others, 2005)

Item	Coal combustion by-product	Lime	Lime kiln dust
Cost of material, $	free	285,000 (75 $/t)	49,400 (13 $/t)
Cost of transport, $	27,000	41,820	41,820
Cost of labour, $	10,000	10,000	10,000
Total cost, $	37,000	336,820	101,220

Dry FGD product from an atmospheric FBC combustion facility at the General Motors plant in Pontiac, MI, firing eastern Ohio coal was considered for use as a tool for reclaiming abandoned mining land in the region. The material was applied to the land at a rate of 280 t/ha on its own and together with 112 t/h of yard waste compost. The biomass yields from this land were then compared with biomass yields from the same land treated with conventional reclaiming treatment (20 cm of re-soil material plus 157 t/h of agricultural limestone). Although the biomass grew better on the land treated with the conventional materials within the first four years of application, after this time the growth rates were similar. The concentrations of Mg, S, Al, Fe and B were also elevated in the biomass treated with the FGD material (compared with the conventional material) during the first 4 years but again, this was not the case after the first four years passed. Even 14 years after the treatment was applied, it seems that the FGD treatment was comparable to the conventional treatment with no negative effects (Chen and others, 2009).

The Maryland Department of Natural Resources Power Plant Research Program (PPRP) and the Maryland Department of the Environment (MDE) initiated the West Maryland CCP/AMD Initiative in 1995. One of the first projects was at Winding Ridge where 4280 m^3 of CCP grout was injected into a small abandoned deep coal mine in Garrett County, MD, USA. The use of the naturally alkaline CCP grout has improved the quality of the mine discharge with acidity, Fe, sulphate, Al, Mn, Zn, Cu and Ni all having decreased below preinjection concentrations. The rate of acid production at the mine has decreased by 80%. Over a seven-year test period, the grout maintained high strength and low permeability in the mine tunnels (Guynn and others, 2006).

Treatment for acidity will vary from site to site. Table 5 summarises the different treatment techniques used to treat acidity in groundwater (near coal refuse tips), lake water and egress water. In most situations, the neutralisation is achieved with alkaline materials such as carbonates and these are either

Table 5 Water treatment techniques (Kuyumcu, 2011)

Water type	Treatment
Tip/groundwater	reduction in new formation of groundwater
	installation of 'reactive walls'in the tip and 'reactive matting' on the slopes by the installation of alkaline materials for neutralisation of organic substrates for sulphate reduction
	addition of limewater during vibrocompaction
	active mining: addition of alkaline additives during installation of supporting elements for the slopes
	microbial treatment such as with sulphate-reducing bacteria
Lake	addition of alkaline materials: calcium carbonate, calcum magnesium carbonate, sodium carbonate
	resuspension of calcium carbonate sediments and ash in the bottom of the lake
	microbial treatment with iron-reducing bacteria
Watercourse/egress water	neutralisation with alkaline additives: calcium carbonate, calcium magnesium carbonate
	electro-chemical sulphate reduction
	water management (dilution)

added directly to the water or applied via the container (in the case of tips). If possible, more natural options such as bacterial additives can be used for groundwater and lake water, or dilution can be used to reduce the impact in water course and egress water (Kuyumcu, 2011).

3.2.2 Passive treatment

Passive treatment systems are regarded a long-term solution after the decommissioning of a site, but only when used as a polishing step combined with other (preventive) measures. Passive methods rely on the natural behaviour of soils, rocks and ecosystems. In order for them to be successful the site has to be large enough to allow sufficient residence time of the AMD with the treatment system in order for the natural processes to have time to occur. For example, many passive systems rely on the natural dissolution of neutralising rocks such as limestone. Passive treatments are more appropriate for closed mines (Cavanagh and others, 2010).

Getting passive systems to succeed requires a careful balance of water flow, acidity as well as the correct choice of plants. Passive systems can either be oxidising or reducing strategies. Oxiding systems continue to the oxidation of Fe so that all of the ferrous Fe becomes ferric Fe which can then be precipitated out of the system. In reducing systems the chemistry is reversed so that the Fe is reduced and reacts to form compounds such as FeS and FeS_2, removing the dissolved Fe from the system. The choice as to whether to oxidise or reduce depends on the chemistry of the site, with highly oxidised AMD sites finding the oxidising system most suitable.

Reducing passive treatment systems involve a vertical flow wetland and a settling pond. Anaerobic wetlands are suitable for this as the microorganisms can cope with the acidity of the system. For more acidic sites these treatment and settling areas must have long residence times in order for the reactions to happen fully and completely. For oxidising systems, at mines with steep topography and stronger acidity, diversion wells, open limestone channels and limestone sand dosing within a settling pond are all options (Cavanagh and others, 2010).

The Somerset County Conservancy, Pennsylvania, USA, acquired federal and state funding for several AMD projects in the county. Around $2.1 million was spent on five passive treatment systems which remove 101 t of iron, 71 t of aluminum, and 804 t of acid per year from the Stonycreek River, lifting the quality of the water to a level that it is now used for drinking water by several communities and trout have established themselves in the river. More details and before and after pictures can be found at: http://www.somersetcountyconservancy.org/restoration.html.

Some organisations have been working to restore polluted mine water streams while at the same time recover metal oxide materials. For example, Clean Creek Products (www.cleancreek.org) have developed passive water treatment systems that allow the recovery of manganese and iron oxides from AMD. These systems use a combination of limestone, compost and plants in a series of ponds, beds, channels and wetlands to encourage and enhance natural processes that restore polluted streams. The manganese oxide can be removed through a horizontal flow limestone bed and the iron oxide through a vertical flow pond, as a result of a complex biochemical treatment. The resulting manganese and iron oxides can be used as colourants and in building products and are used in by local artists in pottery and art.

The greatest costs in passive treatments are associated with the construction of the site, since the chemical costs are negligible. Costs can vary from around NZ$50,000 (around £12,700) for aerobic wetland sites, up to over NZ$250,000 (over £125,000) for specific bioreactor systems. Open limestone channels, anoxic limestone drains, reducing and alkalinity producing systems and limestone leaching beds all come in at between NZ$125,000 and NZ$175,000 (between £63,000 and £87,000) (Cavanagh and others, 2010).

3.3 On-site water use and treatment ponds

In some mines, especially deep mines, water influx during mining activities is a safety issue. Pumps are used to divert water from the active mine areas. Depending on how clean this water is, it can either be released into local waterways or used by the mine for in-mine requirements. In some instances, this dewatering during mining can reduce the levels of natural groundwater or deplete surface water stores.

Water is required during mining for activities such as coal washing and for dust control. During mining operations, water is commonly controlled via pumps and run-offs and stored in ponds or other retention devices. This water must be treated to control suspended solids (using flocculants) and to regulate water chemistry. Any water discharged into the local water table or streams must meet local water discharge standards. The standards to be met vary from country to country and can be quite stringent.

Ardejani and others (2011) studied the potential water contamination from a low-grade coal waste dump at the Alborz Sharghi coal washing plant in Sharhood, northeast Iran. Over the years of production it is estimated that over 3 Mt of coal wastes have been produced at the plant. Pyrite oxidation is visible at the dump in the lack of vegetation and the reddish, orange, yellow and white colouring. Currently there are 'no documented national environmental regulations regarding the management of such wastes in Iran'. However, the operators have ensured that there are no elevated slopes, water is kept from infiltrating the waste piles and caps made from soil and other amendments have been used to promote the growth of vegetation. Chemical analysis of the water in and around the tailings dam demonstrate that there was no change in the pH but that the sulphate concentration was high due to pyrite oxidations from the coal washing wastes. Carbonate was also found to be elevated due to the limestone and dolomite also present in the wastes which would help balance the pH of the sulphate. Trace element concentrations were also elevated. However, although the groundwater at the site of the dump did not show pollution of any great concern, levels of Fe were found to be elevated downstream as the pH rises and sulphate concentrations drop.

In countries such as South Africa, water is a valuable commodity. As mentioned in Chapter 2, the Department of Water and Environmental Affairs (DWEA) has established water management guidelines and a pricing strategy to promote efficient water use in mines. The priorities of the guidelines are (Cogho, 2012):

- keeping clean water clean – this applies to water upstream of mining as well as water from rehabilitated areas;
- containing impacted water with low risk of spillage;
- maximising reuse of impacted water within the mining environment;
- treatment of water to render it fit for use, where it cannot be reused without treatment;
- release of water in terms of a 'water use licence' where permitted by the authorities.

In order to achieve this, several actions are required:

- the average water make for average rainfall should be balanced by either the average water use or else storage is required for the surplus;
- storage is required to balance wet and dry seasons;
- if the probability of spillage is to be $\leq$2%, additional storage may still be required to accommodate wet periods where excess water will require the mine to be dewatered;
- overall impacted water make must be managed and minimised;
- the reuse of impacted water for mining use must be maximised;
- the current use of clean water by the mine must be minimised.

Table 6 shows the balance of rainfall into different mine regions at the Optimum coal mine in Middleburg, South Africa. Because of the collection of waste and rainwater on the site, the mine has an overall surplus of water which must be treated before it can be released into the existing water systems. Figure 15 shows the mine water reclamation system at the Optimum mine showing the input from the dams and the eventual output, after treatment, to the clean water system and municipal water supply. The water treatment component is a complex system involving (Cogho, 2012):

- clarification;
- filtration and ultra-filtration;
- anti-scaling;
- precipitation;
- osmosis and reverse osmosis.

Table 6 Opencast rainfall recharge rates at the Optimum mine in Middleburg, South Africa (Cogho, 2012)

Sources which contribute water	Water sources into open pits	Suggested average values
Rain onto ramps and voids	20–100% of rainfall	70% of rainfall
Rain onto unrehabilitated spoils	30–180% of rainfall	60% of rainfall
Rain onto levelled spoils (run-off)	3–17% of rainfall	5% of rainfall
Rain onto levelled soils (seepage)	15–130% of rainfall	20% of rainfall
Rain onto rehabilitated spoils (run-off)	5–115% of rainfall	10% of rainfall
Rain onto rehabilitated spoils (seepage)	5–110% of rainfall	8% of rainfall
Surface run-off from surrounding areas into pits	5–115% of total pit water	6% of total pit water
Groundwater seepage	2–115% of total pit water	10% of total pit water

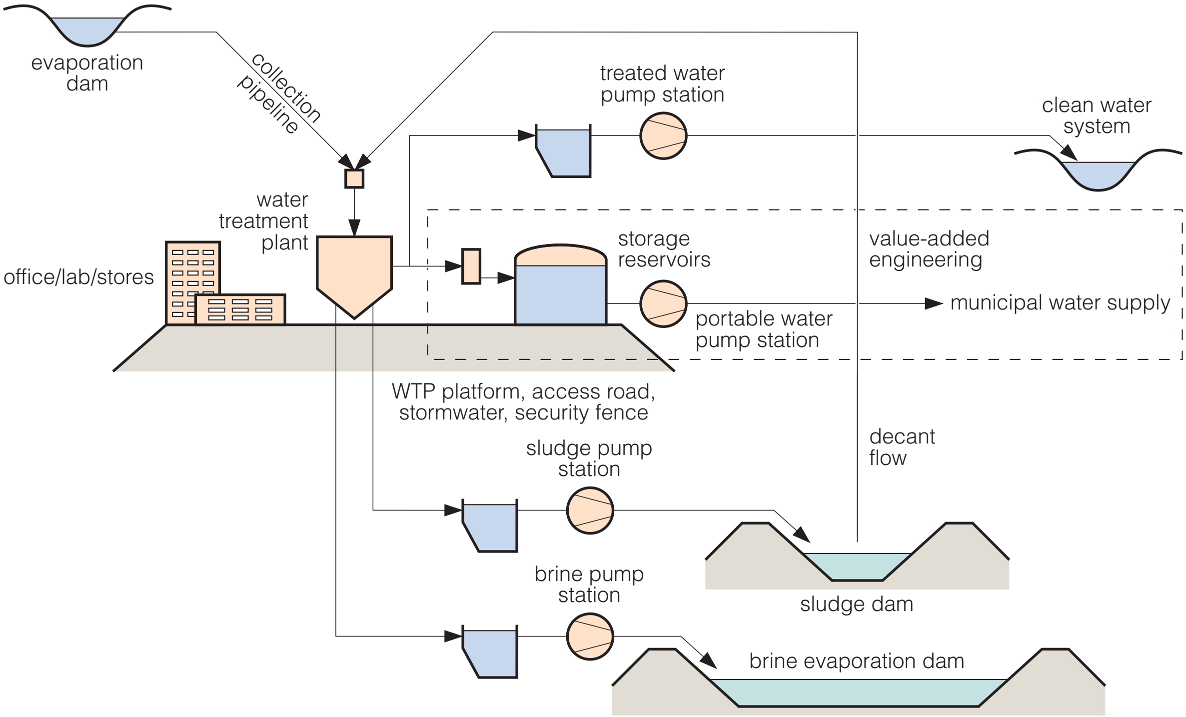

Figure 15 Water reclamation project at the Optimum mine, South Africa – schematic diagram showing the raw water collection, treatment, storage, distribution and sludge and brine disposal (Cogho, 2012)

This eventually results in two waste streams. The first is the sludge stream containing mainly calcium and magnesium salts with a limited metal content (due to the mine water being non acidic). The sludge is deposited in a sludge lagoon for interim storage until it can be co-disposed of with the mining wastes (including by-product recovery, where possible). The second is the brine stream containing high soluble salts, mainly sodium and magnesium. This brine is disposed of to a lined evaporation dam (Cogho, 2012).

