Reclamation and Regeneration of Landscapes after Brown Coal Opencast Mining in Six Different Countries

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1 Problems Resulting from Lignite Mining in Eastern Germany

The states of Saxony and Saxony-Anhalt in central Germany have a long history of heavy industry. This tradition was continued following the foundation of communist East Germany in 1949. However, throughout its lifetime, much of East German industry remained of pre-war vintage. Until the regime collapsed in 1989, efforts were primarily directed towards boosting industrial output, with scant attention being paid to the environmental costs. A similarly negligent attitude prevailed in Poland, Czechoslovakia, and the other Eastern Bloc countries.

East German industry greatly relied on lignite (brown coal). It was used to fire the country's power stations, producing the electricity needed, for example, by the chlorine-based chemical industry and the country's steelworks. Lignite was also decomposed by heating it under the exclusion of air (a process known as pyrolysis) to produce raw materials for the chemical industry.

After World War II the newly founded East German State (the GDR) built upon its industrial legacy by intensifying mining and industrial activities. Until its economic collapse in 1989, the GDR was the world's largest lignite producer, mining over 300 million tons from 33 open pits per annum.

Lignite was mined in the areas surrounding the industrial centres (Fig. 1).

In the east, the Lusatian mining district (about 60 x 60 km) was dominated by opencast mines, while in the western GDR, the central German lignite-mining district, in particular the area around the cities of Leipzig and Halle, measured about 90 x 40 km.

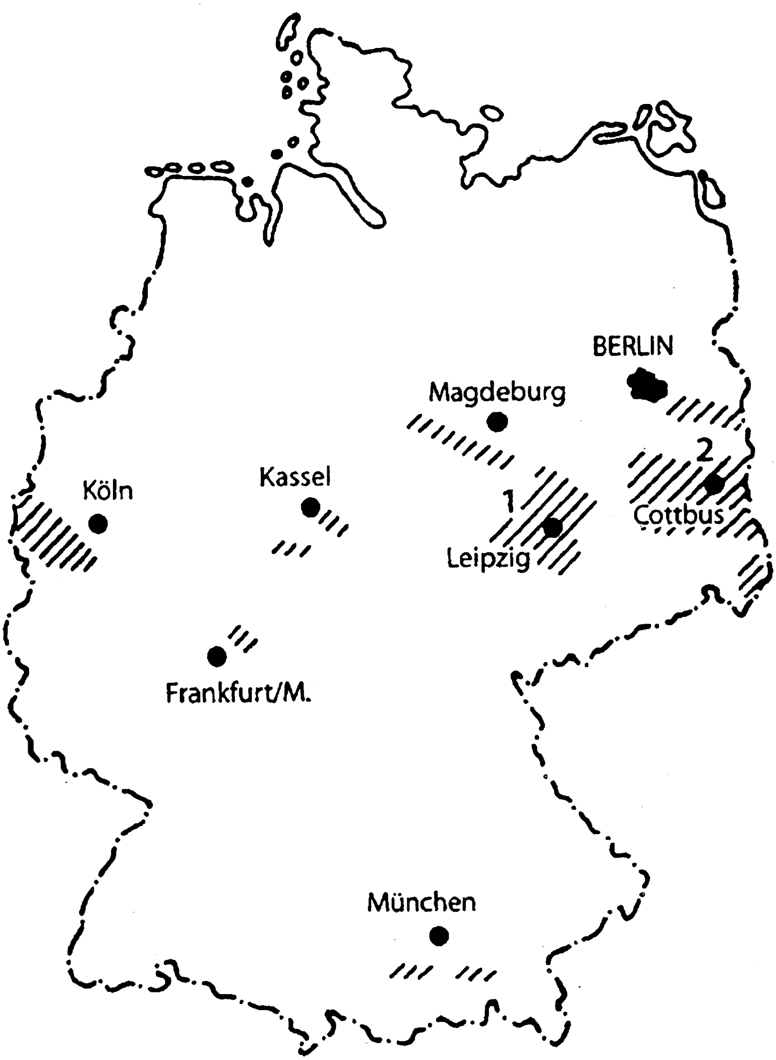

Fig. 1. Lignite mining areas in Germany (1: Saxony, 2: Lusatia; Stottmeister et al. 1999)

Lignite mining resulted not only in a tremendous destruction of the landscape, but also in the massive contamination of surface water and groundwater. The mining had an enormous ecological and sociological impact. It swallowed up entire rural landscapes complete with towns and villages and caused the water table to drop by more than 30 m in places, thereby affecting the water balance and destroying the landscape with little prospects of adequate restoration in sight.

Moreover, emissions from the now obsolete industrial plants impaired the population's health and quality of life. Sulphur dioxide and dust from power plants and domestic stoves, emissions from chlorinating plants, and organo-sulphuric and organo-nitrogenic compounds from pyrolysis were all widespread. Meanwhile the rivers served as sewage pipes for untreated industrial effluent.

However, lignite mining and processing was not solely to blame for the harm suffered by the environment. Other culprits included uranium mining, the potash mines and copper extraction.

The upshot is that Germany now faces a number of colossal challenges – namely the recultivation of ruined landscapes, and the decontamination of the soil, groundwater, rivers and lakes. One especially formidable problem is posed by the clean-up of sites polluted by organochlorines and hydrocarbons.

After German reunification, lignite-mining was drastically reduced and lignite-processing abandoned, causing the environmental situation to rapidly improve. A restoration programme was set up by the Federal German Government to assess the impacts of the former lignite mining. Within the space of just five years (1989 – 1994), annual lignite extraction totals in central Germany and Lusatia have dropped from about 330 million tons to some 100 million tons. The current output target in these two districts is around 70–90 million tons per year.

The following three scenarios typify the current state of abandoned opencast lignite mines in eastern Germany. (No consideration is given here to the lignite mining in the western Rhine River region of Germany, which has further conditions and problems.)

- Open pits are being or have been flooded to form recreational lakes, resulting in a new type of landscape. The new lakes generally do not influence the groundwater levels, but probably the microclimate. Problems include mechanical slope erosion in the shore zones and the acidification of the water by natural oxidation processes (forming "acidic lakes").
- Opencast mines are being naturally flooded, normally by the rising water table and by rainfalls. However, the water is contaminated by uncontrolled municipal waste deposits adjacent to the lake or by agrochemicals and fertilizers.
- Disused opencast mines were used for waste disposal, especially

industrial waste without any safety measures. The nature of the material dumped is often unknown and so it must first be analysed. Studies have to be carried out into the chemical interactions and the formation of metabolids so that proposals for remediation and protection can be drawn up.

Many specific examples of mining lake problems in eastern Germany are discussed later in Sections "Mining Lakes:..." by Helmut Klapper.

2 Reclaiming the Great Surface Coal Mines of the Czech Republic

Restructuring of the Czech coal industry is having a positive impact on the environment in opencast mining areas. This has mainly resulted from the establishment of new environmental legislation and incentive economic mechanism improving and preserving the environment. Adequate planning and implementation of ecologically-sound practices is considered a major prerequisite for improving the environment and quality of life in the Czech opencast mining areas.

The Czech Republic has substantial reserves of high-energy brown coal. This natural resource, exploited almost exclusively by opencast technology, occurs in two separate basins in the northwest part of the Czech Republic. The larger basin is called the North Czech Brown Coal Basin, and the smaller is the Basin of Sokolov (Svoboda 1993).

