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Environmental Regulation of Mine Waters in the European Union

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NATIONAL CASE STUDIES

4. Germany

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EXECUTIVE SUMMARY

Before the German reunification in 1990 two different political and economical systems exited in the western and eastern part of Germany. Whilst in the western part the mines were operated by mining companies, which had to make reasonable profits, the mines in the eastern part were state companies. There were in the most cases not produced on an economical level. Furthermore, due to the lack of money, understanding for environment, NGO's, and local action groups, only minor attention was drawn on environmental protection. Un-remediated abandoned mining sites and quarries may destroy the landscape and can, in particular, be ecological hazards if acid mine drainage exists.

For the last years the political priorities changed and they are focused on environmental protection and the reduction of un-remediated abandoned mines in the eastern part of Germany. In Germany the legal responsibility for remediation of closed down and abandoned mine sites is regulated in the German law (mining law). This is also applied for abandoned mining sites in the eastern part of Germany. Difficulties are determined that in many cases of abandoned mine sites in the eastern Bundesländer the former mine companies are disappeared after the collapse of the GDR. Therefore, the Federal Government has decided to found different state companies and organizations being responsible for the remediation of the abandoned mine sites in the eastern part of Germany (Uranium: Wismut GmbH; coal: Steuerungs- und Budgetausschuss für die Braunkohlensanierung (StuBA); others: Gesellschaft zur Verwahrung und Verwertung von stillgelegten Bergwerksbetrieben mbH (GVV)). In the western part of Germany, the remediation costs usually have to be covered by the mining companies, nevertheless, historical mining areas with potential environmental hazards still exist (e.g. Harz Mountains; Lahn-Dill-Area; Mechernich). Mine owners of current mines are obligated to minimize the negative impacts on the environment during mining activities and particularly after mine closure. The remediation costs have to be paid by the mine owners or mine companies in the western part of Germany, in contrast in East Germany the remediation costs are often covered by both, the mine company and by state.

All mine activities in Germany are regulated in the Federal Mining Law (BBergG vom 13. August 1980, zuletzt geändert durch Gesetz vom 26. Januar 1998). Also, the Federal Mining law regulates the closure procedures. The competent authorities are determined by the Bundesländer (Zuständigkeitsverordnung der Bundesländer, § 142 BBergG) which are responsible for distribution of permissions, approvals, limitations and prohibitions and perform the supervision of mining operations.

By mining a substantial contamination potential is often caused by the use of certain dangerous chemicals during mineral processing, and to oxidizing processes of exposing sulphide minerals. Release of these chemicals or reaction products can negatively affect ground or surface waters. The use of mine water, and demands on discharged mine water into rivers, brooks and sewers, are regulated in the German water legislation - the German water resources law (WHG vom 27. Juli 1957, neugefasst durch Bek. vom 12. November 1999, zuletzt geändert durch art. 18 G. vom 9. September 2001) and federal water resources laws (Landeswassergesetze). The competent authority is the local mining authority, advised by the water authorities. In order to reduce and avoid the impacts from the mining sites on the environment (e.g. acid mine water problems) a monitoring during the whole period of remediation and in some cases thereafter are implemented. If the acid mine water generation cannot be reduced, controlled or avoided by removal of sulphide minerals in waste rocks or exclusion of water and oxygen, then the mine water has to be treated and monitored on a long-term basis (end-of-pipe treatment). In Germany, in most cases active treatment (neutralization procedure) is applied, but there are already some research projects for passive treatment (e.g. constructed wetlands). The monitoring procedures are executed by the mining operator and are controlled by both, the environmental protection authority and the local mining authority.

PREFACE

Both, un-remediated abandoned mines and quarries proof, that have in the past the ecological standards did not reach today's demands. These mining sites may destroied the landscape and can, in particular, be ecological hazards if acid mine drainage exists. The focus of this report is to give an overview of mine water problems in Germany, the determination of the legal framework for mine waters and the evaluation of the level of technical control of mine water problems.

First, an overview of the mining sites in Germany is given and the existing mine water problems are described.

With the help of the stakeholder network and by literature reviews, a STEPS-analysis was compiled. The methodological approach has been broken down into a series of steps:

- social issues
- role of mining in national economy
- scope of regulatory structures of national (local) level and legal framework
- level of technical control of mine water problems
- Environmental impact and development in future

The implementation of the methodology has been demonstrated for two case studies.

D1 NATIONAL CASE STUDIES

4. GERMANY

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1 INTRODUCTION

1.1 Mining hydrogeology

Usually, the natural hydrogeological situation is strongly influenced by mining processes. The degree of the environmental influence depends on the specific characteristics of the mine site, the mine's depth as well as geographical and climatic conditions. Dewatering processes which are undertaken to enable mining in open pits and underground mines have a great influence on the groundwater. Thus, rivers, brooks, and wells may dry out in the surroundings of a mine as a consequence of dewatering.

The environmental compatible, technically safest and at the same time the most economical method to remediate underground mines consists of flooding by switching-off the drainage pumps (BMWi 2000b). After the closure of open pits, large areas will be flooded by river waters or by the rising groundwater table. In both cases, the original groundwater level will not necessarily be achieved again.

1.2 History of mining and mine water

Medium to large scale mining in what today is Germany already exists for more than 1000 years, but already in the Neolithic and during the Bronze age mining took place in Germany. The starts of the mining were in 10th century for example in the Harz mountains or in the Ruhr district. Its time of prosperity were in the middle ages (12th—14th century) and in the renaissance time (16th century; STEUER & ZIMMERMANN 1993). They were prospected for:

- iron metals (e.g. pyrite, iron ore)
- non-iron metals (e.g. lead, copper, zinc, tin, silver)
- industrial minerals (e.g. barite, fluorspar, salt)
- coal