The shortage of water in the area around the Optimum mine mean that any new mines will face a significant challenge obtaining approval. However, there is the potential for the existing mine to generate water to be used in these mines or in other industries in the local area. An agreement was established in 2010 for the mine to supply water to the Tshwete Local Municipality and the town of Hendrina/KwaZamakhule (Cogho, 2012).

South African companies such as Anglo American have water action plans (WAP) to manage the use and release of water from their mining activities. The Witbank coalfields near eMalahleni in the north east of South Africa contain several thermal coal workings which together hold around 140,000 million litres of ingress water and this is increasing at over 25 million litres per day. The eMalahleni area suffers water shortages through reduction in annual rainfall and increased flooding on the occasions that rain does fall heavily. Anglo America commissioned the eMalahleni Water Reclamation Plan in 2007 to process water from the South Witbank Colliery and to deliver it to the local municipality's drinking water system. The plant currently treats around 30 million litres per day with some being used by the mining operations but the majority being used by the local community to provide 12% of the town's water needs. This is expected to increase to 50 million litres per day by the end of 2013 (ICMM, 2012a).

3.4 Flooding and new water feature production

In some cases, flooding of an open excavation site can be part of the closure plan. These flooded areas

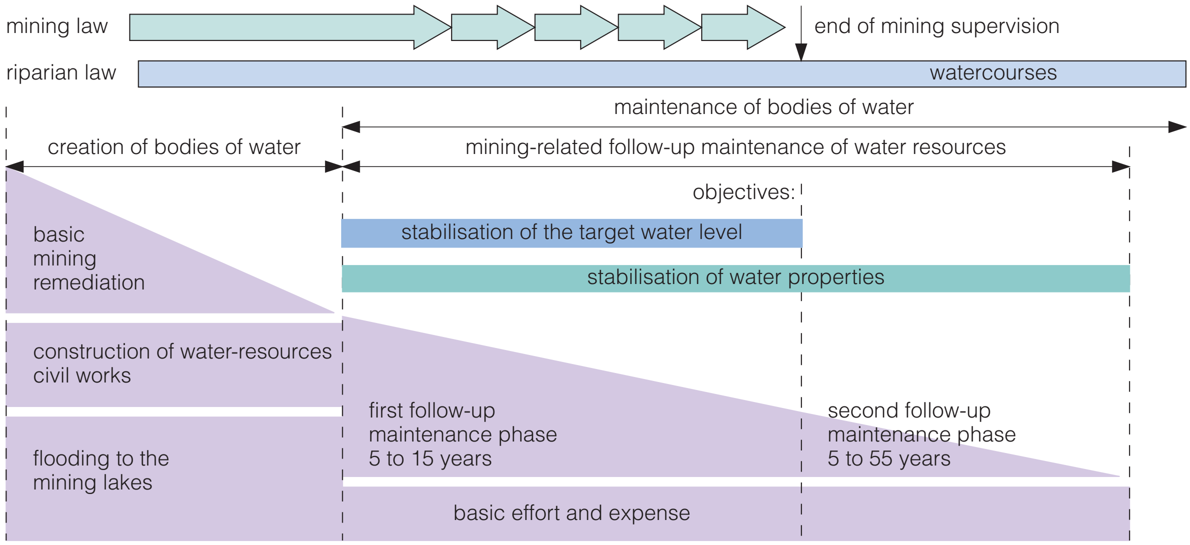

Figure 16 Course and development of expense for mining lakes (Kuyumcu, 2011)

must meet minimum requirements for safety such as the grading of slopes on the shoreline and the treatment and capture of overflow. The potential for acid mine generation must be evaluated prior to flooding and mitigation should form part of the reclamation plan (NSE, 2009).

Lignite mining is generally a relatively shallow, opencast process which leaves huge cavities in the landscape. It is common that these cavities be flooded, following geo-stabilisation of the beds and banks (*see* Chapter 4). According to Kuyumcu (2011) the flooding of mined land is commonly achieved with a maximum amount of incoming river water since flooding by slow, natural rise of the water level would take too long (decades). Groundwater flowing slowly into the basin would lead to extensive AMD and erosion. Rapid river flooding minimises slope erosion and reduces contamination from tips and surrounding areas. This movement of water requires significant water management in terms of pipelines, drainage systems and pump stations. The outflow of the new mining lakes must also be monitored and managed to ensure they can integrate into the existing surface water system without harm.

In the Central German mining region, waters from the Saale, Mulde, Weisse Elster and other rivers, along with sump water from the MIBRAG (company name) mining operations, are being used to flood eight new mining lakes in the southern area of Leipzig. This involved the construction of a new 60 km pipeline to ensure the fast and efficient movement of water. In another mining region, the German Federal ministries and Federal States of Saxony and Brandenburg have established the Lausitz Flooding Control Centre which uses computer modelling to control water movement in the 8000 km^2 catchment area according to the new European Water Directives. Figure 16 shows the path and development of cost for creating mining lakes. The costs are initially high as money must be spent on remediation of the mine works, construction of the lake (to ensure stability and safety) and flooding/filling processes. As the project stabilises, costs reduce over time to simple maintenance requirements under riparian (water body) law. These requirements include maintenance of the water at a pH above 6 and the dissolved Fe concentration below 3 mg/L. Anything above that may suggest an AMD issue. If acidity is a problem, then lime treatment can be used to raise acidity (Kuyumcu, 2011; *see* Section 3.2).

Once deep or sunken mining activities finish, and pumping out stops, mine water levels rise slowly over time. However, during the mining activities, significant amounts of groundwater may have been removed. The return to pre-mining groundwater levels may therefore take a significant amount of time. Since 1990, 51 lakes in the Leipzig area of Germany have been filled by flooding. Of these, 13 have reached their final water level. The remainder should be full and the related aquifers replenished by 2025 (Kuyumcu, 2011).

In Germany, there are currently only three opencast mines remaining in the Rhineland region – Garzweller, Hambach and Inden – with no further mines being planned. The plans for the reclamation of these sites include large residual lakes. In order to avoid any AMD issues, the dump area will be closed off and treated separately over several decades (Lotgers, 2004). In the Lausitz Lake District, also in Germany, eleven new lakes have been created on old mining land, connected by thirteen navigable canals. These include houseboat moorings, water landing areas for seaplanes and water sports centres, thus improving on the old landscape considerably (Kuyumcu, 2011). The Lignite Mining Plan for the remediation of the Rhenish lignite mining area in Germany, in which mining will be active until 2030, includes using water from the nearby Ruhr river and from drainage of the local mines to fill the residual lake. It is envisaged that this will take between 20 and 25 years to fill the lake. However, the design is such that, within five years of the commencement of filling, some of the lake will be available for use (Eyll-Vetter and others, 2011).

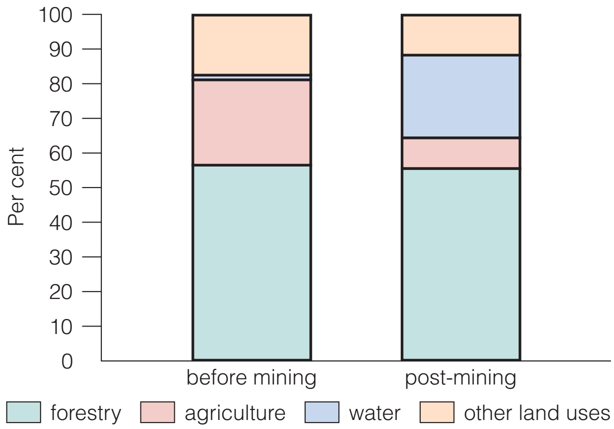

Figure 17 Proportion of land uses in the Lusatia region of Germany before and after mining (Krummelbein and others, 2012)

The Lusatia region of Germany was a major site for brown coal and lignite production. As shown in Figure 17, the amount of lakes and water features in the area has increased significantly as a result of mining activities and reclamation in the area. Although water uses comprised 2% or less of land use in the area prior to mining, the proportion has increased significantly to almost 25%. It is predicted that the continued flooding of closed mine-sites in the region will lead to the largest area of connected lakes in Germany. This is expected to attract tourists and generate new sources of income to the region (Krummelbein and others, 2012).

3.5 Comments

In most countries, water and water quality are protected by law and therefore any activity such as mining which may affect the flow, movement and/or quality of water must pass minimum requirements for ensuring that any damage caused is minor. In many cases mining disturbs existing water courses due to the re-landscaping of areas, affecting the natural flow of water through a region. This can be through disrupting stream or river flow, by change landscapes so that water run-off changes direction and through lowering of the landscape to below natural levels. Computer models are often used to predict potential changes in water flow in advance so that negative effects can be avoided or minimised.

Water which may run into the mining region must be diverted for safety reasons. Water that accumulates through mining activities must be treated and cleaned before it can be returned into natural water courses. The major issue with mine water is the potential to cause significantly increased acidity – acid mine drainage (AMD). AMD can be severe, causing rivers and water courses to reach pHs which are too low to sustain fish or plant life. These low pHs also cause trace elements to leach from surrounding rocks to cause further toxicity. AMD can be treated with chemicals or specially selected bacteria. More gentler, passive treatments can be used for long-term neutralisation of AMD following mine closure. When abandoned mines are being back-filled, the use of naturally alkaline materials such as FGD and FBC ash from coal combustion can be extremely beneficial and cost effective.

During mining, well-planned on-site water management can help avoid problems later when the mine closes down. Further, in countries such as South Africa, which are prone to water shortages, the water produce and collected during mining activities can be treated and provided to the local community.

In areas, such as opencast lignite mining, the final landscape can be significantly lower than was originally the case and this can lead to potential flooding. In most cases, this is avoided by purposeful and controlled flooding to turn flat, mined-land into new water features. Although this is not necessarily an inexpensive option, as minimum levels of safety and water quality have to be met and the flooding of some areas can take decades, these new water features are often regarded as positively beneficial to some communities. Many previously dry landscapes in Germany are now the sites of new lakes and water parks for the benefit of locals and tourists whilst providing new sources of income in the region.

4 Land

The functioning of a coal mine involves the operators making significant structural changes to the land to allow the physical removal of coal from buried seams and also to allow access of vehicles and workforce to the mine during operation. Following cessation of mining, the land must be made structurally sound. The mine site must also have some defined shape to it and this will require the design of terrain to recreate an appropriate landscape and provide a basis for the returning ecosystem.

Mining can have a significant effect on local geography. As shown in Figure 17 in Chapter 3, the proportion of land use in the Lusatia region (Brandenburg and Saxony) in Germany has changed notably as a result of mining, with water features and forestry increasing significantly. In the Yulin coal mining area of western China, fallow land decreased by 1251 hm^2 between 1985 and 2000. During the same period grassland increased by 1080 hm^2 and woodland by 1716 hm^2. This was due to a change in government policy on preserving the environment. However, some areas of China have encountered the destruction of land resources and fragmentation of the landscape – in the Xuzhou coal mining area in eastern China, the farm land decreased by 13% between 1987 and 2001 while construction areas increased by 38% and flooded land resulting from mining subsidence increased by 138% (Bian and others, 2010).

Modern mining practices generally encourage forward thinking through the whole process to ensure minimum disturbance and maximum efficiency in land use. In most developed regions, the plans for the remediation process for the mine will have been outlined even before the first lump of coal is dug. Pre-mining studies must include consideration of legal requirements, climate, topography, soils and community views. These latter community views are often the most important as local populations can halt mining activities completely if they feel that the industry is going to have negative effects on the look and feel of their homes and surrounding areas. Community issues are discussed more in Chapter 5.

The decision on how the land should look following mining is commonly determined in consultation with interested parties such as the local government, the local council, NGOs (non-governmental organisations), land-owners and the local community. However, what it is possible to achieve post-mining is also determined by the land itself. The key physical restraints of mine rehabilitation are considered to be (AGDRET, 2006);

- climate: the landscape must be consistent with prevailing climate conditions – rainfall and temperature will place constraints on what ecosystems can exist on the site;
- size: the size and shape of the site will determine issues such as the colonisation by native plant and animal species and weed invasion;
- soil/rock types: the type of soil (clay, loam, sand); the physical and chemical properties of the land (pH, dispersive/non-dispersive clays) and the availability of nutrients will determine which vegetation will survive following mining activities.

The following sections look at the different stages of mine management and reclamation – the preparation and consideration of existing topography and then the remedial work required to return the closed mine area back to a safe and functional landscape.

4.1 Landscape maintenance and design

Land forms are the result of existing rocks and their erosion over millennia. The vegetation which has grown there has done so because the terrain is suitable. The steepness of slopes, the exposure to wind and rain and the general contours of the land will all affect the local ecosystem. Any changes to land forms and topography will therefore potentially change the shape of the land and affect the ability of vegetation to regrow under the new conditions.

Mine reclamation plans will include the requirement for a map predicting how the site will look upon completion. This usually involves some form of re-landscaping to build up holes and excavated areas and the levelling of any large piles. The final land shape must be stable and compatible with the surrounding geography. Regulations such as SMCRA in the USA often call for AOC – approximate original contour – the reconstruction of the post-mining landscape to resemble the original contours from pre-mining.

In some reclamation plans, the final topography of the land will be a far more level version of what the site looked like before with some changes to accommodate the new dips and rises that have resulted from the removal and reposition of materials. In the USA there are those who support more geomorphic approaches, suggesting that reclamation projects neglect the functional and aesthetic benefits of reclaiming land in ways that mimic natural land forms and drainage patterns. Michael and others (2009) suggest that the original mountain and valley terrain of the Central Appalachian regions are becoming large flat plateau as a result of basic post-mine land forming. They suggest that, instead, the reformed landscapes should include more curves and slopes.