The conditions and problems of mining in both basins are very similar and relate mainly to the complex geological structure. The basins are characterized by the unevenness of coal seams that are pervaded by many irregularities. The areas of the basins are deeply disturbed by past underground mining operations. In addition there is a diverse composition of overlying soils.

Furthermore, the coal is mined in an area with high population density, developed industry, a dense transportation network and other different structures. Therefore, the mining enterprise is continuously required to solve problems regarding clashes of the mining activity with other interests in the region. With a high demand for coal, surface mining became the dominant technique used in coal exploitation.

The strategy in the past was to concentrate the surface mining into a small number of super-mines with modern continuous production technology. Prior to 1989, such intensive mining activities were the result of a national economy with a strategic goal to develop a strong heavy industry and other sectors requiring high energy input.

A significant decrease in mining occurred in 1989 under the new market conditions following the political/economic changes. Nevertheless, as a legacy of the socialist past, the Czech Republic was left with highly damaged territory on which the concentration of industrial production had exceeded the ecological capacity of the region. Many historical buildings, villages and cities were torn down to generate the large super-mines. Occasionally, buildings of special note were saved. Fig. 2b shows a historical cathedral that was transported over several hundred meters to make space for the expansion of one of the super-mines. The opencast mines generated in the Most area of the northern Czech Republic, where the cathedral is situated, are also shown in Fig. 2.a-d. The result of the mining is complete devastation of the landscape.

However, at present, the mining activity is organized in such way that the exploited land will be restored at the earliest possible opportunity. This time period for full restoration is estimated to be approximately 20 to 30 years, but, longer in some areas.

One of the most important tasks for the ecology, and also the economy, of the Czech Republic is a gradual reduction of the area of the land devastated by the coal mining. This is being achieved by a reduction in the number of mining sites and by the implementation of fast and effective methods of land restoration in areas that are no longer used for coal mining or spoil disposal. Presently, the effects of opencast mining on the landscape are being addressed by different methods of re-cultivation, such as agriculture, forestry, recreation and amenities. Fig. 3a shows a mining area restored into a recreational lake in the Most area of the northern Czech Republic. A racecourse was built in the same area after filling a large surface mining open pit with overburden material (Fig. 3b).

There are six large pits of total surface area of 3,600 ha in the North Czech Basin. The maximum depth of these pits is 200 m. Three further pits in the western basin have a total area of 2,000 ha. The coal seams in parts of these mines are up to 50 m thick. Consequently there is not sufficient overburden material to refill the pits.

For economic reasons, it is proposed to rehabilitate these pits by flooding with water. The greatest technical problem to be overcome in the proposed plan is establishing the quality and quantity of the flooding water. The North Czech Republic coal basin is drained by the river Bilina with an average discharge of 4 m^3/sec.

Furthermore, the river has poor water quality, particularly at low flow rates. The situation in the West Czech coal basin is better. There the River Ohre has a flow of 4 to 5 times that of the Bilina and its water is of a better quality. Pumping of the water from the River Ohre to the North Czech mines is an option under consideration.

Fig. 2a.

Fig. 2b.

Fig. 2a-b. Surface mining in the Most region of the Czech Republic (b: transported cathedral)

Fig. 2c.

Fig. 2d.

Fig. 2a-d. Surface mining in the Most region of the Czech Republic

Fig. 3a. Recreation area besides mining pit lake

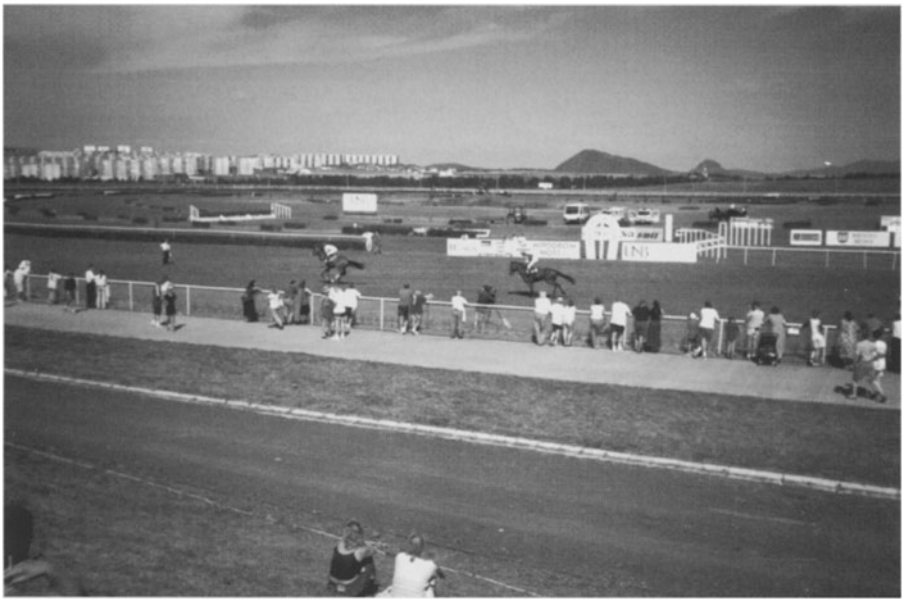

Fig. 3b. Race course

Fig. 3a-b. Reclamation schemes at Most, Czech Republic

3 Environmental Impacts of Surface Coal and Mineral Mining in the Slovak Republic

The Slovak Republic is relatively poor in coal deposits in comparison with Germany, the Czech Republic and Poland. All of the economically significant brown coal or lignite deposits are located in the Neogene Basin. The only surface mine of economical importance in this basin is the Lehota mine in the Novaky deposits. In addition to this mine, there are a few smaller surface coalmines of local significance, from which the coal was exploited for the local use in the past.

Coal mining activities in the Handlova-Novaky coal basin are unfortunately affected by water inflow from water-bearing systems in underlying beds. Water breakouts occurred in the past.

Arsenic emission from coal incineration at the Novaky power station is of concern. Conclusions of a mineralogical study showed that the main sources of arsenic in the coal are the minerals realgar and auripigment. From a hydrogeochemical point of view, arsenic is commonly observed in the region of Upper Nitra in the Slovak Republic, particularly in the "old water" where its concentration reaches 1.2 mg/L. Fluorine compounds are also found in high concentrations.

The exploitation of open-pit mine Lehota from 1981 to 1988 had a devastating impact on the environment (Fig. 4). Much of the damage was to agricultural land. Slip faults of various sizes are common in the area as well as pits and terrain depressions, both water bearing and dry. The physical and chemical properties of the soil have been changed after degradation by water, flooding and different chemical reactions. In addition to degradation of the agricultural land, water regime changes have been observed. Also, there was a considerable impact on the local Lehota community including damage to 110 private homes.

Remediation of the Lehota mining area has so far involved recultivation. This began in 1992 with the refilling of pits in the south part of the mine. In 1994, there were 399 ha of agricultural soil recultivated at a cost of 153,090 Slovak korunas. In the future, there is the possibility of lake development in the Novaky deposit, as well as in the abandoned local coal mines of Backov, Liesek, Drienovec and Obyce. In addition to the above environmental problems generated by surface coal mining in the Slovak Republic, surface mineral mining has caused damage to the environment. Several of the environmental effects of the surface mineral mining experienced in the Slovak Republic are similar to those originating from the surface coal mining. Therefore, these effects are discussed below.

