Investigation and Strategy on Iron Removal from Water Courses in Mining Induced Areas

Friedrich Carl Benthaus[1], Wilfried Uhlmann[2], and Oliver Totsche[1]

1. *LMBV, Germany*
2. *IWB, Germany*

ABSTRACT

The ground water table has been lowered for lignite mining purposes at Lausitz area between Cottbus and Dresden (Germany) for a long period of time. Pyrite contained in unconsolidated rocks as well as overburden oxidized intensively at up to 30 or 50 m depth. High quantities of soluble ferrous iron as well as insoluble ferric iron were generated.

While mining on large scale closed in this area, the ground water table rose in recent years. Water courses again are predominated by groundwater inflow. The iron input into the river Spree and into adjunct water creeks can be observed as a cloudy, reddish brown substance.

Large scale investigations have been carried out in order to detect the most important sources of iron contamination along the river Spree. Measuring the flow at different seasons and measuring pH, alkalinity, iron and sulfate along the river course at one day gives a perfect impression of the river status.

A high concentrated groundwater inflow in rivers had been detected not only in connection with dump areas. Increased ferrous iron concentrations have been detected for example at highly permeable aquifers and the outflow of former bog areas.

In order to remove iron from the Spree river water, various treatment units were designed and implemented. The concept for removing the iron followed the principles of simplicity in process, low cost design and minimal chemical additions. Former water treatment plants are reused as sedimentation ponds. Wetlands are constructed for settling of ferric oxyhydroxide solids. Even microbial treatment of groundwater is in test scale with encouraging results.

INTRODUCTION

Lignite mining makes an important contribution to the supply of electrical energy in Germany. In Lusatian district, the area between Dresden and Cottbus, nearly 65 million tonnes of lignite were extracted in 2013, about a third of Germany total production

The lignite seams are embedded in horizontal strata of soft rock sand and silt of Tertiary and Pleistocene age. In order to extract this coal from depths of 30 to 50 metres, the water in the overlying strata has to be lowered by draining. In the past a depression cone of approximately 2,100 square kilometres occurred (Fig.1), extending well over the borders of the opencast mining area.