Mines on mountain tops generally require blasting work and result in a significant amount of extra spoil material which cannot all be used in back-fill, simply because of the volume. In some cases, a significant valley is left which must be filled. These can range from relatively small to vast sites of over 3048 m in length. Figure 18 shows an example of a deep valley fill at a mountaintop site in Central Appalachia, USA.

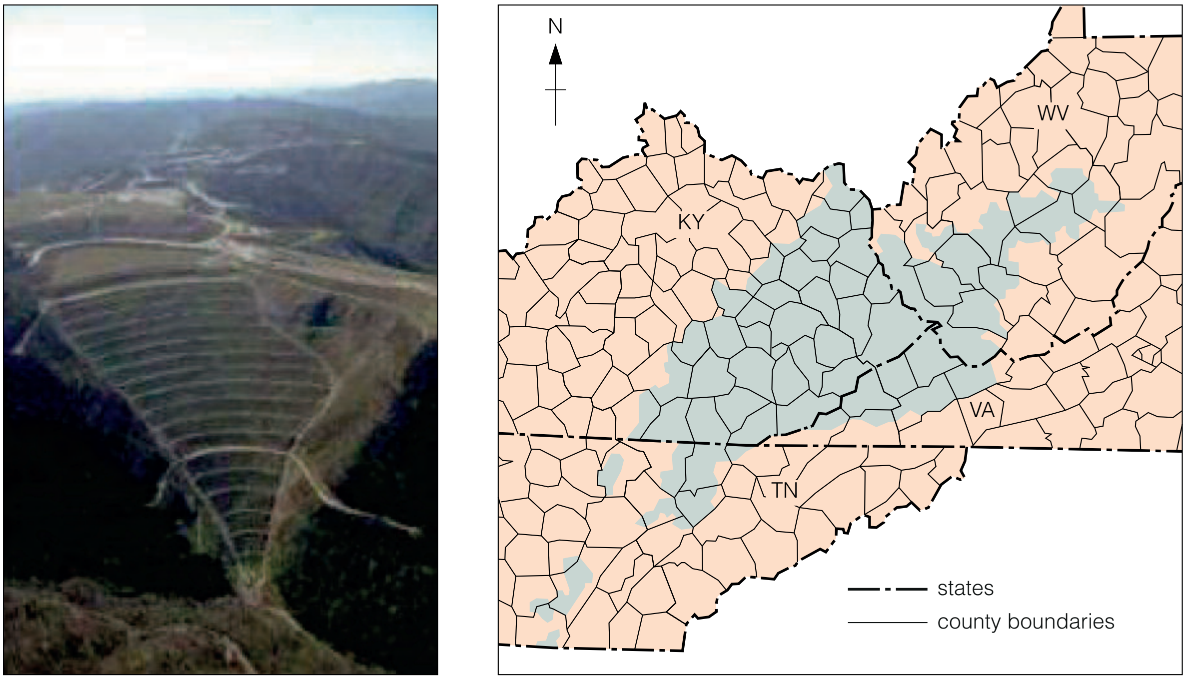

Figure 18 Valley fills in Cental Appalachia (Michael and others, 2009)

Table 7 shows the total amount of coal mined in the Appalachian and Powder River Basin regions of the USA in 2007 along with the amount of overburden removed. In the Appalachian region, up to 15 times as much overburden as coal was moved. This has a significant effect on the topography of the region as mountains and lowered and valleys created. As mentioned above, although AOC is promoted under SMCRA, some mine sites, such as those in mountainous regions, cannot be expected to rebuild a mountain top and so there is an inevitable change in the overall landscape (Kite, 2009).

In situations where care is not taken, deep underground mining can cause more damage to the overall landscape of some sites than surface mining due to the subsidence of land. Bian and others (2010) estimate that there are around 1 billion hectares (10,000 km^2) of subsided land in China. Subsidence

Table 7 Volume of coal and overburden displaced through surface mining in the Appalachian and Powder River basins in 2007 (Kite, 2009)

	2007 coal production	Coal volume	Overburden ratio	Overburden volume	Total overburden+coal
	metric tonnes x 10^6	m^3 x 10^6	m^3/t of coal	m^3 x 10^6	m^3 x 10^6
Appalachian (bituminous coal 1.32 t/m^3)	136	103	12.5	1720	1823
Powder River (subbituminous 1.30 t/m^3	435	334	1.7	733	1068

causes damage to ecosystems as well as posing problems with drainage and damage to nearby buildings. Subsidence in areas of plain land can result in large area flooding whereas subsidence in mountainous areas will include slope failure.

Deep mines tend to become flooded after closure. In such cases reclamation can be achieved by either filling or non-filling methods. In the filling method, coal waste materials such as removed rocks, fly ash or sludge can be used to back-fill. In the non-filling method, drainage is required to lower the water table and to reshape the subsided land (Bian and others, 2010). Back-filling is discussed more in Section 4.3.

For surface mines, the damage to the site is largely the removal of top soil and overburden and the lowering of a wide area of terrain. Lignite is usually shallow and covered with 40–120 m of sands, gravels, silts and clays. Materials such as silt can be mined selectively and used later in the reclamation process. The Lusatian area in Germany was where conveyor bridge technology was invented in 1924 to allow the mechanisation of mining. This allowed the sandy overburden sediments covering the coal seam to be excavated, removed and dumped in one step. Up to 60 m of overburden can be removed at one time which is then dumped on a spoil pile at the rear end of the mine for use as back-fill or landscaping (Krummelbein and others, 2012).

The Lusatia region is one of the largest lignite mining areas in the world. The area, like many lignite sites, is open and flat and was previously swamp land. These regions can therefore be prone to drought in hot periods and flooding during wet periods. And so, although returning the land to this original format would be considered AOC, it may not actually be the most appropriate option, and a change in land terrain and use could actually be beneficial for the area. For example, one of the first major mine reclamation projects, in the EU at least, was the Berrenrath opencast mine in Germany. In the 1960s, the large area of the mine was reclaimed based on an overall planning design based on scientific investigation into the most appropriate use of the land. The site was maintained as a fertile high plain with reforested slopes (Lotgers, 2004). This was not necessarily the original shape or contour of the land. However, it did return the land to a safe and stable landscape which was beneficial to the local community

In addition to planning for the restructuring of a mine following closure, many mines are now changing the way they operate to minimise damage and also to co-ordinate the easiest transition from mining to post-mining landscape use. For example, although lignite mining will continue in the Rhenish region of Germany until 2030, plans are already under way as to how the land at the current lignite mine will be converted into a lakes and farming/park area. In addition, the track used by the overburden conveyor to move topsoil away from the mine site, will be used to create a 'biosphere belt'. The 5 m wide road will be converted into a 14 km 'speedway' for runners, cyclists and inline skaters. The northern rim of the Hambach opencast mine will be maintained to create 'gardens of technology' as part of a 'Terra nova' project. Visitors will be able to view the main mining equipment and drainage system and will also be able to visit a Coal Innovation Centre at the nearby Niederaussem power plant to find out more about environmental issues (Eyll-Vetter and others, 2011).

4.2 Management and restructuring of overburden and soil

During mining, significant amounts of soil and overburden have to be moved in order to access the coal and lignite seams beneath. For deep mines, there is less disruption to the surface in terms of soil and overburden removal but there is a significant amount of removal of weight bearing coal and related rocks which must be replaced to avoid collapse or subsidence. For surface and lignite mining, there can be significant amounts of overburden and soil which need to be removed, stockpiled and then either disposed of or returned to the site for back-fill and contouring. However, during this stockpiling period, maintenance of these materials is important with respect to safety and maintaining the integrity and potential reinstatement.

According to Bian and others (2010) coal mining waste, including overburden and waste rock, accounts for 40% of all solid wastes in China. Mining wastes can be reduced by improving mining techniques – planning to ensure that only necessary areas are dug and the organisation of mining operations to reuse mined areas for access to new areas.

Opportunities to counteract possible negative effects of dumping and storage of overburden have been investigated at the MIBRAG (Mitteldeutsche Braunkohlengesellschaft mbH) lignite mines in Germany. In 1989, following the political changes in Germany, three mines (Peres, Groitzscher Dreieck and Schleenhain) were merged into a single united mine and mining resumed in 1999. The overburden from the united mine will be completely dumped inside the mine. Previous overburden was dumped at the Schleenhain site and further dumping will continue there until the new dumps are sited at the original Peres field. The movement and storage of the overburden from the vast site has been planned right through to the year 2041. The whole of the Schleenhain site and part of the Peres site will eventually be back-filled with the remaining areas set aside for lakes. Since it is known from previous experience that negative environmental impacts can occur at dump sites, MIBRAG have developed a geological model and mine planning software to manage the dump site. The characterisation of the layers, parameters such as sulphur and carbonate content, can be used to determine the acidification potential. Information on local aquifers and other water bodies can be used to forecast potential issues. This tool will now form and important part of how MIBRAG operate mines in future. The following methodology will be performed as standard at all MIBRAG sites (Jolas and Hofmann (2009):

- determination of the geochemical parameters of the site by sediment drill samples;
- joint processing of geochemical and geological data from the site;
- determination of exposure times and level of pyrite oxidation;
- preparation of models taking into account related models;
- determination of groundwater quality in the upstream flow;
- evaluation of acidification tendencies based on water quality and the model results;
- development and implementation of methods to reduce acidification.

By using this model, MIBRAG will be able to manage new dump sites to ensure minimal environmental damage.

Avoiding acidification of dumps can be achieved in a number of ways. The oxidation of the pyrite in the dump material can be avoided by minimising the exposure of the material to oxygen. This can be achieved by storing any pyrite containing spoils in the lower section of the dump, covered by other non-pyrite containing spoils or by covering the pyrite containing spoils with impermeable materials. The establishment of mass distribution facilities, the point where all conveyors come together, provides the potential for the management of materials in this way and this approach is common in central Germany. A two meter thick recultivation layer of impermeable or mixed impermeable materials (such as pyrite free quaternary boulder clay or loam and loess) is usually placed over the final dump surface. Sealed walls may be necessary to prevent inflows. Aquifers may be drained to prevent further spread (Jolas and Hofmann, 2009).

It is also possible to reduce acidification in dumps by the addition of alkaline materials or to establish some other buffering capacity. This can be achieved with lime or even ash from lignite-based power generation, which is readily available in many regions in Germany. One final means of controlling potential acidification from dumps is to treat the outflow of acidic water. This requires the sealing of the site to ensure that all leakage/drainage of water from the dump passes through the treatment centre, usually filter-based, before passing into the environment (Jolas and Hofmann, 2009; *see* also Section 3.2).

Piles of loose soil and rock materials can be a safety risk and so slopes must be kept to a minimum. This is also the case for any piles of materials which are likely to remain after reclamation. For example, in the NSE (2009) guidelines for Nova Scotia, Canada, there is a requirement that slopes greater than 3:1 (18°) should be kept shorter than 20 m by either breaks, terraces, berms or basins. Steeper slopes are more subject to erosion caused by surface water run-off. Uniform slopes are more prone to slipping and erosion during storms and therefore slopes should be short or varied to avoid this (NSE, 2009). In the case of extreme slopes or vertical drops of three metres or more, then specific engineering work may be required to ensure the long-term stability of the site (NSE, 2009).

CSIRO in Australia have produced design guidelines for slope safety in mining under a Large Open Pit Slope Stability Project. The useful manual provides details on geology, structure, hydrogeology, and slope design, evaluation and monitoring in order to ensure that slopes are left safe and secure for the long term (CSIRO, 2012).

According to Kumar and Sweigard (2011) one of the driving forces behind SMCRA was the problem of unstable slopes left after unregulated contour mining in the Appalachian Region of the USA.

In the USA, the majority of mines with excess soil and deep fill issues are in the Central Appalachian region, as shown in Figure 18. The picture on the left in Figure 18 shows the most common method for dealing with excess spoil in layers down the side of a slope. Prior to these layers being placed, the valley floor must be prepared to check for strength and to arrange rock under drains to control groundwater seepage and surface-water infiltration. The rock under drain must be made of durable material with no risk of AMD or erosion. However, according to Michael and others (2009) there is no industry standard or even general agreement between those agencies and bodies involved as to what constitutes a realistic rock durability testing protocol.

Slope instability can be a significant safety issue. Perhaps the most dangerous possibility which must be considered is liquefaction slump. Liquefaction slump occurs when water rises up into stockpiles of closely graded, fine grain sand or soil. The mixing of the water and the fine solids can increase the core water pressure and cause the grain structure to dissipate – the liquefaction of the previously 'solid' pile of material occurs suddenly and without warning. Even tipped slopes that have been regarded as safe for several decades can suddenly collapse and move several million cubic metres of material over large distances. For example, in 1998 the Koschen-Damm in Germany saw around 4.5 million m^3 of 'solid' material become 'liquid' within a matter of seconds and the material flowed downward into the nearby lake covering 12 ha of forest and meadowland (Kuyumcu, 2011).

Michael and others (2009) suggest that the collapse and flooding of a spoil site was due to mismanagement which could have been avoided if the area had been revegetated and surface drains had been created. Instead, the sediment laden spoil fill collapsed and flooded down the hillside causing significant damage, as shown in Figure 19.