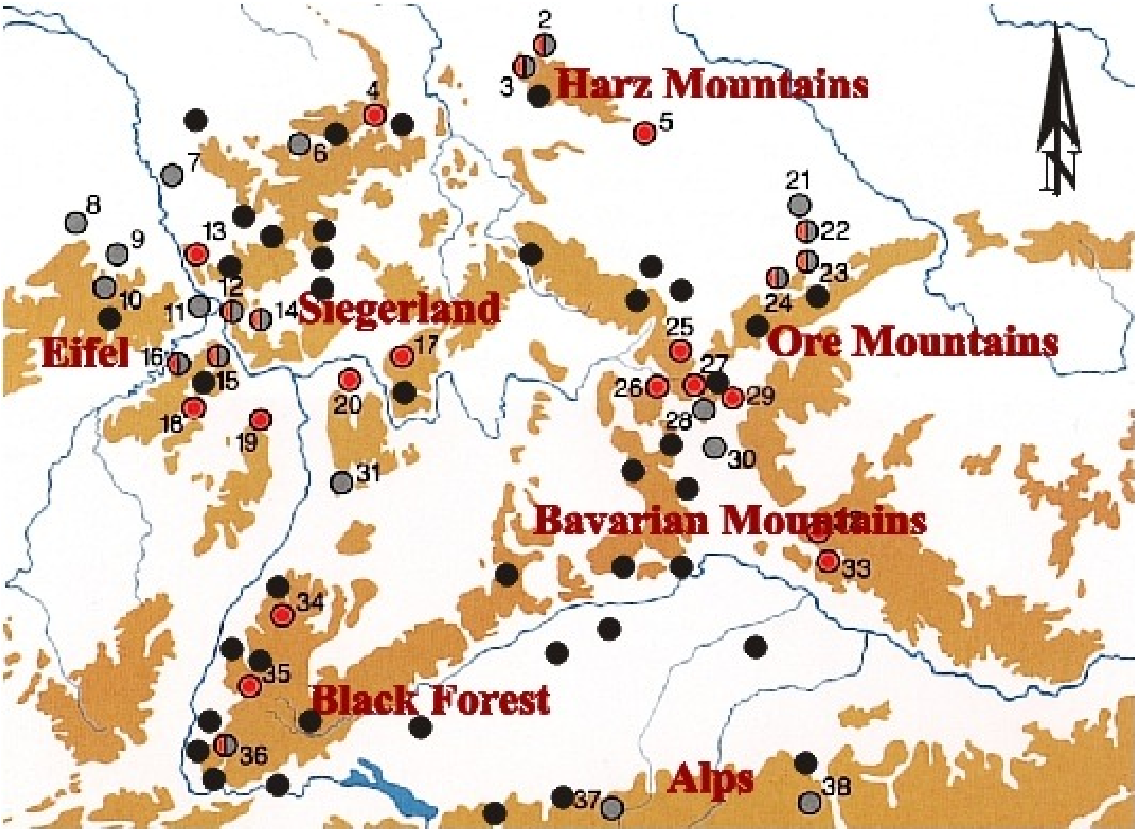

Fig. 1: Metal ore deposits in Germany (● Cu; ◐ Cu/Ag; ● Pb/Ag; ● Fe; STEUER & ZIMMERMANN 1993).

In Germany nearly all metal mines (e.g. iron, copper, tin, lead, zinc, silver) are closed, the majority of industrial-mineral mines (e.g. sand, gravel, stone, calcium carbonate, slate, clays, gypsum, salt, barite, shale) is still active. Among the closed sites, some have been rehabilitated and are now used as landfill sites for industrial (internal landfill) waste or for recreation purposes. In Fig. 1 well known German metal deposits are shown.

Mining and metallurgical engineering, in past and today, strongly influence the environment, depending on the intensity and duration of work. Each step of mining and processing can generate mining waste. This waste generally has different physical and chemical properties, resulting in different environmental impacts. The main types of mining wastes can be classified:

- waste rock
- tailings (processing waste)

Due to the mining operation, secondary minerals, and processing the water usually will be contaminated by heavy metals and is discharged into rivers and lakes. Furthermore, during the mineral processing large quantities of ores containing sulphide minerals are subject to oxidizing steps resulting in sulphur dioxide being released into the atmosphere. During the smelting process of non-iron metals (e.g. lead, copper, zinc, silver, mercury) considerable amounts of heavy metals are released into the atmosphere so that the soils around the processing sites are contaminated. Subsequently, the metals are leached out by surface water or rain.

With the exception of the recently closed open pit and underground mines, contaminated or acid mine water exists especially is occurring in the historical metal ore sector in Germany.

2 GENERAL CLASSIFICATION OF MINE WATER PROBLEMS

The water cycle includes all natural waters released from a mine site including discharge, process water, tailing's water, as well as seepage from impoundment and into the ground (Fig. 2).

Water pollution may occur at different stages in the active mining cycle (e.g. mineral processing operations, dewatering process) and during processes, which are connected to mine closure. Over and above, rain and process water leaches pollutants when seeping through waste rock piles, tailings dams, waste dumps, and flooded voids, giving rise to (Bureau de recherches géologiques et minières 2000):

- sulphide oxidation and potential acid generation
- sulphide oxidation and production of soluble salts
- metal leaching and migration to the surrounding environment
- leaching of residual process chemicals in the tailings, e.g. cyanide, acids, alkalis
- toxic substances of the waste materials

These processes can also result from seepage through the subsoil that is surrounding historical mining sites. In Germany, as in most other countries, four main types of mine water exist (BMWi 2000b):

- flooding water: Groundwater that is used for the flooding of an open pit/ underground mine or discharging after the flooding of the open pit/underground mine
- free or pore water: processing water that is accumulated together with precipitation in tailings ponds
- leakage water: surface water that infiltrates into waste dumps as well as waste rock piles and leaks out at the bottom of waste dumps, waste rock piles or within the open voids of working mines
- geogenic water: groundwater from deeper aquifers, that are typical for hard coal mining

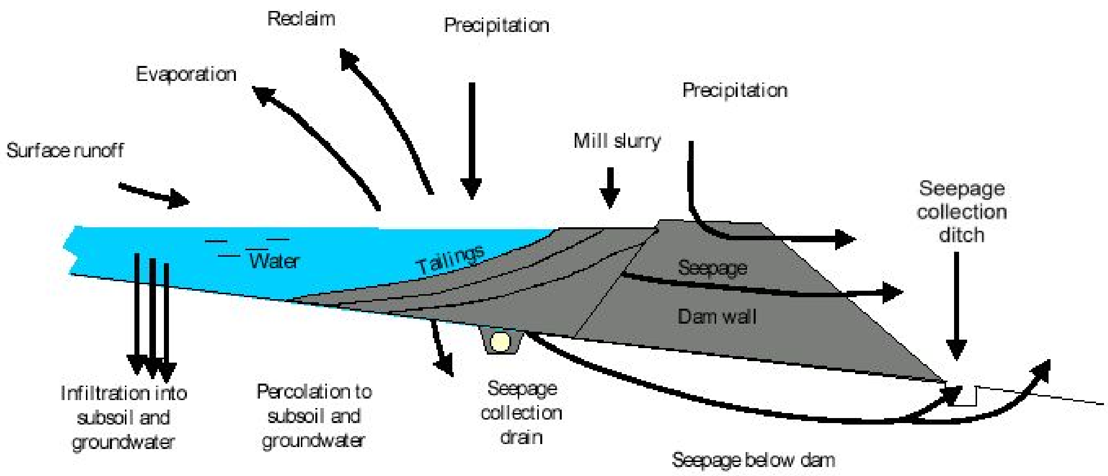

Fig. 2: Scheme from Environmental Management of sites (Bureau de recherches géologiques et minières 2000).