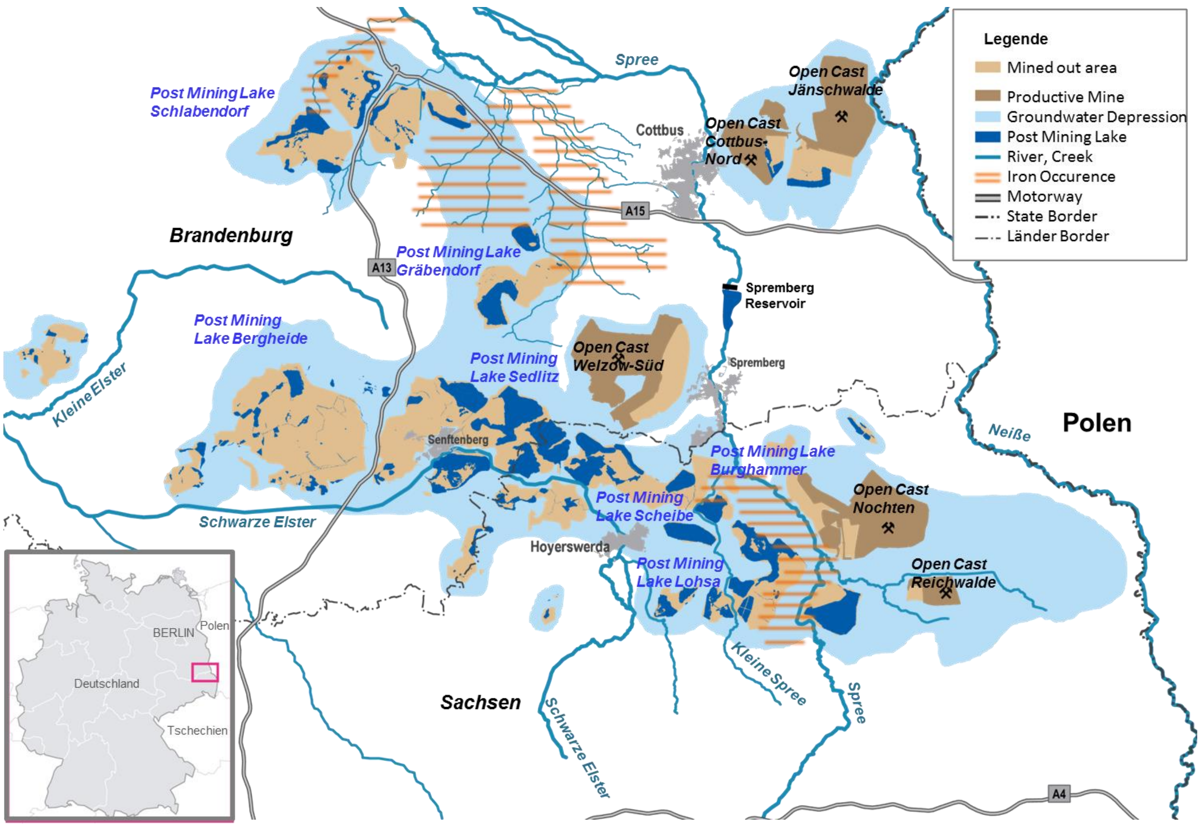

Figure 1 The Lusatian lignite mining district in Germany

Since 1990 a total of 32 lignite mines have had to be closed down. Either deposits have been depleted or the economic and competitive conditions have changed dramatically. The German mining legislation requires that all mines to be rehabilitated. The rehabilitation Lausitzer und Mitteldeutsche Bergbauverwaltungs GmbH (LMBV) has taken charge of. It comprises the removal of all installations, stabilisation of slopes, flooding the opencast mining areas and the restoring the natural water resources.

PROBLEMS OCCURRING WHILE GROUND WATER RISE

Pyrite layers accompanying the seams had previously been under the exclusion of air. While lowering ground water, the oxidation of the drained strata in the depression cone has resulted in soluble iron and sulphate compounds. As the groundwater level rises, these substances are now carried into the water courses.

While sulphate remains in solution in these waters, iron oxidises further, forming iron precipitate. Heavy loads of the resultant iron ochre represent a serious burden for the water course ecosystems affected (see Fig. 2). As a consequence, for example, water plants lack light because of suspended solids. Mussels are smothered by the fine silt and the turbidity deprives fishes of their spawning grounds through the accumulation of mud.

Figure 2 Iron burden in the "Kleine Spree" river (Photo: Theiss)

Investigations by IBW (2010b) and IWB (2013) have shown that there are various sources for the accumulation of iron ochre in water courses (Fig.3). Lignite mining in Lusatia has resulted in large disturbance of the catchment. Besides this, agricultural improvements such as surface draining (1) or turf cutting (6) or even bog iron ore extraction in the last century causes an "initial load" (Fig.3).

The aeration of aquifers following the groundwater depression, takes place even far outside the immediate opencast mining area (2). Oxidation in these aquifers is relatively weak compared with that in material that was relocated in inner dumps (3) or in outer dumps (4) during mining operations. The inner dumps will be submerged again once the water table has been restored. This will result in the cessation of the oxidation process, at least in the long run. The outer dumps will slowly become completely oxidised, and these substances will be carried into the groundwater as well as surface water bodies by precipitation. Groundwater outflows from acid post-mining lakes (5) partly are loaded with iron. In Lusatia the numerous moorlands are a very significant source of iron (6) because large quantities of iron sulphide minerals have formed as they developed. As the ground water rises the oxidised iron compounds are washed out.