Figure 19 Lyburn flood (left) erosion and sloughing on the outslope of the durable rock fill following a storm event; (right) property damage downhill of the fill (Michael and others, 2009)

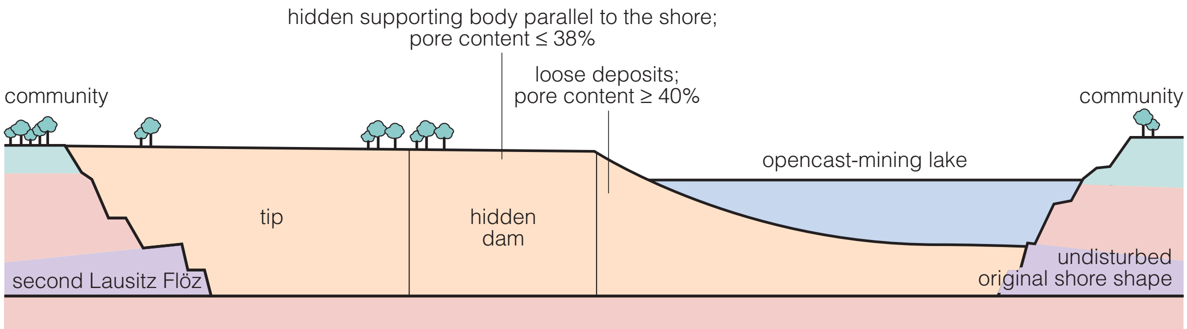

Figure 20 Hidden dam to secure tipped slopes endangered by liquefaction slumps (Kuyumcu, 2011)

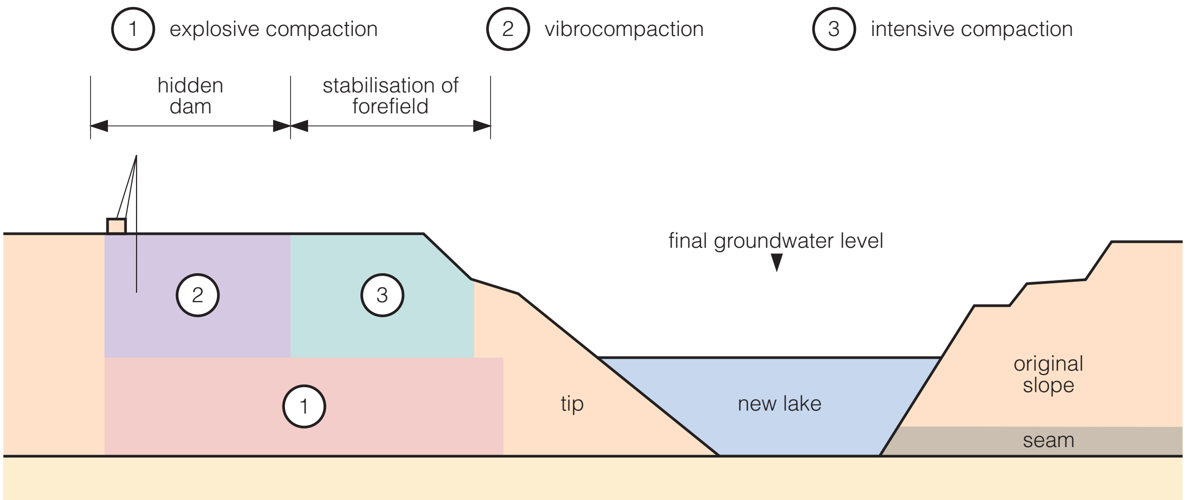

Figure 21 Combination of methods for compaction (Kuyumcu, 2011)

In order to avoid the risk of any more such accidents, tipped slopes of mined or waste materials are now secured with a hidden dam, as shown in Figure 20. Other land around the slope must also be stabilised, generally by one or a combination of compaction methods, as shown in Figure 21 (Kuyumcu, 2011):

- blasting/explosion compaction is suitable for water-saturated slopes down to a depth of about 60 m. The depth must relate to the level of ground water and may therefore need to be done in stages to match the depths accordingly. The blasting and vibration shocks cause the material to compact over a radius around the blast point. However, this means that this method cannot be

used near sensitive areas such as communities or important infrastructure.
- vibro-compaction has a more limited area of effect (2–4 m) and is therefore done in intervals. The equipment for vibro-compaction is now advanced to the point where vibro-compaction can be performed down to 40 m and sensors can be used to determine the strength of compaction achieved in situ.
- stabilisation at the forefront (*see* Figure 21) will use a combination of techniques and materials, including rock fill, geotextiles, pile sheeting and jetties, to ensure that movement of the fill will not occur even over extended periods of time.

At flat surface mines or level deep mines, where the change in the slope of the landscape may be less severe, there may still be an issue with the removal or flattening of any moved materials or spoil heaps. In the forestry reclamation approach (FRA, *see* Chapter 5) for returning land to forest, the land must have a flat or gently rolling surface. The top 1.22 m of soil or substitute material must be loosely graded to avoid compaction. However, loose compaction is an issue on steep slopes as this can lead to slope erosion or failure (Kumar and Sweigard, 2011). In many mine sites, there are areas of land used for tracks and access which become compacted over time. These can be lifted and relayed or scarified (NSE, 2009).

Within the EC guidelines on the good management of tailings and waste-rock includes evaluating alternative options for (EC,2009):
- minimising the volume of tailings and waste-rock generated in the first place, by, for example, proper selection of mining method (open pit/underground, different underground mining methods);
- maximising opportunities for the alternative use of tailings and waste-rock, such as use as aggregate, in the restoration of other mine sites, or in back-filling;
- conditioning the tailings and waste-rock within the process to minimise any environmental or safety hazard, such as de-pyritisation or the addition of buffering material;
- application of a life cycle management approach.

Life cycle management covers all the phases of a site's life. The first phase, the design phase, establishes the environmental baseline for the site including characterisation of tailings and waste-rock and establishing a tailings management facility (TMF). The design phases must also produce plans for site selection, environmental impact assessment, risk assessment, an emergency preparedness plan, a deposition plan, a water balance and management plan, a decommissioning and closure plan, designs for the facility and associated structures, and also a plan for control and monitoring of any environmental effects. Following the design phase are the construction phase, the operational phase and then the closure and after-care phase. The latter includes long-term closure objectives and specific closure issues for heaps and ponds.

4.3 Back-filling

Back-filling is required in deep mines to prevent collapse and subsidence. Back-filling is also required in surface mines to ensure the safety of the mined land and to recreate a smooth landscape. Back-filling can also be a useful way to return piles of overburden and other materials, which were removed during mining, back into the landscape and thus avoiding the need for disposal. However, contaminated materials (such as fuel oil, asphalt, construction and debris materials) cannot be used as back-fill (NSE, 2009).

In the Suncun Coal Mine in Shangdong, China, crushed mining wastes were mixed with cement to back-fill mined cavities as a way to lessen surface subsidence. This type of approach can reduce mining wastes by around 10% (Bian and others, 2010). Bian and others (2009) note that 58% (135.3 Mt/y in 2002) of the coal mining wastes in China is still taken to waste dumps. However, 24% is used for back-filling deep and subsidised mines, 12% for fuel (reclaimed and used in power plants), 5% in brick production and around 1% in cement production.

The reuse of mine wastes and coal combustion ash in back-filling is significant in countries such as the USA. For example, between 1988 and 2006, coal ash was used beneficially in mine reclamation projects at over 120 permitted mine sites in Pennsylvania alone. Ash from FBC power plants is often of particular use because of its alkaline properties. The 16 FBC plants in Pennsylvania have helped in the reclamation of over 1376 ha of abandoned mine lands (Hornberger and others, 2006).

Voros (2006) suggests that dredged materials (moved to make way for mining activities) and alkaline coal combustion by-products (CCBs) can be combined, with cementitious results, to be used beneficially to:

- replace the devastated geology of abandoned mine land;
- remove physical hazzards (void collapses and holes);
- return surface waters to watersheds;
- prevent the formation of AMD;
- restore natural vegetation and habitat.

For example, almost 1 Mt of amended fill was used to return a double high wall along 3353 m of hillside in western Pennsylvania to its original contours (Voros, 2006).

The Red Hills mine in Mississippi, USA supplies 3.6 Mt/y lignite to the local CFBC plant (circulating FBC). Large amounts of heavy truck traffic between the mine and the power plant had led to significant degradation of the roads. However, the use of CFBC ash from the plant for construction of roads for heavy haulage equipment and parking areas not only improved haulage production, reduced diesel consumption and reduced road maintenance but also conserved natural aggregates from quarries and lengthened the life of the power plant's primary ash disposal system (Hawkey and Merino, 2006).

According to Conrad (2006), all states in the USA have managed the placement of coal mine wastes at mine sites in a safe, environmentally protective manner. Further, Conrad (2006) notes that there are no significant gaps in regulatory coverage and suggest that many states continually seek to improve and upgrade programmes to continue the use of CCBs. States such as Pennsylvania have their own Solid Waste Management Acts which regulate the use of coal mine wastes and combustion by-products (Hornberger and others, 2006). Texas has created an initiative to streamline the regulatory process governing the use of CCBs at Texas mines (Nasi, 2006). Dale (2005) points out that, although Indiana, the State producing the second largest amount of coal ash in the USA, used less than 10% of its CCBs in mine reclamation, this is likely to increase in the future. The state introduced a programme which includes new testing procedures to ensure the safety and applicability of CCBs in further reclamation work.

The use of both mine wastes and coal combustion by-products (CCB) in mine reclamation makes both practical and economic sense. However, it is important that these materials conform to minimum performance requirements and do not pose potential contamination issues. Numerous studies have been carried out that suggest that CCBs do not pose a contamination problem in most uses. To ensure that this is the case, these materials must undergo tests on their leaching behaviour. For example, Ziemkiewicz (2006) describes the development of the mine water leaching procedure (MWLP) which sequentially leaches the CCB with a sample of the target site's groundwater until the alkalinity is exhausted and the pH of the leachate returns to that of the mine water sample. During this process, the release of trace elements is monitoring and quantified.

FGD (flue gas desulphurisation) wastes are typically high in sulphites and alkaline material. Depending on the type of FGD system used, the waste material is either a wet sludge or a dry gypsum material. The characteristics of FGD wastes make them useful as alkaline amendments in active coal waste landfills. Noll (2006) reports on the use of 12.2 million m^3 of FGD-sulphite dominated material for placement as the final cap on a 121 ha, 40 Mt abandoned coal refuse site as a stabiliser. The FGD material helps solidify the final material to ensure that there is no leakage of dust or water. Stoertz and

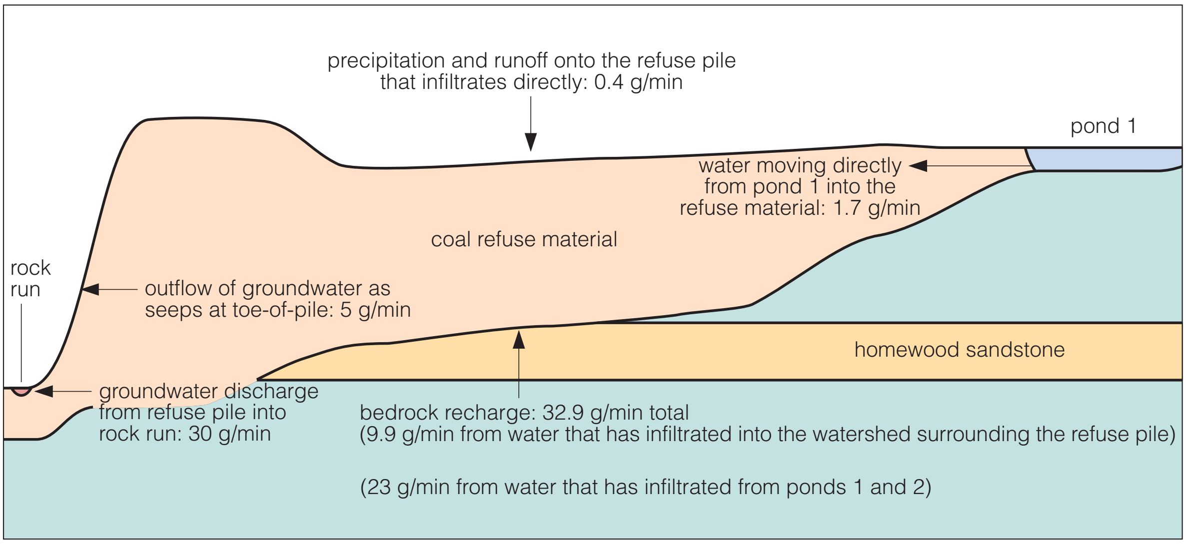

Figure 22 Overall water budget (Stoertz and others, 2006)

others (2006) report on a similar study at the Rock Run valley-fill coal refuse pile in Ohio. Figure 22 shows the overall water budget of the site, prior to the FGD treatment. Water moved into the pile via rain, from the damaged watershed and from a nearby pond. The outflow from the pile was mostly as a groundwater discharge from the pile into the Rock Run stream. Following capping with the FGD material, the post-reclamation water budget showed no infiltration through the cap, no infiltration from the pond discharge, and a 22% decrease in the bedrock recharge. So, although the mine drainage was not stopped completely, it was reduced significantly and made more manageable via a passive treatment system (*see* Section 3.2.2).

Slurried and dry tailings are sometimes used in underground mines or abandoned pits or in portions of active pits as back-fill. In most cases, back-fill is used to refill mined-out areas in order to achieve several benefits (EC, 2009). For underground mining the use of tailings can:
- assure ground stability;
- reduce underground and surface subsidence;
- provide roof support so that further parts of the mine can be extracted and to increase safety;
- provide an alternative to surface disposal;
- improve ventilation.