Mineral mining results in devastation of the environment from the following:

Fig. 4. Lehota pod Vtačnikom brown coal deposit

Fig. 5. Banská Štiavana "Terézia" tongue

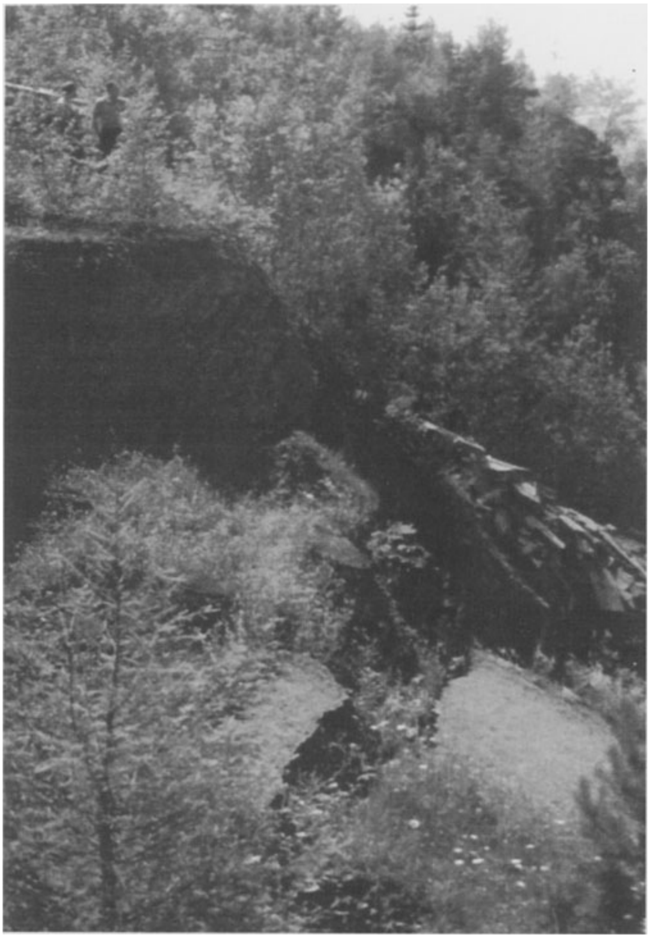

Fig. 6. Rudňany: caved in “Droždiak” tongue in the locality of Baniská

- landscape morphology changes (quarries, settlement, mine dumps),
- changes of hydrogeological conditions (water table decreasing, inundation),
- changes of geochemical conditions (groundwater and surface water contamination and contamination of surrounding soils),
- accumulation of solid wastes (heaps, sludges),
- influence of explosive works (seismic effects, pressure waves, noise etc.).

The Slovak Republic has a mining history lasting several centuries. In the past many types of metal mining were undertaken. However, recently mining has been rapidly declining. Only two metallic mineral deposits are now in operation: a siderite deposit Nižná Slaná in the “Spišsko-gemerské rudohorie” mountains situated in the east part of Slovakia; and a gold deposit in Hodruša in the central part of Slovakia. Nevertheless, over recent years ecological problems relating to metal mining activities have occurred. Two serious ecological accidents occurred in the districts of Šobovo and Smolník (Šucha et al. 1996). When the metal mining industry first developed, only surface deposits were mined for the following reasons:

- metal mineral outcrops were easy to access and they could be mined without expensive mining technology,
- soft, oxidized hematite, an earthy ore that is easy to treat, could be easily exploited at siderite deposits,
- the oxidized zones were often enriched with gold and silver and were, therefore, of more economic interest.

Fig. 7. Rudňany: caved in "Droždiak" tongue in the locality of Baniská

Fig. 8. Šobov: the countryside damaged by acid waters below the quartzite deposit

The metallic mineral deposits were usually just mined down to the water table. Example cases are: the "Boží dar" tongue near Gelnica; the "Hrubá" tongue at the Slovinky deposit; the "Terézia" tongue in Banská Štiavnica (Fig. 5); and the "Droždiak" tongue in Rudňany (Fig. 6 and 7).

Evidence of surface mining can be observed at almost every metal mineral outcrop in the Slovak Republic. Abandoned mining pits of smaller dimensions covered by vegetation occur in several areas. Negative effects of mining can be observed at the well-known Rudňany deposit in the "Spišsko-gemerská" area. There, the important "Droždiak" tongue is located in the northern part of the deposit connected with a prominent tectonic slip line in the West Carpathians (length 6 km, average thickness 6 m, thickness at surface up to 30 m, depth down to 900 m in places). Barite dominates in the tongue down to depths of 200 to 300 m. The barite content decreases with depth, whereas the contents of siderite and quartz increase with the depth. In the past siderite-sulphide ores have been mined there. Later, barite was mined at the surface as can be seen at Baniská (Fig. 6 and 7). Today, there is large abandoned quarry in the past mining area. Many faults and large earth movements have also resulted. For example, there is a mining corridor between blocks of flats in a housing area located in the town Rudňany-Zápalenica, with mining activity down to depths of 80 m. During vertical tongue mining by the means of an upper chimney at a depth of 25 m, the chimney caved in. The pit that resulted endangered the housing area.

Tips containing spoil material and waste created from ore treatment, often concentrated in sludges, are the most frequently occurring environmental problems associated with the mineral mining.

A study by Šucha et al. (1996) has shown the risks associated with the pit tips and sludges in the areas with higher concentrations of unstable sulphides. Rapid decreases in soil pH values and accumulation of iron and aluminum oxihydroxides and sulphates takes place as a result of the unstable sulphides (Fig. 8 and 9). These effects result in serious breakdown of the soil function and its properties, in cases, leading to complete soil degradation and erosion. The underlying cause of this problem is the oxidation of the sulphides present in pit tips. The oxidation rate mainly depends on the type of the sulphide material. Pyrite and pyrrhotine can be broken down most rapidly. Products of the oxidation transferred to the environment are often toxic. Further information on the impacts of mineral mining on the environment at the localities of Pezinok, Smolník, Banská Štiavnica-Šobov, Rudňany and Slovinky is presented by Šucha et al. (1996).

Fig. 9. Šobov: the countryside damaged by acid waters (foreground) from a quartzite deposit (background)

The mining and processing of magnesite has further negative influences on the biosphere, particularly on the soil and vegetation. The magnesite industry in the Slovak Republic includes units in Jelšava, L'ubeník, Hazava and Hnúšt'a. Agricultural soil and forests are damaged by dust and gas emissions in these regions during magnesite mining and processing. Harmful manganese components are released into the atmosphere as solid emissions, which can effect the microclimate of the nearby region that have an effect as deposits under specific conditions. Included in the mixture of Mg-emissions is the very reactive manganese oxide arising at temperatures in the range of 800 to 1100 °C. Surface and underground magnesite mining has further negative effects, such as subsidence, landslides, microseismicity, erosion, etc., causing changes in the hydraulic regimes of surface and groundwaters, as well as their quality. The mining activities in the regions described above have resulted in some spectacular changes to the rock environment. The result of a collapse at a magnesite mine near Jelšava is shown in Fig. 10 and 11.