Acid mine drainage (AMD) is produced by natural processes that occur in underground mines, open pits, waste rock piles, waste dumps, and tailings ponds. When large quantities of sulphide minerals in rocks, mainly pyrite, are exposed to air and water the content of acid, sulphate, iron and other metals in the water is increased. Pyrite reacts with water and oxygen to create sulphuric acid. Some certain types of bacteria usually (*Thiobacillus ferrooxidans*) catalyse the reaction and accelerate the oxidation and acidification processes. The leaching of the trace metals from the waste rock persists as long as the rocks are exposed to water and air and until the sulphides are leached out. This acid mine water is carried off the mine site by rainwater or surface drainage and discharged into rivers, lakes, and the groundwater. The high content on metals and acid may result in a serious damage of the aquatic environment (HELMS 1995).

Heavy Metal Leaching also is a natural process that occurs particularly in abandoned metal mines or where metals are abundant in non metal mines. Heavy metal pollution is caused by metals such as arsenic, cobalt, cadmium, lead, or zinc contained in rocks that come into contact with water. Metal-ions are mobile in natural pH conditions (SIGG & STUMM 1994), but, with some exceptions, their mobility raises under extreme pH conditions (HELMS 1995). The metals can migrate to the surrounding environment.

Pollution of **Processing Chemicals,** if used at all, occurs when chemical agents (such as cyanide or sulphuric acid) spill, leak, or leach from the mine site into nearby water bodies. Mine tailings often contain the same **geochemistry and ecotoxic metals** like the source rock.

3 ANALYSIS OF MINE WATER PROBLEMS

3.1 Social

The mining industry might be risky to the health and security of the people living in the vicinity of mine operation sites, if no suitable measures are seized to decrease the emissions into water and air or in the avoidance of accidents (Kommission der Europäischen Gemeinschaften 2000). Especially the population living downstream mining sites has to be protected against all possible negative impacts e.g. against contaminated water. From the social perspective some important aspects must be considered e.g. in some regions the mining industry and their supplying industries are the only industries giving employment to the local population. An operating mine has a limited life-time. Therefore, before the beginning of the mining, plans have to be made, how negative social and economic effects can be lessened after mine closure to minimize the population's migration after the shut down of the mining operations. After the closure of an underground mine or an open pit the used areas are redeveloped and shaped. This is particularly important at lignite open pits with large areas. In numerous areas of abandoned mining landscapes the pit lakes are attractive recreation areas for the population (BMU 2001).

Tab. 1: Overview of the energy sector (BMWi 2000a).

	1991	1992	1993	1994	1995	1996*	1997*	1998*	1999
					employment (1,000)				
hard coal mining	122.9	115.0	106.3	99.1	92.6	85.2	78.1	71.8	66.4
lignite mining	97.2	73.4	53.7	45.7	40.3	32.7	29.5	26.2	23.5
thermal power		18.4	23.4	12.7	17.2	11.4			
oil sector	37.1	31.1	29.8	27.9	23.2	21.2	19.9		
natural gas	36.9	37.9	35.4	35.2	33.6	33.5	32.8		
electricity	292.8	284.4	249.8	243.2	237.1	229.0	224.1		
Source: Statistische Bundesamt; Statistik der Kohlenwirtschaft									
					coal production (million t)				
hard coal	66.5	65.9	58.3	52.4	53.6	48.2	46.8	41.7	39.2
lignite	279.4	241.8	221.8	207.1	192.8	187.2	177.2	166.0	161.3
Source: Statistik der Kohlenwirtschaft eV; Essen und Köln									
					Investments (million DM)				
hard coal mining	950	786	582	341	565	511	416	374	
lignite mining	1,606	1,454	1,673	1,382	1,242	864	669	828	
Source: Statistische Bundesamt; Statistik der Kohlenwirtschaft									
					production turnover (million DM)				
hard coal mining	20,112	19,034	17,740	18,082	16,874	15,726	14,280	12,652	
lignite mining	11,894	9,266	8,543	7,607	7,440	6,909	6,095	5,419	
Thermal power		5,323	9,141	5,610	7,633	6,210			
oil sector	109,316	104,992	105,188	107,996	94,337	118,433	130,189		
Natural gas	42,892	41,856	42,881	40,496	42,504	48,884			
electricity	150,687	151,794	151,611	156,278	160,276	163,480			

Source: Statistische Bundesamt; Statistik der Kohlenwirtschaft; * non absolute values

3.2 Economic

During the past years the economic development in Germany slowed down, although the economy further grows (BMWi 2001). Reasons are the world-wide decline in economic activity, the after-effects of the energy price raising and the mine closures; particularly in the coal sector. Nothing can be said about the long-term development after the 2001 September 11th terror attacks in the US. Tab. 1 shows a recognizable decrease of the employees in the hard coal sector reaching 54 % and in the lignite sector around 24 %.

By subsiding difficulties in selected sectors of economy are minimized and are desired by politicians at federal, regional, or local level (Tab. 2). In the years 1997—1999 the eastern part of Germany received annual financial aids of 6.9 billion EUR. This volume corresponds to 70 % of the entire German financial aids (Kommission der Europäischen Gemeinschaften 2001).

Coal still remains the only important German primary energy source; only minor oil and gas reserves exist. Nevertheless, in the period between 1985 and 1999 financial aids to hard coal continuously diminished. Although the German mining technique is said to be one of the best in the world, the costs of hard coal production are higher than for imported coal because the geological conditions are very difficult. Without financial aids nearly the whole coal industry would immediately have to be closed (Kommission der Europäischen Gemeinschaften 2001; paragraph 143, page 76). Since 1990 a decline in subsidy for hard coal mining can be registered. In 1999 the subsidence for hard coal mining was about 20 % of the total volume (Tab. 3). Lignite ("brown coal", "soft coal") can be produced on competitive conditions in the open mine pits because favourable geological conditions exist.

Tab. 2: Average volume in Germany – Divided into main fields 1995—1997 and 1997—1999 (in %, Kommission der Europäischen Gemeinschaften 2001).