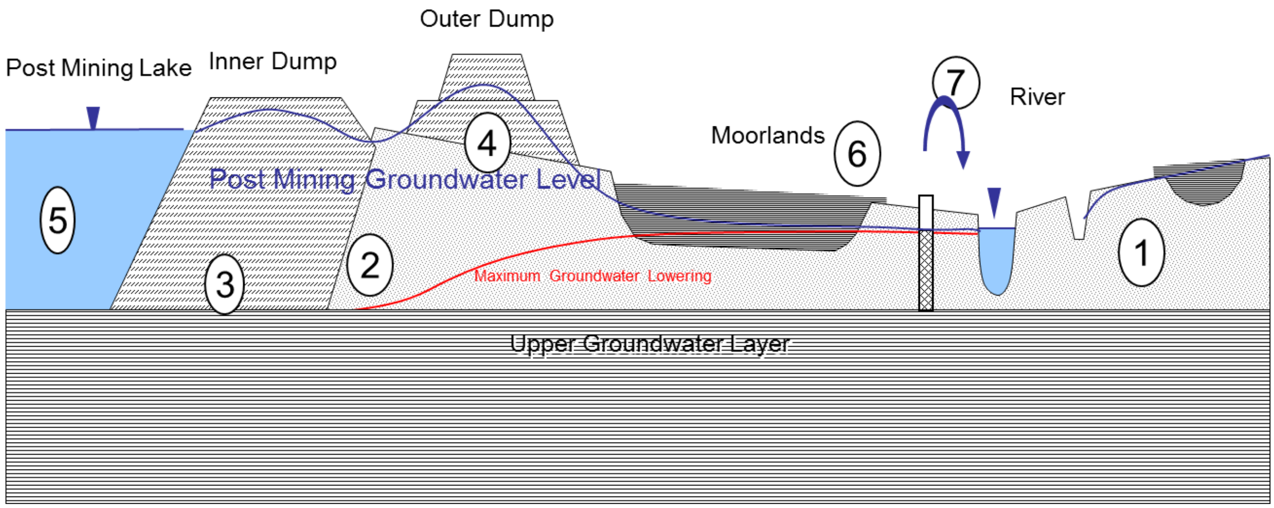

Figure 3 Sources of iron contamination in watercourses in Lusatian district (IWB 2013)

The following article deals with problems on aerated aquifers (2), inner dumps (3), and outer dumps (4).

IRON LOADS AND HOT SPOT AREAS

Initially an elevated concentration of iron was identified from 2003 onwards in a River Spree tributary, called "Kleine Spree" that is fed with ground water inflow. In the "Kleine Spree" river the concentration of iron rose continuously till 2010 up to approximately 10 mg/L while mean low water level in summer time. After a period of heavy precipitation in 2010 and 2011, high concentrations of iron could be seen and measured along some 20 kilometres of the River Spree.

This iron originates from the Pleistocene aquifer in the depression cone of the former Lohsa and Burghammer lignite opencast mines (Fig.4). The ground water level in the Pleistocene aquifer had been lowered by as much as 50 metres, and as a result the sediments had been aerated for many decades. There are no aquitards in the upper level of the aquifer. The clastic Pleistocene sediments show between 0.01 % and, at most, 0.05 % of pyrite by mass, while they do not contain any carbonate minerals whatsoever.

The pyrite weathered significantly because of the good permeability of the coarse, dewatered aquifer. Because of this, groundwater locally contains up to 400 mg/L of iron and 1,400 mg/L of sulphate. Groundwater that is so severely contaminated had previously only been encountered in well-aerated lignite opencast mine dumps. Following the raising of the ground water level, this groundwater now flows into watercourses (Fig. 4).

The historic level of iron in Lusatian water courses is approximately 1 mg/L. The iron comprises of differing proportions of dissolved iron(II), iron(II, III) humic acids and iron(III) hydroxide in suspension. The light adsorption is so strong that even relatively low concentrations of iron(III) hydroxide result in high degrees of turbidity. Above concentrations of about 2 mg/L, the iron(III) hydroxide can be seen colouring bodies of water and water courses ochre and making them turbid (Fig. 2).