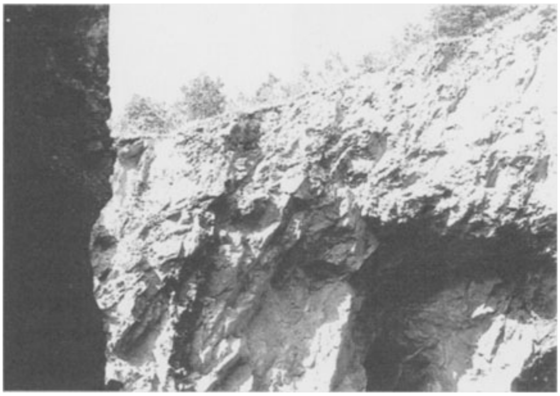

Fig. 10. Magnesite deposit at Jelšava

Fig. 11. Collapse at the Jelšava magnesite deposite

4
The Mining Lakes of Western Poland

Poland is one of the main producers of lignite in the world. Annual exploitation reaches 63 845 000 tons, constituting approximately 10 % of the European production or 6.9 % of the world production. This places Poland as the third highest producer of this raw material in Europe and fourth in the world (Statistical yearbook 1997). Lignite, along with pit-coal, provides the basis for Polish industry. Consumption for energy supply amounts to 62 887 000 tons.

4.1
Current Areas of Exploitation

Mining of brown coal in Poland developed on a large scale in the years after the Second World War and is carried out by means of opencast techniques. This leads to damage of the landscape and biocoenosis of remarkable areas. Exploitation of brown coal causes a complete devastation of soils. Hydrological relationships are subject to transformation, both within the exploited terrain as well as in the surrounding catchment area.

Currently, brown coal is exploited in four large coal basins: Betchatów, Konin and Adamów in Central Poland and Turoszów in southwestern Poland near the confluence of borders with Germany and the Czech Republic. Due to the environmental degradation, the region close to the borders of these three countries is known as the “Black Triangle of Europe.”

It is predicted that the brown coal exploitation in Poland will continue until the middle of next century. However, currently recultivation of the destroyed terrain is conducted on a wide scale. This mainly involves forestation of arising waste-tips and partial filling of opencast pits in the course of further exploitation. However, the problem of recultivation of these environments will not take place in its final form until exploitation of the currently active mines is finished. It is therefore necessary for Poland to follow intently the world experiences in this field to help formulate its reclamation plans for when the mining is finished. Such plans will be of a large dimension for the area of degraded terrain in Poland amounts to 60 thousands ha (Guziel 1988).

4.2
Areas of Abandoned Exploitation

Within today’s Polish borders there are some areas where brown coal was exploited in the 19th century. These are generally in the western region of the country, which was part of Germany prior to the Second World War II. The main region is situated in the province of Zielona Góra under the name of Łuk

Mużakowski. Lignite was exploited there by means of underground methods in addition to opencast mining. After the underground mining, there was no back filling of the mine. Only wooden supports were left, many of which have now collapsed. Consequently, the soil surface has settled forming long kneading-troughs or funnels, which have filled with water. Natural forest stands and arable land in these places have been destroyed (Jędrczak 1992). In this post-mining area there are now a little over 100 artificial lakes of total area over 150 ha. The lakes range from about 25 to over 100 years in age and the area has become known as the "Anthropogenic Lake District" (Kozacki 1976). There is further degraded terrain on the other side of the border with Germany, where 330 artificial reservoirs of total area 535.3 ha are situated (Pietsch 1970).

Polish scientists have investigated the characteristics of this water environment, in respect to both hydrochemistry (Matejczuk 1986; Jędrczak 1992) and hydrobiology (Matejczuk 1989; Koprowska 1995).

4.3 Hydrochemical Characteristics

The chemical properties of the waters in the many of the reservoirs differ from those of natural waters in the catchment basin. The concentrations of iron, and sulphates are increased and the waters are strongly acidic. The cause of this strong acidification is pyrite (FeS_2) associated with the lignite deposits.

Pyrite is subject to chemical and biological processes of decay in three stages (Baker and Wildshire 1970):

I. chemical oxidation

$$2FeS_2 + 7O_2 + 2H_2O = 2Fe^{+2} + 4SO^{-2}_4 + 4H^+$$

or biological oxidation

$$2FeS_2 + 7.5\ O_2 + H_2O = 2Fe^{+3} + 4SO^{-2}_4 + 2H^+$$

II. cyclical degradation

$$4Fe^{+2} + O_2 + 4H^+ = 4Fe^{+3} + 2H_2O$$
$$FeS_2 + 14Fe^{+3} + 8H_2O = 15Fe^{+2} + 2SO^{-2}_4 + 16H^+$$

III. precipitation of iron III compounds

$$Fe^{+3} + 3H_2O = Fe(OH)_3 + 3H^+$$

The speed of the decay process depends upon the pH. At pH > 4.5 this process takes place more quickly by chemical means. When the pH decreases below 4.5, oxidation runs more quickly by microbiological processes. At a pH between 3.5 and 4.5 oxidation takes place with participation of bacterium from genus *Metalogenium*, and at pH below 3.5 with participation of bacterium *Ferrobacillus ferrooxidans* (*Thiobacillus ferrooxidans*).

The most complete hydrochemical investigations in the area of the Polish "Anthropogenic Lakeland" were conducted by Jędrczak (1992). This physico-chemical research considered 63 of the 100 or so existing lakes. Two groups of lakes were distinguished:

- Acidotrophic with pH from 2.6 to 3.7 and redox potential from 605 to 755 mV.
- Near neutral lakes with pH from 5.2 to 7.4 and redox potential from 380 to 600 mV.

The low pH lakes formed where brown coal had been exploited by opencast methods and those with higher pH were created in depressions of soil where underground mines had collapsed. In the latter case the soil surface was not removed in the course of coal extraction.

In the group of acidotrophic reservoirs, of which 30 were examined, concentrations of sulphates ranged from 101 to 1260 mg/l. Content of iron was from 0.3 – 182 mg/l. These waters were poor in organic matters, their oxygen demand was in the range of 1.2 – 21.6 mg O_2 per litre. Concentrations of nitrogen amounted to 0.14 – 11.6 N-NH_4 mg/l and 0.05 – 1.81 N-NO_3 mg/l.

Most of the remaining artificial lakes had waters that were of class I or II purity.

The small river Chwaliszówka, which drains the lake district region had strongly acid waters of pH 3.5 – 4.2. The content of organic matter is low (COD 6.5 – 27.2 mg O_2 per litre). The quantity of sulphates is 108 – 155 mg/l, while the concentration of iron is very high (8.3 – 32.0 mg/l); such values are rarely met in freshwaters (Jędrczak 1992).

4.4 Hydrobiological Characterization

The physico-chemical water parameters of the acidotrophic reservoirs mentioned above do not allow the possibility for good development of biocoenoses. Only extreme biotopes and a small number of organisms are able to colonize such waters. This is further evident from the small number of algae taxa and invertebrates that were found.

A list of algae taxa identified in four acidotrophic lakes, in different phases of succession, and where pH was 2.8 – 3.2, contains only 19 taxons, of which 13 were diatoms (Koprowska 1995). In all four lakes the diatom *Eunotia exigua* was predominate. Most of the species of this genus are recognised as acidobionts. Other species were found in smaller numbers. There were diatoms – *Melosira granulata*, *Nitzschia palea* and *Cyclotella meneghiniana*, green algea – *Ulothrix* sp, cyanobacteria – *Lyngbya ochracea* and euglenophyte – *Euglena mutabilis*. The remaining species were adominants (Koprowska 1995).