Period	1995—1997	1997—1999
agriculture and fishing industry	7	6
trade	41	37
coal mining	**16**	**18**
traffic industry	35	37
Service sector	1	1
Employment and education		1
average volume per year (Mio EUR)	32.228	26.716

The political priorities also changed and they are now focused on environmental protection and the reduction of unemployment (Kommission der Europäischen Gemeinschaften 2001). Mine owners are obligated to minimize the negative impacts on the environment during mining activities and particularly after mine closure. Financial support for the remediation of mine sites by the federal state differs largely in Germany. Whereas in the western part the remediation costs for current mines have to be paid by the mine owner or mine company all alone, in the eastern part the remediation costs are often covered by both, the mine company and by the state. The legal competence for the remediation of abandoned mining sites is often unclear due to insufficient legislation or due to the difficulties to determine the responsible persons (Kommission der Europäischen Gemeinschaften 2000a). Therefore, in the eastern part the remediation costs for abandoned mines are paid by StuBA, GVV, or the Wismut GmbH (mine owner), which are state companies or trust administrations. In the western part, abandoned mining sites that are dismissed from the control of the mining authorities, are usually not remediated (e.g. Burgfey, Holzappel), though exceptions exist for Uranium mine sites (e.g. Schirmberg, Höhenstein, Wäldel, Nabburg, Rudolphstein, Großschloppen, Menzenschwand).

Tab. 3: Total volume for subsidy in the period of 1995—1999 in Germany (in Million EUR; Kommission der Europäischen Gemeinschaften 2001)

main field	1995	1996	1997	1998	1999
agriculture	2,622.3	2,220.9	1,827.2	1,589.0	1,575.3
fishing industry	17.0	15.2	11.3	23.2	23.0
research and development	1,177.8	1,299.7	1,206.0	1,259.5	1,239.2
environment	165.2	137.4	129.3	142.0	114.2
commerce	1,536.7	1,435.4	1,414.6	1,327.7	1,061.2
reduce to unemployment	54.7	99.9	78.0	184.6	182.6
educational grant	92.9	64.7	47.9	31.7	35.3
steel industry	79.8	4.9	2.1	0.0	0.0
shipbuilding	902.1	381.3	429.7	286.3	192.0
coal industry	**4,794.5**	**5,405.5**	**5,378.8**	**4,787.4**	**4,534.9**
traffic industry	13,042.1	10,823.6	10,139.2	10,278.0	9,521.7
others	2,210.8	2,000.8	1,941.7	1,811.1	1,534.4
regional level	10,348.5	9,609.3	7,891.4	7,106.9	4,598.3
Total volume	35,519.4	32,073.9	29,089.3	27,503.1	23,554.6

3.3 Political

Mining wastes (underground mines, open pits) and wastes of quarries, though sometimes usable as recyclable or backfill material, are the largest waste streams in the community (Kommission der Europäischen Gemeinschaften 2000b). In the Germany mining waste is regulated by the mining law. Some of the waste (e.g. extraction of industrial material or processing of ores and industrial material) contains large quantities of dangerous materials, for example heavy metals, which may cause a huge environmental impact. Mining exposes these metals to the earth's surface were chemical reactions give raise to the metals' mobilization. Therefore, monitoring procedures and environment protection is of great importance.

Yet, no European regulation exists that applies to waste from mining operations and especially to closed mines and closure procedures (Bureau de recherches géologiques et minières 2000), but since the Baia Mare/Romania and Aznalcóllar/Spain accidents actions are undertaken by the European Commission, to regulate tailings dams and mining wastes. Each of the member states has its own mining and environmental legislation which more or less completely and sometimes separately covers the different branches of activities mentioned above (Bureau de recherches géologiques et minières 2000).

The groups and authorities involved in decisions concerning mining can be seen in Fig. 4 and Fig. 6.

All mine activities in Germany are regulated in the Federal Mining Law (BBergG 1990). For the establishment and management of a mine site a mine management plan, an operation plan and special operation plans (§ 52 Art. 2) are submitted to the mining authority prior to start of mining (§ 51, Art.1). Also, the Federal Mining law regulates the closure procedures (§ 53 Art. 1). The competent mining authority is the local mining authority of each German state ("Bundesland"; BergbhZV 1999) which is competent for distribution of permissions, approvals, limitations and prohibitions and performs the supervision of mining operations (§ 69 Art. 1).

Generally, mining sites with an area of 25 ha and larger are covered by the directive 85/337/EWG "Umweltverträglichkeitsprüfung bei bestimmten öffentlichen und privaten Projekten" (UVP; "Environmental Impact Assessment Mining"). For smaller mining sites the relevant authority checks the impacts on the environment by a simplified authorisation procedure.

Mining implies a substantial contamination potential due to the use of certain dangerous chemicals during mineral processing, but also because minerals that had been under reducing conditions under the earth's surface are exposed to oxidizing conditions. Release of these chemicals or reaction products can negatively affect ground or surface waters. If such a pollution is detected the competent authority permits or prohibits the discharge of contaminated waters. This procedure guaranties an effective reduction of pollution (Dangerous Substances Directive 76/464/ECC and daughter directives).

To regulate the use of mine water, the German water resources law ("Wasserhaushaltsgesetz", WHG) has to be used. This law contains demands for discharging off used water into rivers, brooks and sewers (§ 7a Art. 1) and provides the provisions concerning the licensing and emissions of some industrial installations (§ 7a Art. 5), thus, environmental pollutions can be avoided and reduced. The competent authority is the local mining authority with the help of the water authorities.

With the introduction of the European Water Framework Directive (2000/60/EC) the following Directives are removed:

- Dangerous Substances Directive (76/464/EEC) and its daughter directives
- Surface Water Directive (75/440//EEC)
- Groundwater Directive (80/68/EEC)
- Freshwater Fish Directive (78/659/EEC)

The Directive will have to be transferred to German law by modifications in the water resources law (WHG) and in the national water laws as well as by means of regulations.

3.4 Technical

In most parts of Germany water is a nearly inexhaustible resource. Water serves not only as drinking water for human beings, but is also the essential basis for all life and economic development. Despite the fact that drastic and conspicuous effects to surface waters, such as fish kills, as a result of measures taken over the past thirty years, is hardly evident today, the results in many areas are still unsatisfactory (Federal Environmental Agency 2000). Two sources of pollution exist: point source and non-point source. A typical example of non-point source pollution would be a mine site in its whole, whereas different point-source pollutions might be recognized at the site. The two phases of these potential pollution sources are: solid and liquid (Bureau de recherches géologiques et minières 2000).