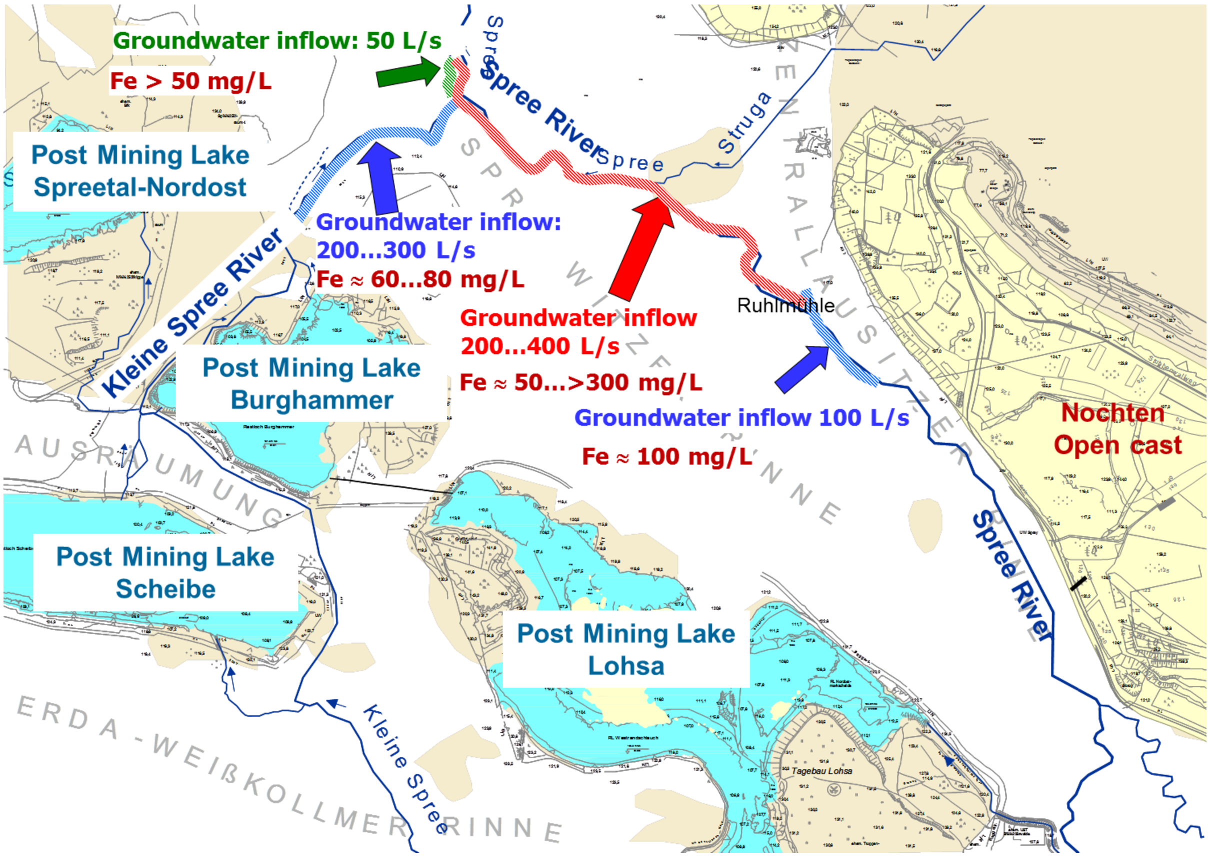

Figure 4 Iron loaded groundwater inflow into the River Spree and the River Kleine Spree

Because of the high quantity of groundwater inflow (1,0 m^3/s) along the River "Kleine Spree", the concentration of iron has risen up to 20 and 30 mg/L. The iron is transferred from the groundwater as iron(II). The oxidation of iron(II) in the watercourses is dependant on temperature and pH value. The hydrolysis of iron(III) lowers the pH value so that conditions for iron oxidation in the watercourses deteriorate further. As a result, particularly in winter time when through flows are higher, the dissolved iron(II) is transported over considerable distances. At present iron(II) at a pH value ranging from 5 to 6 is being found in the River Kleine Spree because of the pH-limited oxidation.