The list of animals is yet poorer. Only one species, *Brachionus* sp., was found in the seston. In the benthos were two species of Chironomidae – *Chironomus plumosus* and *Limnophyes pusillus* and one species of Simulidae – *Sialis lutaria* (Koprowska 1995).

Not all species found were represented in each lake. In the lake of the most primary state of succession, the number of algal species amounted only to five and of the animals only *Chironomus plumosus* was found. In two lakes of more advanced succession 15 to 17 species of alga and 3 of larvae of insects were found. The larvae *Chironomus plumosus* did not attain large sizes (maximum 14 mm; Koprowska 1995). This confirmed the investigations by Ryhänen (1961).

Overall, it is important for Poland to address the problems of its relatively small acid lakes in the west, for when the far greater current lignite mines are closed down, they will constitute a considerable environmental problem.

5
Development of Lakes in Alberta, Canada

This contribution is a summary of an extensive report "Development of Sport Fisheries in Lakes Created by Coal Mining Operations in the Eastern Slopes" prepared in 1994 by Luscar, Ltd., Luscar-Sterco (1973), Ltd., Cardinal River Coals, Ltd., Pisces Environmental Consulting Services, Ltd., and Bighorn Environmental Design, Ltd., Edmonton, Alberta, Canada. We would like to express our thanks to the staff members of Luscar, Ltd., Edmonton, Alberta, for responding to our request and releasing the report to the members of our project team.

The Land Surface Conservation and Reclamation Act (LSCRA) was promulgated in Canada in 1973. Prior to 1973, the major goal of reclamation of surface coal mining areas in Alberta, Canada, was to stabilize the land surface and establish a vegetative cover. The reclamation did not consider returning the mining areas to their previous land uses or establishing specific land use goals. However, following the 1973 LSCRA, the primary objective for the reclamation has been the return of the mining areas to their pre-mining values and capabilities. The goal of all companies participating on the reclamation of surface coal mining areas in Alberta has been the creation of post-mining landscape suitable for multiple use. Creation of the lakes for recreational activities and potential fisheries has been added to regular reclamation activities that focus on returning productive forestry or wildlife land uses. These reclamation activities have also been supported by the following considerations. For mines operating at high topographic locations, such as those in Alberta, the cost involved in re-handling overburden for back-filling of mined out pits is often prohibitive. Therefore the creation of pit lakes may be the only economically feasible reclamation alternative. Lakes are preferred by the public because of their recreational potential for fishing, boating, swimming, etc., as well as for their aesthetic value. In addition, generated lakes are beneficial to the overall ecology of the rehabilitated mining area by providing wetland habitat for waterfowl and wildlife.

In the past, several ponds have been created by coal mining operations in Alberta. However, only few records exist about most of these water bodies. For example, in 1977, a mine pit near Forestburg, Alberta, was converted to a 7 m deep pond with a surface area of 6.2 ha. The pond was first stocked with rainbow trout in the spring of 1980. Data obtained from 1979 to 1981 did not identify any trends in water quality of the pond. Although the content of dissolved solids was high (in the range of 2,000 mg/l), it did not affect trout survival and growth. Due to intensive fishing, the lake is stocked on an annual basis.

Black Nugget Pond located near Round Hill, Alberta, was created by the Dodds Coal Mine. The pond was first examined in 1957 for sport fishing potential. The pond has a surface area of approximately 7.3 ha with a maximum water depth of 5.4 m. It was formed by a series of abandoned mine pits, which created irregular lagoons. The 1957 investigation revealed that the concentration of oxygen in surface water was 6.4 mg/l, and the concentration of dissolved solids was greater than 900 mg/l, with unusually high concentrations of sulphates accounting for half of the dissolved solids. Plankton and benthic fauna were scarce. Despite these poor habitat characteristics, the pond was stocked with fish the same year. Since 1970 the pond has been stocked with rainbow trout on an annual basis. Detail chemical analysis of the water conducted in 1985 showed high concentrations of dissolved solids (826 mg/l), sulphate (397 mg/l) and nitrate (1.3 mg/l). The range of the concentrations of cations was also unusual for lakes in Alberta with sodium being the dominant cation (167.4 mg/l) followed by calcium, magnesium and potassium. Other measured parameters were within the natural range occurring in surface waters. Occasionally recorded concentrations of dissolved oxygen varied between 6.2 and 9 mg/l. In the summer of 1986 five rainbow trout measuring approximately 340 to 390 mm in length were submitted for mercury analysis. The results showed that the concentration of mercury in the fish tissue was well below the recommended standard of 0.5 μg/g, and varied between 0.088 and 0.225 μg/g.

Little information is available on the generation of the Pleasure Island Pond near Camrose, Alberta. Alberta Fish and Wildlife recorded that the pond used to support good recreational fisheries on a "put-and-take" basis for rainbow trout. However, stocking of the pond with fish was discontinued in 1979 due a dispute over the pond access between a private land owner and the public.

At Whitewood Mine near Wabamum Lake, Alberta, a lake was created as a replacement for two shallow lakes that had to be drained during the mining operations. Construction for the replacement lake started in 1987, and was scheduled to be completed in 1990. The replacement lake covers 18.5 ha, has a shoreline of 3,500 m and water depth of approximately 7.8 m. The lake site has been designed to have the potential for development as a "put-and-take" fishery, day use recreation and nature viewing. Special features planned to be incorporated in the lake design were a picnic area, campsite, boat launching ramp and beach.

A mine cut near Canmore, Alberta, was successfully developed into a sports fisheries lake. The development of the lake was a part of a joint program conducted by Alberta Environment's Land and Reclamation Project and Alberta Fish and Wildlife Division. Reclamation activities involved re-sloping of steep banks to less than 30^{o} and re-contouring of old spoil pile into the surrounding landscape. A ramp for canoes and rowboats was developed. The lake has a 2 ha surface area, and maximum water depth of approximately 30 m with an average depth of 18 m. The site is extensively used for fishing and picnicking.

The lakes generated in surface coal mining areas in Alberta have unique physico-chemical properties and are located in a mountainous area characterized by restricted climatic and physical conditions. For theses reasons, the Coal Valley Mine and the Luscar Mine, Alberta, conducted a research program to examine and evaluate construction and management guidelines for creating lakes in this environmentally-sensitive region. The program was divided into the following phases:

1. Review of the North American literature pertinent to the development and characterization of lakes and ponds created by surface coal mine operations (survey was conducted in 1991 by Luscar Ltd.).
2. Limnological and fisheries investigation of study lakes (conducted by Luscar Ltd. and Pisces from 1991 to 1993).
3. Fisheries enhancement program implementation and assessment (conducted by Coal Valley Mine from 1992 to1993).
4. Cost-benefit analysis of lake construction and development (conducted by Coal Valley and Luscar mines in 1994).
5. Ecological benefits of lake development (conducted by Bighorn in 1994).