Because of the small particle size and the fluid mobility, slurried and dried tailings are easy to pour into spaces, filling gaps and holes easily. In some cases these materials will have slight pozzolanic properties, meaning that they will harden over time to given even more structural support.

For open pit mining the use of tailings is beneficial for:
- decommissioning/landscaping reasons;
- safety reasons;
- minimise the foot print (as opposed to building ponds or heaps);
- minimise risk of collapses by back-filling the pit instead of building a new pond or heap.

There are 4 types of mine back-fill (EC, 2009) – dry, cemented, hydraulic and paste back-fill:
- **Dry back-fill** generally consists of unclassified sand, waste-rock, tailings, and smelter slag which are dropped into the target area and moved with loaders or trucks. Despite the name, the dry back-fill generally contains some adsorbed surface moisture. Dry back-fill is more useful for mechanised ‘cut and fill’ mining methods or other methods where the back-fill is not required to be structural.
- **Cemented back-fill** generally consist of waste-rock or coarse tailings mixed with a cement or fly ash slurry to improve the bond strength between the rock fragments. The back-fill comprises both

coarse (<150 mm) and fine (<10 mm) aggregate. The cement is prepared as a slurry which is poured into voids or percolated over rocks. Cemented back-fill provides a more structural fill than dry back-fill.

- **Hydraulic back-fill** can consist either of classified slurried tailings or naturally occurring sand deposits mined on the surface. The back-fill mixture, which can be cemented or uncemented is hydraulically pumped from the surface through a network of pipes and boreholes to the target area. The materials used in hydraulic back-fill must be closely monitored to ensure that grain size and flow are workable. Even in uncemented back-fill, the strength can be use due to compressive and shear strength.
- **Paste back-fill** is a high density back-fill (>70 % solids depending on the density of the solids) which is pumped by piston type pumps of the same type used to pump concrete. Whole mineral processing tailings can often be used to make paste back-fill. The final product has a lower void ratio so the back-fill is denser (EC, 2009).

Following back-fill, the site must be tested to prevent subsidence and compaction and settling over time (NSE, 2009). In cases where there is water influx and/or AMD, grouting with alkaline materials is seen as a permanent means of reducing acid production (Bulusu and others, 2005; *see* Section 3.2).

In most mines, much of the back-filled material is waste material from the mine which had been removed and stored during mining activities. However, in some cases, where several mines are in close proximity, back-fill material can be moved between sites to optimise the speed of back-filling whilst reducing storage requirements. For example, in the Bergheim lignite mine in the Rhenish region of Germany, only around 14 % of the 14 million m^3 of overburden was used in the Bergheim mine itself. Around 20% was transported to the Fortuna-Garsdorf opencast mine by belt conveyors and 66% was transported to the Frechen opencast mine by railway. Conversely, 88% of the material used for the recultivation of the Bergheim was transported long distance from the Hambach opencast mine. The proximity of the mines in this Rhenish region and the high availability of different transport options means that the Bergheim lignite mine is regarded as a ‘mass hub’ for materials in the area (Gartner and others, 2010).

In India, the current immense growth in coal mining activities has meant that many mines are not run in a satisfactory manner. In many cases, back-filling costs are seen as prohibitive and the easy option is simply to abandon the mine. Mukhopadhyay and Sinha (2006) reported on the development of a techno-economic computer model which can take basic mine and overburden information to test difference options for back-filling the same or adjoining quarries at an optimum cost.

4.4 Topsoil management

Topsoil must be removed in order to gain access to the coal below. If managed properly, this topsoil can be maintained so that it can be returned to the site following mine closure. Most reclamation plans will include some form of requirement for revegetation of the land (*see* Chapter 5). This section deals only with the movement and storage of topsoil before it is used for either back-fill or replacement.

For the reuse of topsoil to be successful, the top soil must be moved and stored carefully to preserve the original characteristics. Soil management includes issues such as (NSE, 2009):

- quality assurance during excavation;
- identification of stockpile locations to maintain soil quality;
- temporary seeding;
- permanent vegetation of stockpiles to control erosion and invasive plant species.

Untreated post-mining soils can show signs of reduced fertility due to contaminants released during mining activities. Ghose (2004) studied soil samples from a large opencast mine site in Jharkland, India both before and during mining. The mine began operation in 1980 and is expected to have a lifetime of over 70 years and to cover a total of 2177 ha. Prior to mining, the land was used to cultivate paddy, sugar cane and gram. Measurement of the soil characteristics in the stockpiled soil (moved to make way for the mine) showed that the soil became biologically unproductive after six years. Ghose (2004) regarded this as the ‘shelf life’ of the soil. If the soil is to be used then these stockpiles must be treated to maintain nutrients and microbial activity.

4.5 Management and reuse of waste materials

Coarse discards are produced from coal mining (mine stone and coal rejects) along with fines that are produced during any coal washing process. These materials must either be used or disposed of. Mining waste have the potential to leach contaminant into local groundwater as well as causing dust pollution. Mine waste can also be a risk through spontaneous combustion. The treatment and disposal of the waste can be problematic and costly (Bian and others, 2010). Mining wastes in China can be a safety issue as around 200 of the current 1700 waste dumps, containing around 4.5 Gt of coal wastes, are self-igniting and therefore a risk to the local community (Bian and others, 2010). The USA produces almost 500 Mt of dredged materials every year through mining activities (Voros, 2006).

Some mining wastes can be burned or cofired to produce power. For example, in Pennsylvania, USA, coal refuse materials are fired at FBC plants (Hornberger and others, 2006). However, the efficiency is for mining waste combustion is often low and the majority of the materials still end up as wastes as constituents of combustion ash and fly ash.

In some cases, remnant coal can be reclaimed from old colliery spoil tips, rejects from coal processing, run-of-mine feed, clay contaminated coal seams, top of seam coal cleanings and remnant floor coal from seam interfaces. For example, companies such as RecyCoal specialise in reclaiming usable coal from waste coal piles (http://www.recycoal.com/). A project at the Langton Colliery, UK, has recovered around 445 kt of coal from 4.5 Mt of spoil at the site. Following the removal of viable coal, the site is being re-established with a combination of woodland, scrub, hedgerow, grassland and agricultural land. Another site in Park Springs, Grimethorpe, Yorkshire, has recovered 750 kt of coal from 9.5 Mt of colliery spoil and returned the site to an attractive habitat for nature conservation (RecyCoal, 2012).

Coal can be recovered using the dual density natural medium (DDNM) process, a two phase density-based process which allows efficient coal recovery from spoils contaminated with shale and clay. The process includes a water treatment stage and therefore does not result in tailings ponds (RecyCoal, 2012).

4.6 Comments

The first issue that must be dealt with following mine closure is to ensure that the land is safe and not likely to sink, subside or collapse. Once the site is safe, then more aesthetic issues such as contouring and landscaping can be considered. Although most mining plans require the return of the site to approximate original contouring, this may not be possible at all sites and some may actually benefit for a modification of the landscape to suit a new purpose.

If a mine is operated correctly, then it is possible for topsoil and overburden materials to be moved to the side and stored during mining. Much of this material may then be reused as back-fill and re-landscaping materials. The addition of other coal-use wastes such as FGD gypsum and FBC ash can actually improve the structural integrity of back-fills whilst also providing neutralising potential to combat AMD.

5 Rebuilding ecosystems

Ideally all coal mine reclamation projects would return the sites to areas of either fruitful agricultural use, successful forestry or productive industrial or leisure uses. However, in most situations the end use will partially be determined by what is physically possible at the site and the cost. Mine reclamation can be costly – $1.5 million per mine, according to some estimates (RLCH, 2011) or 24,710 $/ha (according to MII, 2012). Therefore mining reclamation either has to be funded in advance, through the mine permitting and bonding process, or else a very expensive legacy is left for future generations to clean up. Further, some end uses for reclaimed sites are more valuable than others. Figure 23 shows a comparison of the economic value of different options for reclaimed land. The sale of a reclaimed site for residential or commercial buildings will raise far more revenue than leaving the land to forestry or farming (Dogan and Kahriman, 2008).

high economic value

construction
- industry
- housing
- public buildings

agriculture
- cultivation
- productive grazing
- marginal grazing
- allotments

forestry
- economic
- marginal

fishing
- economic
- marginal

recreation (intensive)
- sport
- picnic sites
- caravan and campsites
- car parks
- waterscapes

recreation (extensive)
- casual/public open space
- country parks

wildlife
- casual/education
- nature
- conservation/education

productive uses with some economic value

amenity uses with little or no economic benefit

low economic value

Figure 23 Economic value of future usage for reclaimed land (Dogan and Kahriman, 2008)

Chen and others (2007) have created an interactive decision support system to evaluate the ecological benefits of rehabilitating coal mine waste areas. The system takes input data from water and nutrient models as well as air quality models and geographical and physical data from the site being studied. Figure 24 shows the model management subsystem and the different parameters considered within each area. Although the paper by Chen and others (2007) does not include any information on the use of this model and no further publications have been found relating to this work, Figure 24 does provide a useful summary of the different parameters relating to the potential benefits which could be achieved by a mine reclamation project. These include effects on the characteristics and nutrient contents of the soil, the water movement through the system, and the effects on atmospheric gases including CO_2.

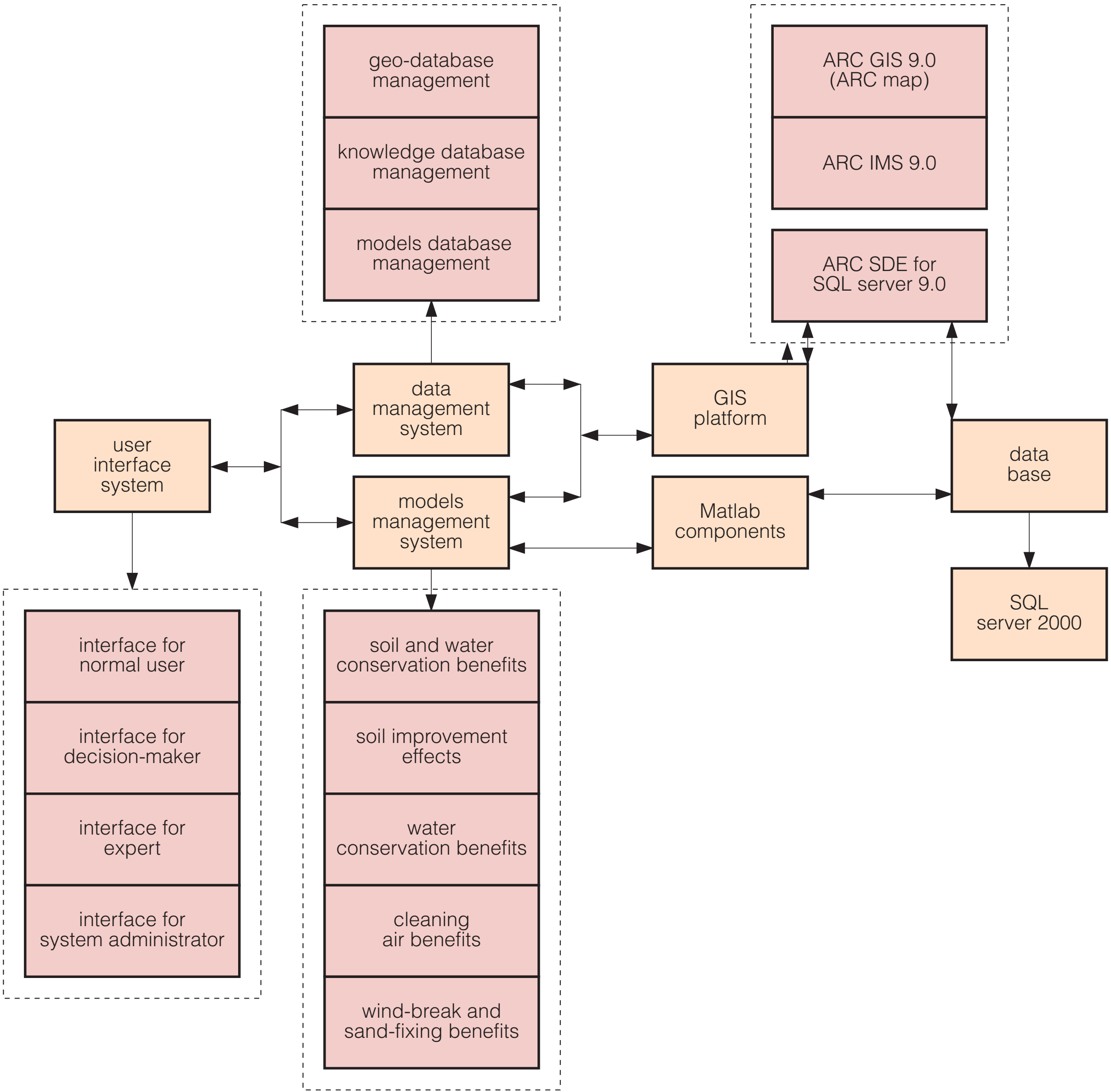

Figure 24 Model management subsystem: index system (Chen and others, 2007)

Mine reclamation can return mining areas to their pre-mining state or can provide a whole new use for previously unappreciated land. This can mean the shift from an otherwise abandoned area to one which provides useful forestry or agricultural use. However, for this to be successful, great care must be taken to ensure that the new landscape and soil is appropriate for the new ecosystem.