In order to control or eliminate acid mine water problems, the impacts from the mining sites on the environment are monitored. To protect engineered buildings and the environment (soil, air and water) against negative impacts, it is essential, that these environmental monitoring facilities are controlled and supervised on a regular basis. The monitoring is necessary throughout the whole period of remediation and in some cases thereafter (BMWi 2000b). Systematic monitoring of surface water and groundwater quality and quantity will be done in several categories:

- base monitoring (during production)
- monitoring during the remediation
- long-term monitoring

In the base monitoring only the most important surveillance parameters are measured at predefined measuring points according to the state of technique and independently of the future remediation activity. Furthermore, the base monitoring is intended to be the basis for the long-term monitoring. The monitoring during the remediation process is restricted to this period of the mining cycle only. It complements the base monitoring in this period of time.

In Germany the monitoring procedures are executed by the mining operator and are controlled by both, the environmental protection authority and the local mining authority.

The acid water creation can be controlled, avoided, or reduced through the following methods (HELMS 1995):

- removal of the sulphides
- exclusion of the water
- exclusion of the oxygen
- control of the pH value
- control of the bacteria activity

Waste rocks with a potential amount of reactive sulphides might be treated in the way of removing the sulphides by flotation processes. By covering and sealing waste dumps and waste rock piles the contact with water and oxygen is excluded. Another effective method for the delimitation of the oxygen contact is the flooding of open pits, underground mines and tailings ponds. All acid-forming minerals must be under the water surface. A neutral or alkaline pH value of drain water can be achieved by adding buffering material.

In the case, acid mine water generation cannot be reduced or eliminated, the mine water is to be treated and monitored on a long-term basis (end-of-pipe treatment). Procedures for mine water treatment are:

- active treatment: neutralization procedure
- passive treatment: e.g. constructed wetlands

The basic principles of the neutralization procedure for acid mine water are the raising of the pH value, the precipitation of iron and aluminium, or the decreasing oft sulphate-, magnesium-, manganese contents in a technical water treatment system (conventional method). Water treatment will be necessary in several mining sites for many years, consequently conventional methods will not be efficient economically. Possible alternative methods are constructed wetlands at less expenditure for operation and maintenance or reactive barriers. In Germany, in most cases of ore mine sites technical water treatment systems for mine waters are applied to, but there are already some research projects for constructed wetlands (e.g. Pöhla, Lehesten, Peitzdorf, Straßberg/Harz).

3.5 Sustainability

New mining operations in Europe have to take into account the sustainability principle. This implies, that the natural resources water, air and soil have to be protected wherever possible and techniques to be used that use as less natural resources as possible. While this is true for the time of the mine’s operation, it must also be considered for the remediation or cleanup processes. The ecological principles for mining aim to give back intensively used industrial sites to nature or for the use by other industries, recreation or housing. With an optimised mine closure and the following remediation of mining sites, toxic emissions and contamination can be reduced and even avoided concerning the protection goods water, air and soil.

One of the focuses during and after mine operation is the protection and improvement of the status quo of aquatic ecological systems and the groundwater. These aims can be achieved and controlled on the basis of a monitoring program only. First the impacts of human activities (mining) on aquatic ecological systems and the groundwater are evaluated and the status quo of the water parameters is recorded. Therefore, in Germany, before any mining operation or remediation plans are realized, a one year ecological study has to be conducted. Finally, based on these results, a monitoring program is determined.

The landscape design of past mining sites is of socio-economic importance. In the future these areas can be used for agriculture and forestry, for protected areas, for industrial settlements or for recreation area (open pit lakes, skiing centres) of the population. Thus in former mining regions new jobs, which were lost after the mines’ closures are formed again.

In order to achieve these aims, the Federal Government of Germany must go ahead with financially supporting the remediation of ore mining sites.

4 EXAMPLES

4.1 Introduction

Before the German reunification in 1990 two different political and economical systems exited in the western and eastern part of Germany. Whilst in the western part the mines were operated by mining companies, which had to make reasonable profits, the mines in the eastern part were state companies. Ores and coal in the eastern part of Germany were in most cases not produced on an economically sensefull level, but due to the communists' focus on self-sufficiency ("autarchy") this fact was only of secondary importance. Furthermore, due to the lack of money, NGO's, local action groups, and a strict secret policy, only minor attention was drawn on environmental protection. Therefore, the Federal Government has decided to found different state companies and organizations being responsible for the remediation of the abandoned mine sites in the eastern part of Germany (Uranium: Wismut GmbH; coal: Steuerungs- und Budgetausschuss für die Braunkohlensanierung (StuBA); others: Gesellschaft zur Verwahrung und Verwertung von stillgelegten Bergwerksbetrieben mbH (GVV)). In the western part of Germany, the remediation costs usually have to be covered by the mining companies itself (e.g. Rammelsberg/Goslar; Meggen), nevertheless, historical mining areas with potential environmental hazards still exist (e.g. Harz Mountains; Lahn-Dill-Area; Mechernich).

Both case studies are from the eastern part of Germany, because the focus of this work is on "recently incorporated states" of the European Union. Nevertheless, the procedures described hereafter also apply to in the western part of Germany. It should be mentioned here, that every mining site has its own characteristics. Therefore, up-scaling of the two case studies is not possible in all aspects.

4.2 Fluorspar mine Straßberg/Harz mountain

4.2.1 Overview

The fluorspar mine Straßberg is located in the eastern Harz mountains and is divided into three mining districts, that are connected by underground adits (from north to south):

- Brachmannsberg
- Straßberg (Biwender)
- Glasebach

The surrounding area of the mine consists predominantly of Lower Devonian rocks. In the northern part Lower carbonian rocks outcrop. They are partly influenced by metamorphism of the Ramberg plutone (290 ± 10 million years). The minerals produced were galena, sphalerite, pyrite, arsenopyrite, fluorspar, and barite.

There is a fissures aquifer with a permeability of about $k_f = 10^{-6}$ m · s^{-1}. The groundwater circulations through fissures, faults, karstic features, and galleries (Wolkersdorfer & Hasche 2001). Due to the many decades of mining the natural hydrologic situation in the groundwater was impacted substantially.

In the first half of 18th century the fluorspar mine Straßberg had have its first high mining phase (silver, lead and copper ore). The second high mining phase began in 1850 (fluorspar, barite) and the mine closure was in 1990.

Mine flooding is seen to be the most economical method for redevelop of underground mines. Consequently the environmental impacts are limited but pollutions are carried off the mine site by rainwater or drainage water and deposited into rivers, lakes and the groundwater.