Four lakes were selected for the study: Silkstone Lake, Lovett Lake, Lac Des Roches, and Fairfax Lake. Silkstone and Lovett Lakes are located within the Coal Valley Mine area about 80 km south of Edson, Alberta (Fig. 12). These two lakes, constructed from 1985 to 1986, were the first mine lakes designed specifically for fisheries and recreational uses in the Alberta Foothills. They represent water bodies produced following dragline mining operations. The third lake, Lac Des Roches, is located in the Cardinal River Mine area about 40 km south of Hinton, Alberta. This lake was formed in 1987 in one of the mine's pits and represents water bodies produced by truck and shovel mining. The limnological investigation also included naturally formed Fairfax Lake. This lake, located near the Silkstone and Lovett Lakes, served as a "baseline" and a source of biological material for transplanting and inoculation for these other two lakes.

During the project the following issues were addressed:

1. Characterization of existing habitat conditions in three coal mine lakes created in pits produced by two surface mining methods: dragline, and truck and shovel, to establish specific considerations for the region.
2. Evaluation of various habitat enhancement alternatives to maintain or improve the characteristics of surface mine lakes for fisheries habitat.
3. Examination and establishment of pit lake development and management guidelines for optimum management practices.
4. Documentation of the benefits of lake development to wildlife and the areas ecosystem.
5. Analysis of economic benefits of lake development.

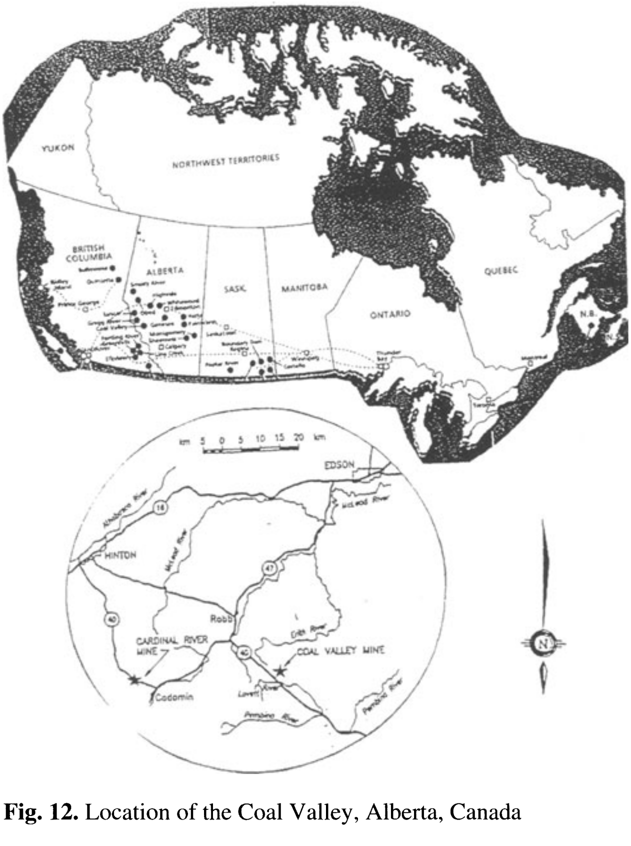

Fig. 12. Location of the Coal Valley, Alberta, Canada

5.1 Construction of the Lakes

The initial development of Silkstone and Lovett Lakes involved re-sloping and leveling operations on the shore line and bottom configuration, top soil replacement and seeding of the surrounding area. The construction of the lakes was completed and the final, stable water levels were achieved in 1985 and 1986 for Lovett Lake and Silkstone Lake, respectively. Both lakes are dependent on inflow from groundwater sources and runoff from their surrounding drainage basins to maintain lake levels. Silkstone Lake has an outflow to the nearby Lovett River, with exit flows dependent upon lakes levels. In the case of Lovett Lake, underground seepage out of the lake maintains the shore line at a constant level. Littoral zones (i.e., area less than 3 m deep) were constructed to account for over 30 % of the lake areas. The shoreline and bottom configuration were left irregular to increase habitat diversity and minimize wave action. Additional development activities involved introduction of macrophytes, transplanted from Fairfax Lake and an isolated ox-bow of the Lovett River located in close proximity to the mine site. Physical and hydrological characteristics of the lakes are summarized in Table 1. The morphometry of Silkstone and Lovett Lakes is shown in Fig. 13, and Fig. 14 is an areal view of both lakes.

Table 1. Physical and Hydrological Characteristics of Lac Des Roches and Lovett, Silkstone and Fairfax Lakes

Parameter	Lovett Lake	Silkstone Lake	Fairfax Lake	Lac Des Roches
Surface Area [ha]	6.0	6.4	28.4	16.2
Maximum Depth [m]	18.0	14.8	7.6	70
Mean Depth [m]	5.5	4.7	3.2	37
Volume [m^3]	330,000	300,800	909	6,000,000
Watershed Area [ha]	161.6	146.2	153.7	No information
Outflow Channel	No	Yes	Yes	Yes
Shoreline Length [km]	1.34	1.35	No information	1.98
Littoral Zone [%]	32	37	63	5
Elevation [m]	1,360	1,360	1,360	1,593

The third study lake, Lac Des Roches, was created by Cardinal River Coals, Ltd. in an open pit formed by truck and shovel operations. The decision to create the lake originated from the prohibitive reclamation costs associated with re-handling sufficient overburden for backfilling of the pit, according to the governmental specifications. As the pit was located in a natural creek valley and water supply could be guaranteed, the approval from the government agency was granted (Luscar Ltd. et al. 1994). The development of the lake was initiated in 1985. It involved construction of 0.7 ha of littoral zone, re-sloping of overburden, placement of top soil and re-vegetation of the surrounding area. The majority of the littoral area of the lake was constructed at the east end, where the lake water exits to the natural channel of Jarvis Creek West. A berm was built at the final water elevation, to separate the warmer, more productive shallow area from the main body of the lake. The berm also serves to intercept heavy wave action during windy periods. The littoral zone area represents only approximately 5 % of the total lake surface area. Any further development of the littoral zone would have involved placement of backfill at a prohibitive cost. The remedial work focused, therefore, on providing accessible shoreline and habitat enhancement. Physical and hydrological characteristics of the lake are summarized in Table 1. The morphometry of the lake is shown in Fig. 15, and Fig. 16 is an areal view of Lac Des Roches.