The following sections look at the different aspects of making the most of reclaimed mining land. The chapter then ends with some examples of exemplary mine reclamation projects.

5.1 Soil amendment

As discussed in Chapter 4, the removal and stockpiling of topsoil is necessary to access the coal seams. However, how this topsoil is managed will determine whether it will still be viable for plant growth if returned to use as topsoil or whether it has been depleted of any nutrients and has degraded to be useful only as back-fill.

Where possible, topsoil will be reused. However, where little or no topsoil exists, the introduction of new material is required and this new material must be appropriate to the ecosystem. To help with this, information on soil types according to region in the USA, including chemical properties, can be found through the National Cooperative Soil Survey on line at http://websoilsurvey.nrcs.usda.gov.

Most mining permits will include a minimum requirement with respect to the amount/volume of soil replaced over the mined substrate. In German lignite mining a minimum depth of 2 m is required and this media must be lignite and pyrite-free (Krummelbein and others, 2012).

With topsoil that has been removed and stored over an extended period of time, compaction can be a major issue. Compaction results in increased soil strength and density but over-compaction can have a negative effect on tree survival and growth. According to the USA FRA (discussed more in Section 5.2) process, the top 1.22 m of soil or substitute material must be loosely graded to avoid compaction (Kumar and Sweigard, 2011). In Lusatia, Germany, where extensive lignite mining still takes place, recultivation includes deep ploughing or ripping (50 cm soil depth) to reduce the compaction caused during dumping and levelling of the replacement soil substrate. Since these new substrates can have low mechanical stability, especially under wet conditions, rapid revegetation is encouraged to establish new root growth into the soils for long-term stability and revegetation success (Krummelbein and others, 2012).

Soil analysis is necessary at several stages of coal mining – soils must be evaluated prior to the commencement of mining and also during the revegetation process. Soil is naturally heterogeneous, layered and variable with changes in vegetation, treatment and so on. Soil analysis therefore requires a firm understanding of the methods used and the uncertainty associated with any sampling regime. Hursthouse (2012) lists the important factors in soil analyses:

- sample location – sample locations must represent the inputs to the site (from human activities) and must be remote from direct inputs from contaminating activities. Multiple sampling points should be used to reflect natural variability;
- sampling process – samples can be treated with extraction procedures such as acid treatment and solvents to release different components for analysis. The different methods and solvents used will release different components and therefore give different results. Methods must be consistent for intercomparison studies to be useful;
- sample treatment and handling – volatility and degradation of samples must be considered for any comparative studies;
- detection limits and quality assurance and control (QA/QC) – baseline concentrations for many substances are likely to be very low, possible at or below the detection limit. Precision and accuracy are therefore required to ensure that non-detects and extremely low values are valid;
- comparison of data – enrichment of components (for example, as a result of alleged contamination) must be proven by comparison against valid baseline data for the same location or, where this is not possible, for locations which can be proven to be similar or representative.

Mine spoils and stored topsoil are usually deficient in nitrogen, carbon and phosphorus. Disturbance of the soils during removal for mining disturbs plant and microbial growth and this disturbs the normal nitrogen cycle of the soil. In warmer climates, such as India, the lack of moisture in the relocated soil will also reduce growth of plants and soil bacteria. In order for these soils to become reusable, they must undergo some form of restoration (Tripathi and Singh, 2008).

The acidity of the soils is of major importance for ensuring return of plant growth. If the pH is too high (alkaline) then pyritic waste or organic matter can be combined with the top soil and weathering or alkaline tolerant plant species can be seeded. If the pH is too low (acidic) then lime or fly ash treatment, covered with clay, can help remediate this (Bian and others, 2010). Many mined soils have high pyrite contents and consequently have low pH. Acid-base balance methods for soils were developed in the 1960s. Prior to 1990, sites in Germany also used brown coal ash for this purpose. Treatment depths are recommended at a minimum of 100 cm. According to Krummelbein and others (2012) 'well-ameliorated' soils over pyrite and lignite-containing sites will approach normal development after several decades, although these kind of sites can still have quantitative and qualitative effects on water and element fluxes in the surrounding region for more than 50 years. High fluxes of Al, Ca, Fe and sulphur (as SO_4) can be transferred to deeper soil layers and can reach several t/ha/y. Sites in Germany which had been recultivated with brown coal ashes still displayed high acid neutralisation capacity after 34 years of cultivation, demonstrating the high buffering capacity of materials such as calcium which had been present in the ashes.

If the heavy metal content of the soil is too high then organic matter can be applied along with an initial growth of metal tolerant plant species. In the case of high salinity, gypsum can be applied or the irrigation of the site can be altered (Bian and others, 2010).

Nitrogen is usually the limiting nutrient in the rehabilitation of mine soils as soil nitrogen is commonly restored by microbial and plant activity which is disturbed during soil relocation. Planting appropriate plants into the mine soil will help restore the nitrogen balance within five to ten years of reclamation (Tripathi and Singh, 2008). If necessary, top soil can be amended with organic materials, mulches, pH adjustments, fertilisers and other soil amendments. In some cases, deeper soil from the mine workings can be mixed with top soil (NSE, 2009).

The amount and type of fertiliser needed to ameliorate topsoils will depend on the state of the soil on the mining land and the projected future use of the site – whether the land will be returned to forestry or to agricultural use. Commercial fertilisers can be used. Some sites have tried remediation with sewage sludge, which can provide a longer-lasting nitrogen dose to the topsoil. Other organic residues (from farming practices) can also help with soil structure and water-holding capacity. Such organic additives can be very effective for returning microbial activity to soils. Brown coal filter ash with added lime was also found to be a useful medium for promoting microbial establishment in soils (Krummelbein and others, 2012).

5.2 Revegetation and reforestation

Although the chemical constituents of soil are important, soil must house a functional mix of bacteria and other microbes in order to provide the basic nutrients for plant growth. The substrates used for recultivation of mines in the Lusatia region of Germany are mostly sandy and unstructured local soils, lacking in organic matter. Topsoils from adjacent forests have been tested, since these contain natural organic materials and microbes. Sites which had been treated with forest topsoils showed far improved plant growth than those with only local soils. At sites where microbial activity is low, certain rhizosphere bacteria such as Pseudomonas fluorescens and Agrobacterium rhizogenes can be added to the soil. Ectomycorrhizal fungi are also useful for helping return the soil to a natural balance and promote seedling growth. Applications of bacteria and fungi simultaneously can have a significant effect on plant growth, although the correct combination of species must be used to ensure that they do not behave antagonistically (Krummelbein and others, 2012).

The Lusatia region of Germany has been the location of significant lignite mining over decades. To help return the land to profitable use, the Research Institute for Post-Mining Landscapres eV Finsterwalde developed a crop rotation system to increase the fertility of the dump soils which was recommended to be applied over seven years (Wustenhagen and others, 2009):
- reclamation of the dump soil;
- forming humus;
- activating soil-biological processes;
- supporting soil structure;
- supporting soil formation.

Plants for crop rotation should then be selected based on their suitability for the location and their properties for increasing soil fertility, based on the following criteria:

- utilisation of the yield potential of the dump substrates;
- low requirements for the soil structure and fertiliser supply of the dump soils;
- rational use of water reserves;
- root penetration;
- yield amount of crop and root residues.

For the Lusatia region, this meant the use of alfalfa-grass mixtures as the main elements of the crop rotation (40–50% of the share) with grain crops amounting to 25–35% of the share.

Revegetation on reclaimed land must be controlled to ensure that any species of plants and animals which are introduced to the area are appropriate to the local conditions and not likely to be invasive or have any other negative effects on the area. In some cases this will require successive reclamation, a multi-stage process relying on different treatments over a period of time (NSE, 2009)

During revegetation, the selection of native species is commonly encouraged, although in some cases non-native species may be used as initial colonisers and these will then be succeeded by native species. Where possible, patches of land containing the original vegetation can be protected to increase seed propagation and encourage the return of native species (NSE, 2009).

One of the options for mine reclamation is the turning over of the land to forestation. This can either be to return the site to a tree-covered landscape or to create a commercial forestry programme. Under SMCRA in the USA it was found that the basic regulatory requirements for soil chemical properties were suitable for herbacious plant species but were not often favourable for planting trees. This meant that the operators of many SMCRA mine sites did not plant trees as they knew that the survival rate may be low. Any trees that were planted were early successive and non-native species which were able to withstand the soil conditions. This lead to a deficit in the return to forest in the Appalachian regions and, in response, a new approach to reforestation – the Forestry Reclamation Approach, or FRA – has been promoted by state mining agencies and the OSM (TASM, 2012).

The FRA has been developed under the Appalachian Regional Reforestation Initiative, which aims to promote the establishment of forests on old surfaced mined land. The FRA is a five step process (Sullivan and Amacher, 2010):
- creating a suitable rooting medium for good tree growth;
- loosely grading the topsoil or topsoil substitute;
- using tree-compatible ground covers;
- planting both early and successional trees for wildlife and soil stability and commercially valuable crop trees;
- using proper tree planting techniques.

More detail on the FRA process are given in Table 8. In addition to creating useful and native forest land, the FRA is also contributing to carbon sequestration (Zipper and others, 2011). Most mines in Virginia and Tennessee have been reclaimed using the FRA since 2006 and more than 4000 ha have been reclaimed with another 12,000 ha permitted for FRA reclamation (Zipper and others, 2011).

The Kentucky Department of Surface Mining and Enforcement (KDSMRE) has over two decades of working with SMCRA and concludes that unsuccessful reforestation is commonly due to excessive compaction of soil or growth media, inappropriate growth media and excessive competition from herbaceous ground covers. The requirements of SMCRA are such that, to alleviate the dangers of steep slopes and drops following high wall completion, a considerable amount of compaction is required and this is the major cause of problems when trying to establish tree growth (Kumar and Sweigard, 2011).

Agriculture and recultivation techniques which evolved during the second half of the 20th century in the Rhenish mining area of Germany as a means to upgrade mining land into farming land are seen as

Table 8 Intended relationship of the FRA's five steps to ecosystem service restoration (Zipper and others, 2011)

FRA steps	Ecosystem restoration goals				
	Restore forest productivity	Restore plant communities	Restore fauna habitat	Restore hydrology	Protect water quality
Select best available materials	generates soil media and chemical properties that are favourable to tree survival and growth	favourable soils air native plant recruitment	use of soil with organic debris aids restoration of soil habitat structure	use of soil with organic debris can aid infiltration	'best available' materials are often low TDS*
Loose and uncompacted	as above	aids recruitment	aids restoration of soil habitat structure	aids water infiltration	
Tree-compatible ground cover	enables survival of planted trees	aids recruitment of native plants		deep rooting by invading natives aids infiltration	protect against excessive erosion
Select native crop and nurse trees	establishes crop trees that are productive in favourable soils restores native trees	aids native plant recruitment	atracts wildlife	as above	

*TDS Total dissolved solids

state-of-the-art around the world. Reforestation in the Lusatia region of Germany has focused on the planting of pine and, more recently, oak. The trees are selected specifically to minimise forest fires, insect catastrophes and soil degradation. Around 60% of the post-mining area has undergone forest recultivation. Agro-forestry is a system for integrating reforestation with agricultural crops or livestock which can give more value to reclaimed land. For the first 20 years of a reforestation site, the tree growth can act as a carbon sink. These sites can also be used to produce crops for biomass energy (Krummelbein and others, 2012). Following extensive brown coal and lignite mining in the region, the landscape of Lusatia has changed significantly, as was shown in Figure 17 in Chapter 3. The amount of forestry has remaining similar, although the amount of different tree species will have changed. The Brandenburg Ministry for Food, Agriculture and Forestry established a State Forest Programme which determined targets for reforestation – 9% of the state forest areas were to be converted from coniferous to deciduous forest and another 35% from coniferous to mixed forest. In total, around 120,000 ha were assigned for forest reconstruction over the next 60 years. The main reason for the required adjustment in the types of trees was to reduce forest fires, and to avoid long-term damage to soils. The reclamation of mining land in this region therefore worked well to allow these changes in planting to be established in a co-ordinated manner through the 30,000 ha of dump sites in the region. Figure 25 shows the growth in the amount of forests which have been developed in the Lusatia region until now (data for 2009) and into the next few decades (Rosler and Preussner, 2009).

By the middle of the 21st century, the activities in the Rhenish mines in Germany will result in 1900 ha more forest than there was before. This is regarded as beneficial as these areas provide new habitats for animals and plants, retain water, bind CO_2 and benefit the climate. RWE energy use the principles of 'Naturalistic Silviculture' and select plants and trees accordingly to achieve certifiable status of the reforestation as a renewable resource (Logters, 2004).