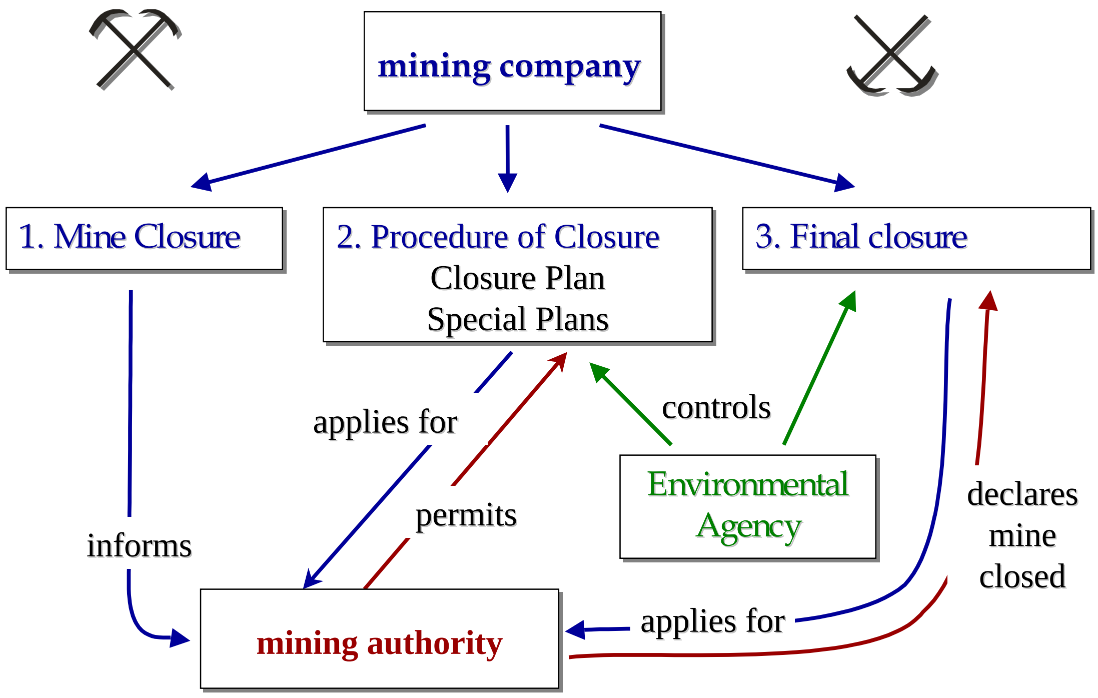

Fig. 3: Scheme for mine closure procedure.

4.2.2 Social and economic

From 1990 to 2001 the number of workers in the Straßberg fluorspar mine was reduced from 560 to 25. Today the miners are remediating the flooded mine.

Since 1945 the annual fluorspar production decreases continuously (Tab. 4). The reason is that the costs of mineral production and extraction in Germany were higher than in other countries were geological conditions are simpler and workers cheaper. During the mining operation the surrounding area of the mine was strongly influenced. Due to processing water heavy metal contaminants are deposited in adjacent rivers and lakes.

4.2.3 Political

All mining activities are regulated in the Federal Mining Law (BBergG 1980). For the establishment and management of a mine site a framework of operation plans and special operation plans is submitted to the mining authority beforehand the start of mining (Fig. 4). The Federal Mining law also applies to closed mines and closure procedures (Fig. 3). In every case the local mining authority (BergbhZV 1999) is responsible for distribution of permissions, approvals, limitations and prohibitions and performs the supervision of all mining operations.

The local mining authority is also the competent authority for questions concerning water. It permits water discharges, including quantity and quality of the discharge, fixes emission limits

Tab. 4: Fluorspar quantities extracted in the Straßberg/Harz mine.

mine	time	Fluorspar, t	Conc. CaF_2, %
Straßberg	until 1945	658,000	77.5
	since 1945	593,000	70.0
Brachmannsberg	since 1945	179,000	62.0
Glasebach	until 1945	23,000	65.0
	since 1945	253,000	66.0
total		1,706,000	

for mine water based on the water law and advised by the water authorities (Fig. 3).

4.2.4 Technical and sustainability

The characteristic of the Straßberg mine water is due to acid mine water drainage and heavy metal leaching, which seems to be well buffered by carbonates and backfilled sludge of the treatment plant. After the mine closure large quantities of sulphide minerals are exposed at the open rock surfaces (e.g. pyrite, galena, sphalerite). Oxygen and water react with these minerals to produce secondary minerals that are easily soluble in the rising water. Due to the pyrite weathering, sulphuric acid is produced, which results in acid mine water and leaches more trace metals from the rocks. The acid mine water and heavy metals are then drained into the ground-water and are carried off the mine by rainwater or surface drainage into rivers, brooks, and lakes.

Still, the Straßberg mine water contains high amounts of iron and non iron metals (Tab. 5). Therefore, the mine water is treated before its discharge into rivers. In Straßberg a conventional method for water treatment is used. The bi-weekly monitoring at pre-defined sampling points is carried out by the mine operator itself and by the environmental agency. Currently, iron, manganese, pH and the flow rate are analysed. A regular but unannounced monitoring is practised by the environmental agency. Based on the actual data, the water treatment will be necessary for 1—2 decades together with the remediation of the mine site. To reduce the water treatment costs, a passive treatment plant will be constructed the next year.

Tab. 5: Mean values of main hydrogeochemical parameters of the mine water.

parameter	value	unit
pH	6.5—6.9	1
Fe	18—23	mg/L
Mn	1.2	mg/L
SO_4^{2-}	≈ 400	mg/L
Co	≈ 115	µg/L
Ni	125—130	µg/L
Zn	600—680	µg/L