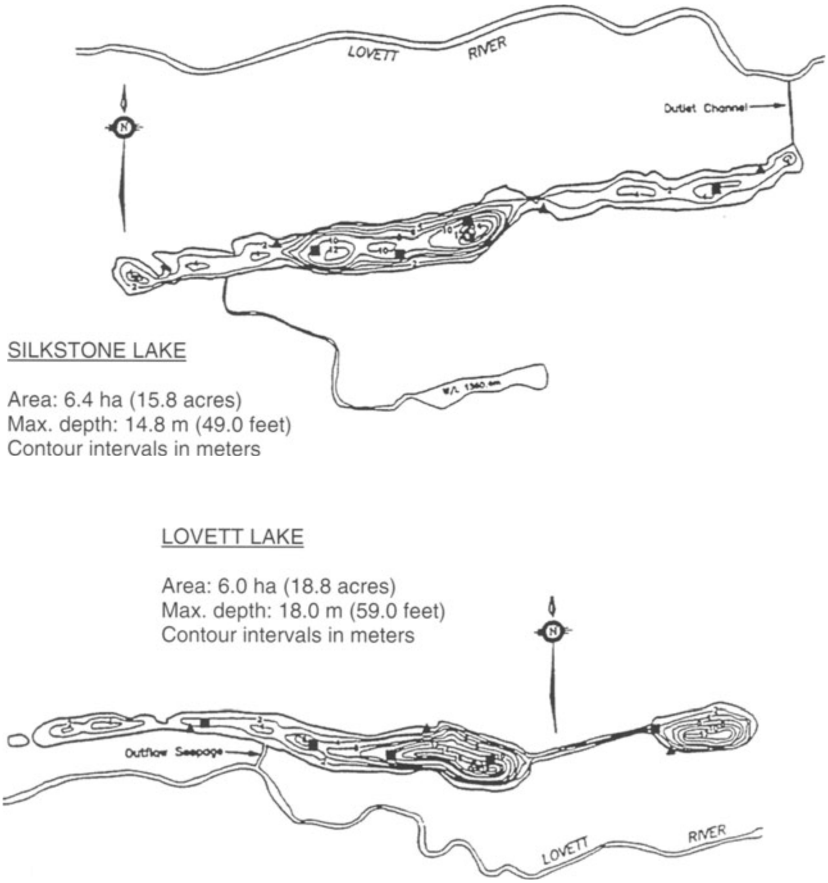

Fig. 13. Morphometry of the Silkstone and Lovett Lakes

A number of measures were taken to promote wildlife at Lac Des Roches. A large number of truck tires were placed in the shallow safety bench to offer an area for periphyton attachment and fish cover. Organic soil and partially decomposed hay were placed in the littoral zone to provide suitable habitat for benthic invertebrate and macrophyte communities. Macrophytes from nearby Mary Gregg Lake were transplanted. Reclamation activities also included seeding of high walls and the construction of benches for bighorn sheep and mule deer which regularly utilize the lake area (Luscar Ltd. et al. 1994).

The lake development program was finalized in 1987 when a full water supply level was reached. The source of water included ground water, the diverted flow from upstream Luscar Lake and surface runoff.

Fig. 14. Aerial view of Silkstone and Lovett Lakes

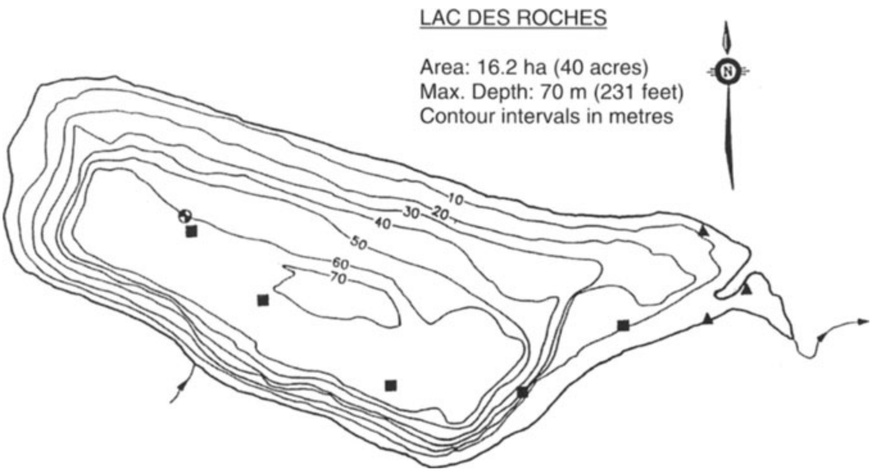

Fig. 15. Morphometry of Lac des Roches

Fig. 16. Aerial view of Lac des Roches

An extensive habitat improvement program of the lake outflow channel was undertaken in 1987 to improve the spawning potential immediately downstream of the lake. The program included the construction of a gabion mat and a 4-m deep plunge pool to ensure a constant water level. Small step dams placed at 8-m intervals over a 75-m distance created numerous small pools. Fine washed gravel was placed behind each dam to provide spawning areas. Rainbow and brook trout were observed in these areas since 1988 (Luscar Ltd. et al. 1994).

5.2 Results of Lake Studies

Results of the limnological investigation indicated that the lakes are capable of supporting fish populations suitable for sport fishing. Initially, the water in all three generated lakes was turbid. However, it reached an excellent clarity within three years, and it continues to exhibit very low turbidity. The concentrations of compounds potentially toxic to aquatic life, such as metals, phenols, nitrites and cyanides, are very low and remained below the federal and provincial freshwater quality guidelines and objectives.

Several water quality indicators, such as sodium, sulphate, alkalinity, bicarbonate, and dissolved solids, are present at greater concentrations in the pit lakes than in the naturally formed lakes in the area (i.e., Fairfax Lake). However, the levels of these parameters are within the natural variation for surface waters and are not high enough to adversely affect aquatic life. Elevated levels of these parameters are expected in areas filled with groundwater. Nitrites, typically found at high concentrations in mine pit lakes, have no apparent effects on the primary productivity of the lakes.

Based on their chemical and biological characteristics, Lovett and Silkstone Lakes are oligo-mesotrophic. Both lakes have a high density and diversity of benthic invertebrates, comparable to those observed in Fairfax Lake. These characteristics remained unchanged after the introduction of fish to the lakes in 1991 and 1992. The main impact of fish predation appears to be a decrease in the number of zooplankton larger than 1 mm. This is common in lakes following the introduction of fish (Luscar, Ltd. et al. 1994).

Lac Des Roches is oligotrophic. The low productivity of the lake is regulated to a large extent by its morphometric characteristics, i.e., the relatively large size and water depth, with limited mixing of the deeper part of the lake, prevents recycling of nutrients. Another factor limiting the lake productivity appears to be the relatively small littoral zone. There was no substantial change in chemical and biological character of the lake due to fish predation over the 1991 to 1993 period of investigation.

The studies showed that the three mine lakes, Lovelett and Silkstone Lakes and Lac Des Roches, can support sport fish population and that the growth rates of the fish are superior to those in adjacent natural water bodies. Lovelett and Silkstone Lakes have been approaching maturity and stability with aquatic communities that are similar to those in the neighbouring natural lakes. Both lakes are productive, with abundant and diverse invertebrate populations that are able to sustain high fish growth rates. Both lakes were stocked with hatchery rainbow trout in the spring of 1991 and 1992. The follow-up fisheries investigation revealed that the fish growth in the lakes exceeded that of the natural lake in the immediate vicinity. This was due to the abundance in food organisms that had accumulated in the 4- to 6-year period prior to fish introduction. However, both lakes lacked escape cover for fish at the time of stocking and fish were susceptible to predation, which considerably reduced survival rates. The low survival rate of fish in Silkstone Lake was additionally caused by fish escaping through the outflow channel. These problems were mitigated in 1993 by introducing additional escape cover (i.e., rock and brush piles) and modifying the outflow channel. Maintenance stocking of rainbow trout will be required in both Silkstone and Lovelett Lakes.

Lac Des Roches is unique to Alberta because it may be the first created mountain lake that has become occupied by native fish from downstream. The lake is relatively cold and deep with a small littoral zone relative to its area. These features make the lake an oligotrophic water body with limited fish production capabilities. However, the lake approaches the ideal objective - it has become occupied by native fish and is a self-sustaining recreational sport fishery lake. Two native fish species occupy the lake: rainbow trout and bull trout. Both species are of particular interest. Bull trout are a species of concern in North America and the Athabasca strain of rainbow trout has recently been noted as a unique population with possible future subspecific status. Enhancement of spawning habitat in the outlet stream from the lake has been effective and it is intensively used by rainbow trout.