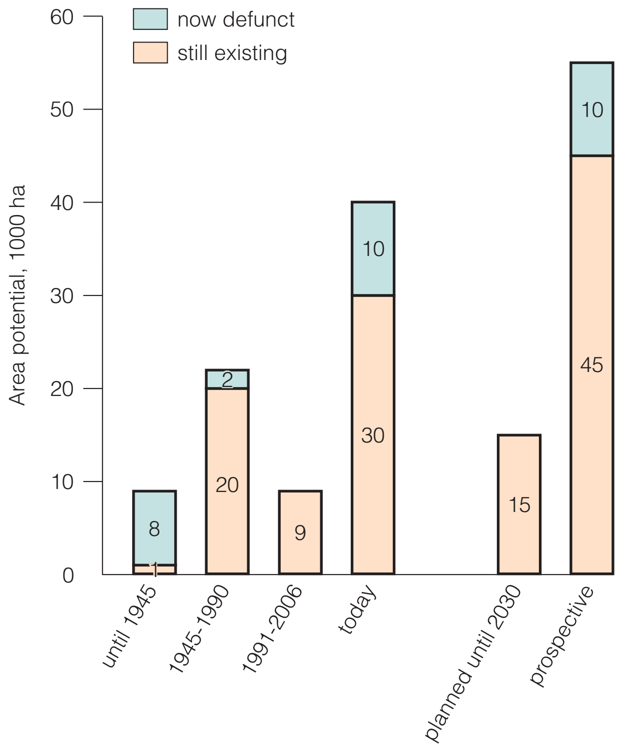

Figure 25 Potential for lignite mine dump recultivation as forest in Lusatia, Germany (Rosler and Preussner, 2009)

This report has emphasised that, left untreated, abandoned mines will lead to the land around them becoming contaminated with AMD so that many species do not return to grow where they had grown previously. However, studies in the Ostrava-Karviná region of the Czech Republic, where there has been significant deep coal mining in the past, have shown that, although the original species have not returned to the site, new biotypes have been found including 'very rare biota, animals in particular'. Changes in the region due to subsidence of undermined areas and the development of convex relief forms (waste heaps, spoil banks and other moved landmasses) mean that different plants and trees arise due to the new contours and wind/sun exposure patterns. Lacina and Koutecky (2005) suggest that the optimum way to recultivate mined land is an interconnection of two processes – first the spontaneous recovery or invasion of natural species which are clearly suited to the new landscape followed by regulated and cultivated planting and sowing of additional plants which also suit the new environs.

The balance between any spontaneous site recovery and organised planting and revegetation must be monitored. Reclamation plans commonly include requirements for site monitoring schedules. This will include continued monitoring until vegetation is successfully established – soil analysis for nutrients and pH and, where necessary, remedial treatment must be applied (NSE, 2009).

Wei and others (2009) report on the use of the normalised difference vegetation index (NDVI), vegetation fraction, soil brightness and vegetation greenness to determine the recovery of vegetation growth in the waste dump of the Haizhou opencast mine area in China. These indexes can be determine remotely using spatial and spectral data from satellite imaging data. Wei and others (2009) compared data for the site over the years from 1975 to 2000 and identified a progressive increase in vegetation over time. Of the parameters studied, the vegetation fraction was determined to be the optimal to depict vegetation condition and to monitor change.

5.3 Community

Mining activities can be significant within local communities. There are the positive effects of new work opportunities but also the potential for negative environmental and social impacts due to the arrival of a large industrial activity into a previously rural area. As with any industrial activity, coal mining includes minimum requirements for public safety during and following mining activities.

It is common in many developed countries for the local community to be involved in the planning process prior to any mining activity. For example, in the USA, Peru and Brazil, public hearings are held before any approval is given on environmental impact assessments. Public hearings are also law in Malaysia, Mongolia, Thailand and the Philippines. In Canada, the proponents of proposed new mining activities must bear the costs of panel reviews and mediations (Andrews-Speed and Xia, 2003).

In some regions or communities coal mining is automatically seen as ‘dirty and invasive’. For example, according to Milojcic (2011), lignite is denounced by the ‘green’ sector in Germany at the national level but accepted as a ‘neighbour and problem solver’ at the regional level. Milojcic discusses the importance of honesty and open dialogue between the mine operators and the local community to ensure that mining is accepted not only as acceptable but also as potentially beneficial to the region.

The siting of the Bergheim lignite mine in the Rhenish region of Germany was regarded by many as less than ideal but the requirement for fuel meant that the mine took priority over other considerations. During the late 1970s, the mine project commenced in the densely populated area. However, care was taken to minimise the long-term effects of this and other mines in the area. The original town had to be relocated and new flats were created nearby. The population actually increased significantly due to the increased demand for labour. The Bethlehem monastery, founded in 1648, had to be torn down to make way for the mine. However, following mine closure a new memorial site for the monastery was created. The major highway close by also had to be relocated. After closing the legacy of the mining activities did cause damage to local buildings and back-filling began in 1991. A contact point was established for those affected by the mining damage to deal with the issues promptly. The St Remigius church already had some problems with sinking and structural damage prior to the mine operation but this became worse. The entire church was fitted with a new supporting framework and the building declared safe by 1994. The reclamation of the mine site was carried out following consultation with the local community and, as a result, much of the land was prepared for future agricultural use rather than forestry (Gartner and others, 2010).

In China, the removal of residents and farms to make way for mining activities has lead to conflict between communities and mining companies in the past. These residents can either be moved to permanent new homes elsewhere or, following closure of the mine, can be returned to the original site where their homes are reconstructed. Bian and other (2010) mentions the requirement for specially built foundations on these new homes with anti-deformation measures to counteract any subsequent subsidence in the area.

The extensive lignite mining area in Lusatia, Germany, left significant amounts of land in need of recultivation and, following German reunification, the economics of reclaiming all this land was a significant challenge. In some areas, financial help was provided. For example, in the Jänschwalde area, a working group called Recultivation Heinersbrück was established which allowed the farmers co-operatives of Heinersbrück, Grießen and Forst to join forces and take over the recultivation services in the Jänschwalde/Cottbus-Norde mining area. This meant the creation of jobs and the stabilisation of the farming co-operatives, although the workers often had to use their own equipment. Once the lands were recultivated, they were awarded as partners in the project on a buy or lease basis. Declarations of interest for the ‘Awarding of future agricultural areas’ meant that the mine and farmers could work together for the best outcome for the land. The local Farmers’ Association worked with the co-operatives to determine the long-term future of the region (Wustenhagen and others, 2009).

It is becoming more and more common for the reclamation of a mine to not only return the site to pristine conditions, but also to take into account the wishes of the local community with respect to the final look of the site. Sklenicka and Molnarova (2010) have carried out a survey to determine the visual rating of post-mining landscapes. Local and non-local people in different age groups were asked to rank photographs of different reclaimed mine sites based on how ‘beautiful’ they were. The results indicated that the landscapes ranged from managed coniferous forest (highest), wild deciduous forest, managed deciduous forest, managed mixed forest and managed grassland (lowest). The older, more established habitats were generally preferred to the newer habitats. However, the ranking of the landscapes varied with the age of those involved in the survey and also with their background – where they grew up and the landscapes to which they were accustomed. The result of the study indicated that it is important to take into account the personal preferences of the local community when designing a post-mining landscape but suggests that there will always be the factor of personal preference to consider which means that some people will like the resulting landscape whereas others may not.

In the UK, the Land Restoration trust works with local communities to reclaim sites. This may include (LRT, 2012):

- taking land into trust ownership to allow management into perpetuity;
- acting as interim manager on sites until an economically viable end-use is identified;
- offering design services to ensure that ongoing management is cost-effective;
- involving landowners, the local community and other stakeholders in the development of appropriate maintenance plans and management regimes;
- acting as a facilitator of community engagement to ensure the ‘emotional’ ownership of open spaces;
- providing specialist advice and consulting services, pioneering best practice in the industry.

And so, in many respects, the ethos of mine reclamation is changing from simply remediating any damage to the environment to actually improving the area and leaving a legacy for future communities.

5.4 Conservation and diversity management

As with any major proposed change in land use, coal mines must comply with legislation relating to the conservation of species, especially endangered species or species at risk. In some cases, where endangered species are present at a proposed site, any relevant national Endangered Species Act may mean that the mine permit is refused or that specific requirements must be written into the permit to ensure the best action is taken under the circumstances. For example, in the USA, in order a mine proposal to be exempt from the Endangered Species Act, the regulatory authorities handling the SMCRA compliance must consider the following terms and conditions (Henry, 2000):

- species-specific protective measures must be developed in co-operation with the regulatory authority and the coal mine operator;
- whenever possible, the regulatory authority must quantify any detrimental effects – whenever a dead or impaired individual of a listed species is found, the local authorities must be notified.

The permit may also include a requirement for the implementation of conservation programs for the benefit of endangered and threatened species which should involve a recovery plan and requirements for monitoring and information collection.

One of the most common species affected by mining activities is bats. In many cases the mining activities can actually be seen as a benefit to the bat community rather than a threat. However, the conservation of the bats using abandoned mines relies on the appropriate management of abandoned mine sites. Abandoned mines serve as important year-round sanctuaries for bats. According to Ducummon (2000), many of North America’s largest remaining bat populations roost in mines, including more than half of the continent’s 45 bat species and some of the largest populations of endangered bats. Before closure, mines should therefore carry out a full survey to ensure that the site has not become a roost for bats. Because of their large appetite for insects (a single brown bat can catch more than 1200 mosquito-sized insects in an hour) bats play a very important role in pest control and local ecosystems. It is estimated that millions of bats have already been lost during abandoned mine safety closures or renewed mining in historic districts. According to Ducummon (2000) the cost of surveying and protecting key mine roosts is small compared to the benefits provided by bats.

Some ecosystems are well established yet fragile – containing endangered species or species not found elsewhere. Mining in these regions must respect the diversity and importance of these ecosystems and ensure that they remain undisturbed. Many forward thinking companies now have biodiversity management plans, which include policies and goals for the way their company will respect valuable ecosystems. Many will have goals such as ‘zero harm’. For example, the BHP Billiton Charter, Sustainable Development Policy involves minimising the footprint of mining operations and looking further than the area of mining itself to achieve high standards in biodiversity conservation management. The IndoMet Coal Project (ICP) is located in the Maruwai Basin in Borneo. The mining strategy includes active engagement with NGOs in several groundbreaking initiatives in the region (ICMM, 2010):

- conservation of the Bornean orangutan;
- sustainable land use planning;
- offsetting negative impacts of mining on biodiversity around the mine site.

Activities of the IMC project included the transfer and reintroduction of rescued and rehabilitated orangutans into the mined region, following reclamation, to replace the orangutan population which had been exterminated over 100 years previously. BHP Billiton have also been working with Fauna and Flora International (FFI) supporting the conservation of rainforest in the region (ICMM, 2010).

The International Council on Mining and Metals (ICMM) also works to promote sustainable mining and mine reclamation. The Cerrejón open-pit mine in northeast Colombia is large, covering 70,000 ha and producing 32 Mt/y of thermal coal. As mining proceeds, where necessary, wildlife is captured by the national environmental authority and released into similar habitats which have not been set aside for mining. Over the last five years, over 26,000 mammals, fish and reptiles have been rescued and relocated. The mine works closely with the local community and with experts in the field (The Nature Conservancy and the World Wildlife Fund) to establish initiatives and projects in the area. As part of this work, it was highlighted that the local sea turtle population was under threat. As a result, a five stage programme was established to monitor the species, to work with indigenous communities to raise awareness and to establish conservation agreements and programmes in the area (ICMM, 2010).

Rio Tinto, the global mining group, has made a commitment to biodiversity conservation and has a goal of 'net positive impact' (NPI). In 2007 the company carried out an assessment of all their holdings and surrounding areas to rank each according to the potential threats to conservation. For those sites ranked as 'very high' or high', biodiversity action plans will be developed in order to achieve the NPI target. Two separate areas have already been identified for action in the Bowen Basin and Hunter Valley in Australia (ICMM, 2010).

'Development by Design' is a new concept which aims to create science-based mitigation planning processes which balance the needs for planned development such as mining with those of nature conservation. The four step approach can be summarised as follows (ICMM, 2010):

1 develop a landscape conservation plan – this includes everything from spacial data on the area to considering climate change factors;
2 blend landscape planning with mitigation hierarchy – this involves determining when impacts should be avoided and when offsets are more appropriate (making changes that could be seen as improvements);
3 determine project impacts and identify portfolio of best offset opportunities – determine potential impacts on plants and animals and plan accordingly (relocation or reintroduction);
4 evaluate offset options in terms of their potential contribution to conservation goals and their cost effectiveness – evaluate to what extent the offsets will compensate for impacts and select the highest conservation value options with least cost and risk.

Several international organisations including Birdlife International and Conservation International have formed an alliance and created the Integrated Biodiversity Assessment Tool for Business (IBAT). This is an online system which provides centralised information on biodiversity. This information can be used to prioritise information gathering and assess risks in certain areas. The IBAT includes information on protected sites and key diversity areas allowing users to determine potential issues and concerns with a potential new site (ICMM, 2010).

5.5 Fixing past mistakes

Mining activities began in the Saxony region of Germany more than 660 years ago although the greatest activity was around 30–60 years ago. Many regions in the area became contaminated with AMD and trace element enrichment (Mn, Co, Ni, Zn, As and Cd) from untreated dumps. Willscher and others (2009a,b, 2010) studied several mine dumps in the region dating from the mid-1850s and later. Many of these had become part of the local landscape since they had been around for so long. The results of the comparison of the sites is shown in Table 9. The dump at Mine A, around 50 years old, had no topsoil applied and only birch trees planted at the time of closure. The site had signs of AMD and potentially for continued AMD due to trickling water penetration. The results indicated that the idea that sites such as this did not need topsoil and that natural topsoil development would be suitable for long-term stabilisation was incorrect. A second, similar site (Mine B), had also not been treated with topsoil but had subsequently become partially covered by a landfill site did not show such severe AMD issues, largely due to the reduced air and water into the dump. The third and oldest site (Mine C) had been treated with compacted loam and topsoil and trees and gardens had been planted and showed little or no sign of AMD with the pH being virtually neutral and the conductivity and sulphate concentrations being relatively low.