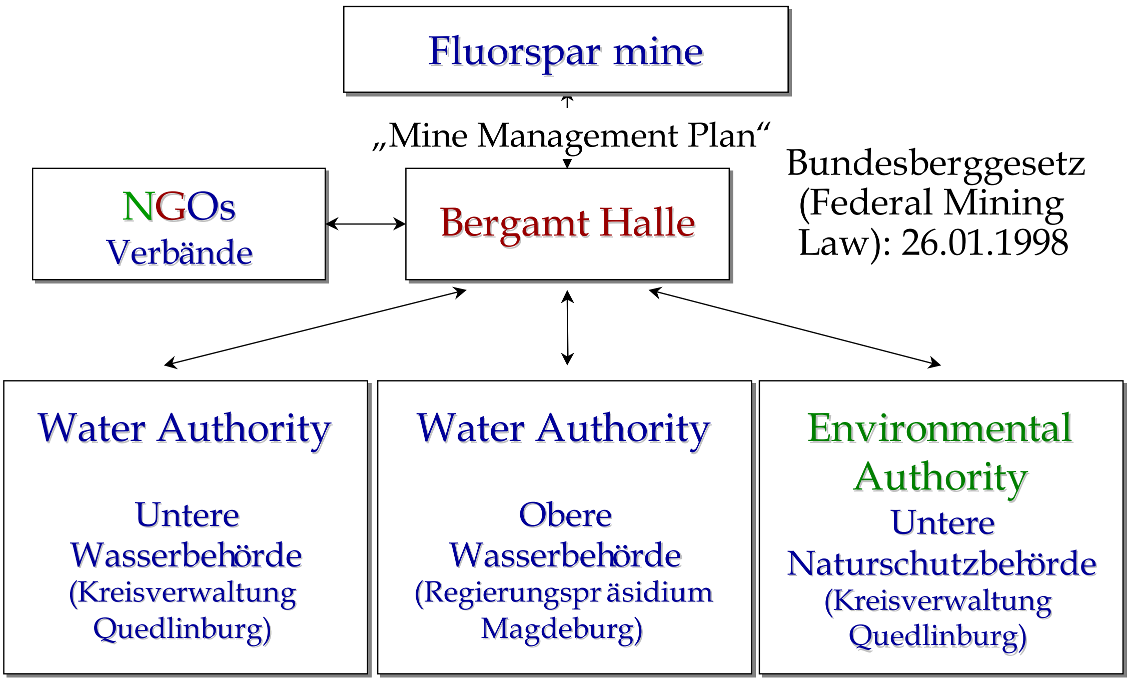

Fig. 4: Scheme for the regulation of the Straßberg/Harz mine.

4.3 United Schleenhain mine / Middle Germany

4.3.1 Overview

The open pit „Tagebau Vereinigtes Schleenhain“ is located in the Freistaat Sachsen in Middle Germany, covers an mine area of about 19.2 km^2, and is divided into three mining fields divided by the river Schnauder (Fig. 5). In the southern part of the mine the pit’s depth is 100 m. According to the Saxonian Brown Coal Plan production will be ceased in. Off the resources of 407 million tonnes of lignite 10 million tonnes are produced per year. The three mining fields are part of the geological structure of the Weißelster basin of which the basis consists of Pre-Tertiary and Zechstein rocks and sediments. Within these Tertiary sediments four brown coal seams with an average thickness of 5…12 m were deposited. The hydrogeological situation is as complicated as the geological one with six porous aquifers existing (k_f: 10^{-3}...10^{-4} m/s) and being connected to each other horizontally and vertically. The flow direction is to the east at both, the Groitzscher Dreieck and Peres mining fields and to the west at the Schleenhain mining field. Mainly, the receiving streams at this area are the Weiße Elster in the west and the river Pleiße in the east of the open pit. In 1949 mining started and since 1990 the mine owner is the MIBRAG (“Mitteldeutsche Braunkohle AG”: middle German lignite stock company). From 1995 to 1996 the mine was closed for modernization works.

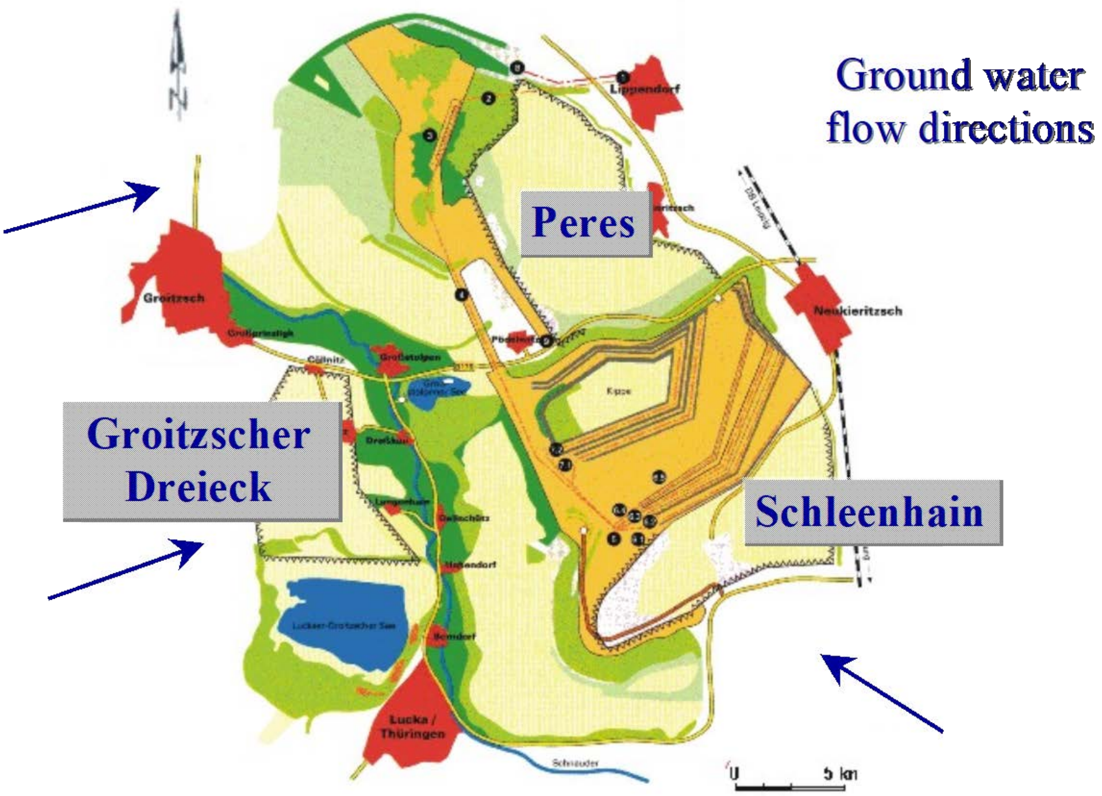

Fig. 5: Tagebau Vereinigtes Schleenhain (SPEKTRUM MIBRAG 1999)

4.3.2 Social and economic

Although coal for Germany still remains the only import domestic energy source the number of open pits reduced gradually since 1989. Thus, also the number of workers has been reduced in this area (Tab. 6). Lignite can be produced on competitive conditions in the open pit mines because the geological conditions in Germany are favourable. Thus, the production of lignite is