All three lakes are a valuable addition to the lake ecosystem and to the diversity of fish habitats in the eastern Slopes of Alberta, particularly for their ability to support self reproducing populations of native species. These man-made features add new waterbodies to a region that is not typically characterized by standing water. The addition of new waterbodies to the region has augmented or provided habitats for many species. Generally, the lakes provide staging areas for migrant shore birds and waterfowl, with feeding on invertebrates on the route to the Arctic. Further, the lakes provide breeding habitats for local amphibians, which establish another link in the food chain. The lakes are a source of water for many animals living in the area, such as elk, mule deer, white-tailed deer and moose, and are habitat for aquatic fur-bearers, such as muskrats and mink, as well as for marsh birds.

Eighteen new species of water-oriented birds, which had not been observed prior to the development of the lakes, were noted during the period of the study of the lakes. Occurrence of many of the birds was attributed largely to the presence of the man-made lakes.

5.3
Costs of Lake Developments

The reclamation of coal mine dragline pits and truck/shovel pits to lake habitat has proven to be a desirable economic alternative to upland forest reclamation. The cost savings are associated with less backfilling and earthmoving costs than would be required to reclaim the mining area to accepted standards of upland forest. The cost of a lake development can be relatively consistent from one area to the other. However, due to the amount of backfilling and sloping/leveling required, the cost of generating dry land is quite variable. Mining conditions that affect the relative reclamation cost, i.e., dry land vs. lake, are: thickness of coal seam, down-dip angle of coal, depth of overburden, and width of final cut.

The cost analysis conducted by the Coal Valley Mine in Alberta, which compared the lake development in dragline operations to upland forest reclamation, showed that the savings ranged between Can \$50,000/ha and Can \$135,000/ha or approximately Can \$0.85 per clean metric tone (CMT). The cost analysis conducted by the Luscar Mine, Alberta, showed that the lake development in truck/shovel operations in mountainous settings may result in savings ranging between Can \$151,000/ha and Can \$416,000/ha or Can \$0.80 to Can \$3.00 per CMT, depending on lake configuration and coal recovery.

5.4 Management of the Lakes

The study of the three mine lakes contributed significantly to the development of a working model for post-mining land use that will have applications to other mining operations in Alberta's eastern slope region. The results of the study will be used to improve the recreational potential of the area. From the fishery management perspective, the following components need to be evaluated and implemented in the development of further lakes: lake water supply (hydrology), which must be considered in the pre-construction planning stage; watershed reclamation, erosion control and basin stabilization activities; lake morphometry and habitat enhancement; post construction lake monitoring and management.

The results of the habitat investigation and literature review suggested that there are many critical habitat components that must be considered when establishing viable sport fisheries in mine pit lakes. Some of these components, such as size and depth of the lake and orientation of the lake, will be predetermined by excavation practices and other mining operations. However, many important factors in lake habitat design, such as shoreline contour and slope, litoral zone, substrate type and composition, can be manipulated. The most important factor appears to be the establishment of adequate littoral zone, provision of escape cover for fish, introduction of invertebrates and macrophytes from local sources, and the delayed introduction of fish to allow biological communities in the lake to approach stability. It takes approximately 2 to 5 years to establish aquatic vegetation after the lake is filled with water. The establishment of aquatic plants in lakes is ecologically important. The plants form the base of a complex food web and have a major impact on wildlife by providing food and cover for wetland mammals, such as muskrats, nesting structures for marsh birds, food and cover for aquatic invertebrates, amphibians and fish, cover for nesting waterfowl and food for migrating waterfowl. It is desirable to promote self reproducing populations and avoid the potentially expensive long term commitment associated with fish stocking program. However, this may only be possible in lakes with features similar to those of Lac Des Roches.

6 Overview of Opencast Coal Mining and Reclamation in the UK

The UK has a long tradition of coal mining and although overall production has decreased in the past half-century, there has been an increase in opencast mining since 1970. The main regions of shallow coal are the Scottish low-lands, the Northeast of England, the central East (including Yorkshire and Nottinghamshire), the Northwest (Cumbria, Lancashire and North Wales), the Midlands and South Wales (Fig. 17). Opencast mining in these areas is of particular environmental concern due to the high population densities. Furthermore, since UK surface mines are generally small by world standards, averaging only 200 hectares in surface area, site lives average 5 to 6 years only and consequently 10 to 12 new pits must be opened each year to maintain current capacity.

Opencast mining began in 1942 to meet the War demand and reached a local production peak of 15 million tons per year prior to the 1958 Opencast Coal Act. With the shift in responsibility to local planning authorities, production dropped, until in 1974 the Plan for Coal, sparked by the Oil Crisis, set a target of 15 million tons again. This target was reached by 1982. Despite a recommendation by the Flowers commission in 1981 for a reduction in opencast mining, by 1992 the production reached 19 million tons.

Fig. 17. Areas of present and potential opencast working in the UK (HMSO 1981)

Relative to total coal output, the increase in opencast activity is quite dramatic. From 1965 to 1985 the percentage of opencast coal increased from 5 % to 30 %. This increase can be attributed to the profitability of opencast coal during a period that saw coal subsidies reduced and market forces encouraged. The miners strike of the early 1980s may also have been important, since it only involved workers from underground mines.

Opencast lands have been predominantly restored for agricultural use in the UK, although there has been a shift away from this policy in recent years (Proctor 1990). As UK surface mines have a high ratio of overburden to coal (on average 19 to 1) it is possible to restore most areas close to their original contours. From 1942 to 1990 of the 60,000 acres of worked land, 90 % was restored for agriculture. However, since the late 1980s there has been a change in practice away from agricultural restoration due to massive European food surpluses and perhaps also criticism of environmental impacts of capital intensive farming techniques in the UK. In many cases, restoration of mining areas to the natural environment is now considered. In the early 90s hedgerows were being planted at the rate of 40 km/year on former mining lands. Habitats are now being designed with woodlands, ponds, ditches, wetlands and sanctuaries for birds and wildlife. Proctor (1990) reports on the return of a river to its natural sinuous path and the creation of heather moorland in a former upland mining area.

Alternative reclamation strategies now include the formation of leisure areas, country parks, golf courses and ski slopes, as well as refuse disposal sites. At one site near Shipley, an area of former industrial dereliction has been transformed, post surface mining, to a commercial theme park and country park. The country park includes a series of lakes for sailing, windsurfing, water-skiing, fishing and wildlife (Brook 1989).

A proposed development scheme for the Windsor opencast mine in West Yorkshire highlights the attention to nature conservation that is considered in UK mine reclamation (R.J.B. Mining U.K. Ltd. 1997). While the plan is to recreate a sustainable agricultural landscape, which contributes to the rural economy, the development includes:

- an increase in species and habitat diversity,
- the accommodation of locally occurring protected species,
- an increase in open and running water habitat,
- a doubling of woodland cover in the district,
- the protection and enhancement of green corridors,
- an increase in public rights-of-way to encourage countryside recreation.

The Windsor restoration scheme includes the planting of at least six categories of woodland, four categories of grasses, four categories of herbs and further categories of hedgerow plants and reeds, with five to ten different species per category.

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