RecyCoal in the UK specialises in recovering usable coal from oil spoils and cleaning plants and returning closed mines to useful conditions. Examples include (RecyCoal, 2012):

- at the closed Barnburgh site, around 3.8 Mt of spoil was treated and the site restored over a period of three years. The site used discarded material from the coal recovery process to contour the land. The soil had been severely contaminated with arsenic, cyanide and polycyclic aromatic hydrocarbons (PAH) – some of this soil material was removed and disposed of and then the top metre of soil was treated and planted with grass and trees. The site has now been returned to public recreational use;
- the Langton Project in Derbyshire was the site of a spoil heap, as shown in Figure 26. A previous attempt at restoration had failed. Around 4.5 Mt spoil was excavated and washed to recover

Table 9 Comparison on different hard coal mining dump samples from the Zwickau region in Germany (Willscher and others, 2009b)

	Mine A	Mine B	Mine C
Dump operation period	1856-1954	1900-1977	1855-1933
Pyrite content, %	1.42–4.35	0.64–1.63	0.42–1.76
Total sulphur, %	1.71–4.07	0.83–2.09	0.36–0.97
Oxidation grade of S, %	12.8–57.7	30.7–58.3	3.1–11.72
pH	3.61–5.12	4.4–7.42	6.4–7.15
Eh (redox potential), mV	497–732	–254–533	104–355
Conductivity, mS/cm	0.96–9.91	0.96–11.79	0.856–3.23
SO_4^{2-},mg/L	641–8538	187–5490	226–1840
Cd, μ/L	180–1950	<0.2–390	<0.2–20
Ni, μ/L	270–7358	2.8–1200	4.4–210
Zn, μ/L	10–337	<0.02–26	<0.02–16
As, μ/L	<1–17	<1–1.3	<0.1–86
Seepage water rate, mm/y	237	100 (covered)	125 (natural)
		350 (uncovered)	25 (irrigation)

Figure 26 Former Langton Colliery Spoil Heap Coal Recovery and Reclamation Scheme
(Photograph courtesy of RecyCoal, 2012)

Figure 27 RecyCoal project to reclaim the spoil heap at the Hesley Wood site, Sheffield
(Photograph courtesy of RecyCoal, 2012)

445,000 t of coal. Once the site is cleaned, it will be transformed to woodland and scrub with new hedgerow, grassland, wetland and agricultural areas;

- the Thurcroft site in Rotherham saw the conversion of a former tip at the Thurcroft colliery into a new landfill facility. The surrounding area has been restored and, although not suited to ‘beneficial’ use, has been restored to a valid ecosystem with successful relocation of Great Crested Newts.

Table 10 Operational phases of reclamation at Hesley Wood spoil heap (RecyCoal, 2012)

Phase	Stage	Approx time period, months	Description
Site mobilisation	Site prep box cut, pond, prep	0–5	Preparatory site works Box cut A and B Creation of plant platform Plant mobilisation Creation of stockpile Hydro-seeding of stockpile Profiling to relocated pond and drainage feed
Coal extraction and washing	Cuts 1–5	0–13	Consecutive extraction cuts 1–5 with material sent for processing Unsuitable material (U/S) pile created to south of extraction area Processed coal sent off-site Pressed cake used as back-fill as extraction proceeds southwards Grading of back-filled material U/S pile graded/buried under regraded land Stockpile untouched
	Cuts 6–7	13–19	Consecutive cuts 6 and 7 with materials sent directly for processing Processed coal sent off-site Pressed cake used as back-fill as extraction proceeds southwards Grading of back-filled material Discard piles A and B created on restored grade Stockpile untouched
	Cuts 8–9	19–27	Consecutive cuts 8 and 9 with materials sent directly for processing Processed coal sent off-site Pressed cake used as back-fill as extraction proceeds southwards Grading of back-filled material Discard piles A and B extended on restored grade Stockpile untouched
	Feed stockpile and Cut 10	27–26	Discard pile A material to back-fill cuts 7–9 and box cut B Stockpile full worked with cut 10 Pressed cake used as back-fill Processed coal sent off-site Grading of back-filled material Discard piles B used to regrade water treatment area Site regraded prior to restoration
Restoration	Restoration	36–42	Removal of site plant/demobilisation Restoration of plant platform Importation of soil making material Creation of paths and drainage network Planting/biodiversity Ongoing maintenance of landscape works

Table 10 shows the planned operational phases of a new RecyCoal project to reclaim the spoil heap at the Hesley Wood site, near Chapeltown in Sheffield, as shown in Figure 27. The project, which will take three to four years, will involve cleaning of the spoil heap and the recovery of usable coal. This requires the removal, in stages, of a large number of 'cuts' through the spoil heap materials. Once the coal is recovered and the contaminated area remediated, usable materials will make up back-fill to level of the site. The final stages of the project will see the return of the soil to good condition along with the creation of paths and drainage. Then there will be tree planting and landscaping to return the site to a valid and attractive ecosystem with public access. The project will involve a staff of 35 (www.recycoal.com).

Figure 27 RecyCoal project to reclaim the spoil heap at the Hesley Wood site, Sheffield (Photograph courtesy of RecyCoal, 2012)

Figure 28 Northumberlandia (Photograph courtesy of Banks Group, 2012)

5.6 Above and beyond

In most cases, because of money and time constraints, mine reclamation projects will be completed as quickly and as cost-effectively as possible. However, in some cases the project managers have decided to go 'above and beyond' what is required for redevelopment of a site and have really worked towards making a statement. For example, in West Virginia, a previously ugly mining area was reclaimed by Stravaggi Industries to develop into the impressive Star Lake Ampitheatre (MII, 2012). Consol Energy

Figure 29 Aerial plan of the St Ninian's open cast project (Courtesy of Scottish Coal Ltd, 2012)

have won many awards and carried out numerous mine reclamation projects. Along with Mon-View LLC, they have converted 32.4 ha of the former Arkwright Mine in Granville, Monongalia County, WV, USA into a shopping complex.

Peabody Energy has completed Mongolia's first coal mine restoration project at the former Ereen Mine near Bulgan. The $1-million project transformed a 17.8 ha-site to productive pastureland for traditional livestock grazing. Peabody trained a local workforce to lead the initiative, which contributed significant economic benefits and jobs to local communities (Peabody, 2012).

Shotton surface mine in Northumberland, UK, demonstrates the concept of 'restoration first' where surplus soil and clay from the Shotton mine site have been used to developed a 19 ha public park. The park is built on an extra piece of land donated by the landowner, the Blagdon Estate, adjacent to the mine. The £3 million cost of the project has been privately funded by the Banks Group and the Blagdon Estate. The park includes the largest landscape sculpture of the human form in the world – 34 m high and 400 m long. The sculpture, designed by world renowned artist Charles Jencks, celebrates the earth's natural power and the human ability to reshape landscape into a dramatic form. Work on the site redevelopment began in 2010 and is now open to the public. Visitors can view the work and machinery at Shotton mine next door which is still operational. More details on the project can be found at: http://www.northumberlandia.com/. Figure 28 shows an aerial photograph of the site.

For several years the St Ninians opencast mine near the M90 motorway in Fife was regarded by some as an eyesore. However, the site is now the location for another Charles Jencks art project which is intended to reflect 'The Scottish World'. The ethos behind the project has been presented as part of the BBC report, which can be viewed here:
http://www.bbc.co.uk/scotland/landscapes/fife_earth_project/.

An aerial map of the site is shown in Figure 29 along with an artists impression of the final view in Figure 30. The design is meant to represent the ways in which Scots have travelled and made their mark on the world. The landscape includes pyramids, mounds and water features which represent an atlas, the ide being that you can 'walk the world in a day'. There are four large mounds to represent the four corners of the Earth where Scots have settled and the site includes a loch in the shape of Scotland. The site is expected to be completed and open to the public in spring 2013.

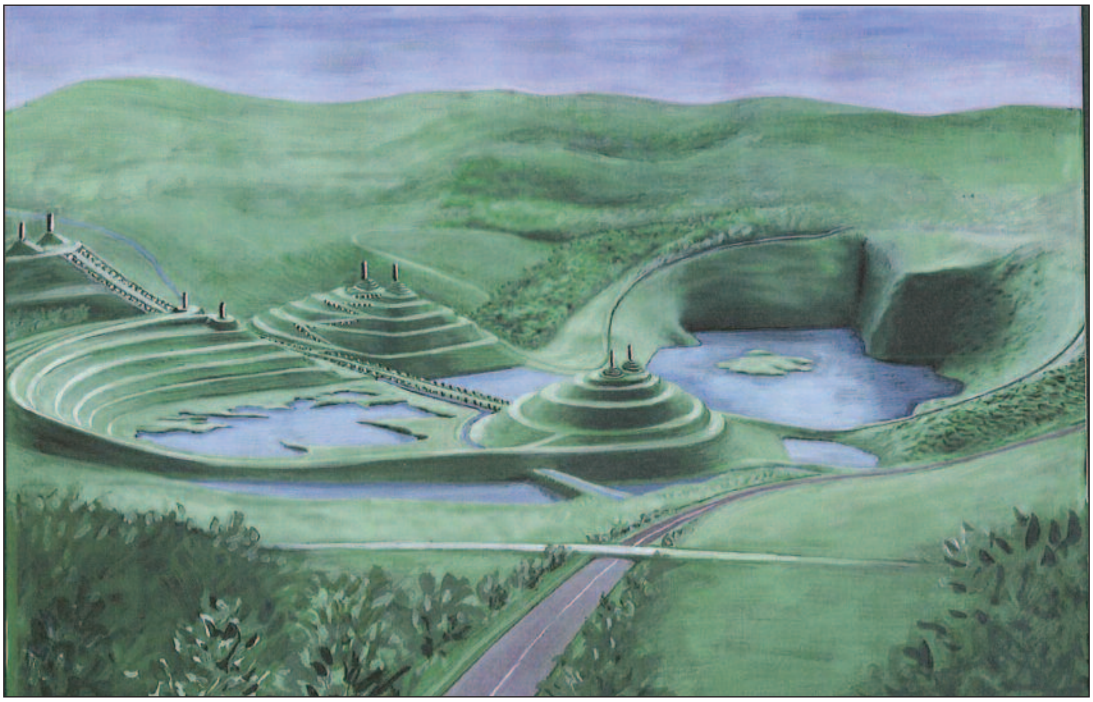

Figure 30 Artists image of the final St Ninian's site (Courtesy of Scottish Coal Ltd, 2012)

5.7 Comments

In recent years, in many areas of the world, the whole ethos of mine reclamation has moved from simply cleaning up the land and leaving it safe to moving towards making the site better than before and leaving a useful and valuable legacy for future generations. For this to be successful significant amounts of money must be spent and significant effort must be put into making sure that the entire site is left as a functioning and sustainable ecosystem. This will require working through soil management and appropriate vegetation and tree planting to encourage a successful combination which will continue to grow and develop.

In most cases, previously mined lands are turned over to agriculture of forestry, depending on the local community requirements and desires. However, successful projects have also created new recreational ground, shopping centres, theatres and even world-class land art forms.

6 Conclusions

In the past, the recovery of coal for energy took precedence over any consideration of the environment and many thousands of hectares of mined land were decimated and left with dangerous subsidence and severe acid drainage problems. Over time laws were developed, first to deal with abandoned mine safety and then to take action against further damage to landscapes and ecosystems. Today most developed countries have legislation which requires mine operators to produce a plan demonstrating how the site will look after closure even before the site has opened. In many cases, funding will not be granted or bonds must be set aside to ensure that the site is fully reclaimed as promised. Although this is leading to a new 'environmentally friendly' approach to mining, there are still many abandoned mines sites around the world that require reclamation. Funding bodies have been set up in countries such as the UK, Germany, Australia and the USA to recover these mines.

Most people can accept that it is not always possible to return a pre-mining landscape to how it once was. And in many cases, this is not the goal. The goal, however, should be to return the land to at least a safe and sustainable environment if not an actual valuable local commodity. If a mine plan is prepared with adequate forethought, the operation of the mine can be carried out in such a way as to limit the damage caused and the maximise the reuse of original features.

Perhaps the most emotive and visible damage which can be caused by mining is acid mine drainage (AMD). The release of sulphates and iron into water systems causes further leaching of other trace elements and the overall effect is the destruction of all living organisms within the area and severe discolouration of water courses. There are many techniques which have been developed to counteract this, including active treatment with neutralising chemicals and, over the longer term, passive treatments which take advantage of natural neutralising properties of indigneous rocks. Water management can be of particular importance in dry regions such as South Africa. However, well-planned water management systems can ensure the economic reuse of mine water or even provide cleaned mine water for use as potable water in local communities.

Restructuring land following mining is required for both safety and aesthetic reasons. Back-filling holds and hollows can be an important means to dispose of rocks and other coal waste materials whilst providing additional strength. Coal by-products such as FGD and FBC waste often have acid neutralising and/or self-cementitious properties which actually give them and advantage over other natural rock and back-fill materials for use at closed mines.

Returning vegetation and trees to mined sites is a balance between recovering the natural vegetation which is native to the region and the addition of new species which may be more suited to the newly modified landscape. The decision on the function of land following mining is a combination of decisions by the land owner, the local authorities and the local communities. In Germany the trend is to turn mining land to forest and lignite mines to lakes and water features. In China, where productive land is more important, agricultural uses are favoured.

In some situations closed and abandoned mines have not only been returned to active and productive land use but have been turned into recreational facilities, shopping centres, theatres and even works of art. By working closely with the communities involved, mining companies can change their old image of being industries who cause the destruction of local beauty, to being industries who bring both employment, wealth and new ecosystems to previously unappreciated areas.

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