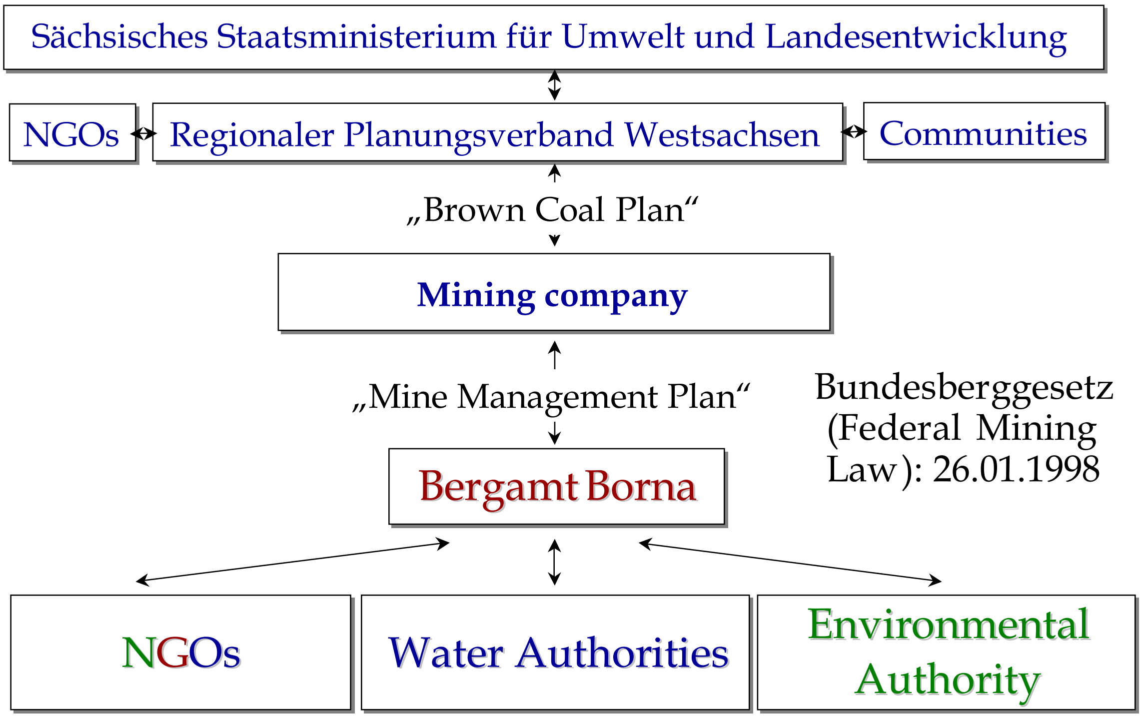

Fig. 6: Scheme for regulation of current open pit brown coal mine.

not financially supported in Germany. As open pits for coal production are great areas, a lot of used land is affected by remediation.

4.3.3 Political

In Fig. 6 the regular scheme of mining operations for Saxony is shown on base of the Federal Mining Law (BBergG). The Regional Ministry (“Sächsisches Staatsministerium für Umwelt und Landesentwicklung“) compiles a “Brown Coal Plan” which contains the aims of the local and regional planning. Included are all mining projects in the coal sector, the sites, the carry out of the mining operations, and also the aims of remediation. All environmental agencies, NGOs, and the communities were involved in this project phase.

For each mining activity the mine operator must submit a special plan to the mining authority (BBergG § 52 Art. 2) which then checks the plan and permits or regulates all activities. Water, nature, and environment related subjects are managed in collaboration with competent water and environmental authorities.

4.3.4 Technical and sustainability

The impacts on the water cycle are:

	1989	1991	1993	1994	1995	1996	2000
open pits	21	11	5	4	3	3	3
briquette factories	27	12	4	2	2	2	2
lignite production, mill. t	106	51	28	22	18	17	≈ 19*
overburden removed, mill. t	398	143	83	55	38	37	≈ 27*
employees				3608	3263	2802	2126

Tab. 6: Overview of the German coal sector after the reunification (*Schleenhain mine and Profen mine).

Tab. 7: Mean values of main parameters in mine water of the open pit "Tagebau Vereinigtes Schleenhain" (JOLAS 1998).

parameter	unit	value
pH	1	> 6
Fe	mg L^{-1}	6
SO_4^{2-}	mg L^{-1}	1000

- The mining process itself
- lignite processing operations
- dewatering process (pumping of 30 million m^3/year) and flooding process
- Seepage of contaminated leachate from waste rock piles and waste dumps

The quaternary aquifer faces an anthropogenic influence detectable by high contents of ammonium, nitrate and nitrite of which the source is thought to be agricultural use in the past GDR time.

In the tertiary aquifers high contents of iron, manganese, and sulphate are detectable (Tab. 7). The reason for these concentrations is acid water drainage caused by pyrite oxidation in the sediments between the coal seams. During the mining activity these sediments are exposed and come in contact with water and air as well as already existing acid mine water. To avoid and decrease the acid mine water, overburden with a higher buffer capacity is used to cover the overburden with lower buffer capacities. In conjunction with these procedures, a monitoring is executed during the mining activities and also scheduled for the time after mine closure. As usual, the monitoring procedure is executed by the mine operator itself (iron, sulphate, pH) and is verified and controlled by the environmental agency. Before discharge into the local rivers, pit lakes, and the sewer system the pumping water is treated.

After mine closure the mine area will be reshaped. Waste rock piles and waste dumps will be covered with special material to prevent acid rock drainage. Finally, the open pit will be flooded by the use of surface water and a composition of pumping waters from the open pits "Tagebau Vereinigtes Schleenhain", "Tagebau Profen" and "Tagebau Zwenkau" (JOLAS 1998).

5 CONCLUSIONS

As the report showed, some old mines were not properly closed in the eastern part of Germany. Impacts of abandoned mines on the water environment might be extremely harmful if remediated incorrectly. The impacts are acid mine drainage, leaching and pollution through non-remediated waste rock piles, waste dumps and tailing dams.

Therefore, the remediation of these highly contaminated areas in Eastern Germany represents one of the largest ecological and economic projects in Germany. The legal responsibility for remediation of closed down and abandoned mine sites is regulated in the German law (mining law and the general law).

In the eastern part the remediation costs for abandoned mines are paid by LMBV, GVV, Wismut GmbH (mine owner). In the western part responsible companies or mine owners for abandoned mines pay for rehabilitation measures.

Today mine owners are obligated to keep the impacts on the environment during mining activities and particularly after mine closure as low as possible. Concerning the financial support by the state for the remediation of mine sites large differences between west and east can be noticed. In the western part, the remediation costs for current mines are paid by mine owner or mine company. In the eastern part the remediation costs for current mines are paid by both, the mine owner or mining company and by the state.

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