Currently between 4 and 8 mg/L of total iron are measured in the River Spree (14 m^3/s). The majority of the iron occurs as iron(III) hydroxide. During the winter months as much as 50% of the iron is found as dissolved iron(II).

The iron oxide sludge is deposited along the banks and stagnant water zones of the affected watercourses. It is re-suspended during high water periods and carried further by the flow. Consequently the total concentration of iron in the River Spree can reach 10 to 20 mg/L. Iron can currently be identified along Spree River as far as the Spremberg reservoir (fig. 5). This reservoir contains more than 20 million cubic metres. At average flow rates into the River Spree the retention period varies from 2 to 4 weeks. At present the Spremberg reservoir is providing reliable protection to downstream stretches of the River Spree. This includes the Spreewald biosphere reserve and tourism destination.

Figure 5 Iron load carried into the Spremberg reservoir (photo Rauhut)

Currently investigations are being carried out to determine whether the Spremberg Reservoir will retain its protective capacity. The reservoir had been erected for water management purposes, as increasing the flows during low water episodes and for flood control while high water. The high iron load of the River Spree is harmful to its ecology. European and German water legislation do not permit the deterioration of a body of water or of a water course. It requires to localise the sources of contamination precisely so that targeted preventive measures can be planned and implemented.

MONITORING

The localisation and quantification of inflow presents a challenge to hydrogeological monitoring. The diffuse iron-loaded inflows can be measured directly at very few sites. Depending on the local and hydrological conditions there are various methods that are suitable for measuring diffuse material discharges:

- hydrochemical groundwater exploration
- flow monitorings in the entire watercourses on particular days

Hydro chemical groundwater surveys in the immediate neighbourhood of the river allow the inflow area to be delimited. This requires a close-meshed network of groundwater wells. The Pleistocene aquifer is geohydraulically and hydro chemically very heterogeneous. In the entire River Kleine Spree, monitoring of flows and water quality on particular days are promising. When a section of the watercourse is closely covered with flow monitoring and sampling points, the volume and material inflows can be spatially defined with a high level of resolution. Errors had been minimised by multiple repetitions of targeted monitoring. To determine the loads of dissolved substances the monitoring was made on a particular day at low outflow rates and under stable hydraulic and geohydraulically conditions. To determine the hydraulic conditions, the water levels in the watercourses and the groundwater level near the river are measured with load cells and continuously logged. With knowledge of the process dynamics along the river, the results of monitoring can be interpreted reliably. The sensitivity of the monitoring can be assessed using associated geohydraulic modelling.

A diffuse ground water inflow of between 200 and 300 L/s was identified along a stretch of the river "Kleine Spree" approximately 4 kilometres long (fig. 4). The emerging groundwater had a mean iron concentration of between 70 and 80 mg/L. An iron concentration ranging from 3 to 450 mg/L was measured at about 20 monitoring points in the groundwater surrounding the river "Kleine Spree". The median for iron concentration in the groundwater is between 50 and 60 mg/L.

In the Spree with comparatively high flow rates, the water quality has been successfully monitored at short intervals. The hydro chemical results have been associated with flow rates at continuously monitored wells. This allows a reliable determination of iron loads over a longer monitoring period. Drawing up an overall balance involves a number of specific problems. At low rates of flow, there is a relatively high proportion of diffuse inflows from ground water. Some of the iron remains in the riverbed as iron sludge. That iron is not registered by discrete monitoring. Usually the sedimented iron sludge is remobilised during a high water event. On the other hand, during such event the diffuse inflow of groundwater is pushed back. Consequently during high waters, in spite of the short flow times, mainly iron(III) hydroxide and hardly any dissolved iron(II) are found. In the Spremberg Reservoir three monitoring campaigns were set up: upstream of the auxiliary dam, downstream of it, and downstream of the main dam (Fig. 6).

As the flows at these positions are known, it was possible to assess the transformation and the retention of iron in the reservoir (5 to 20 million m^3). Using the results from the monitoring point above the Spremberg Rervoir the seasonal and hydrological influences on iron transport can be identified

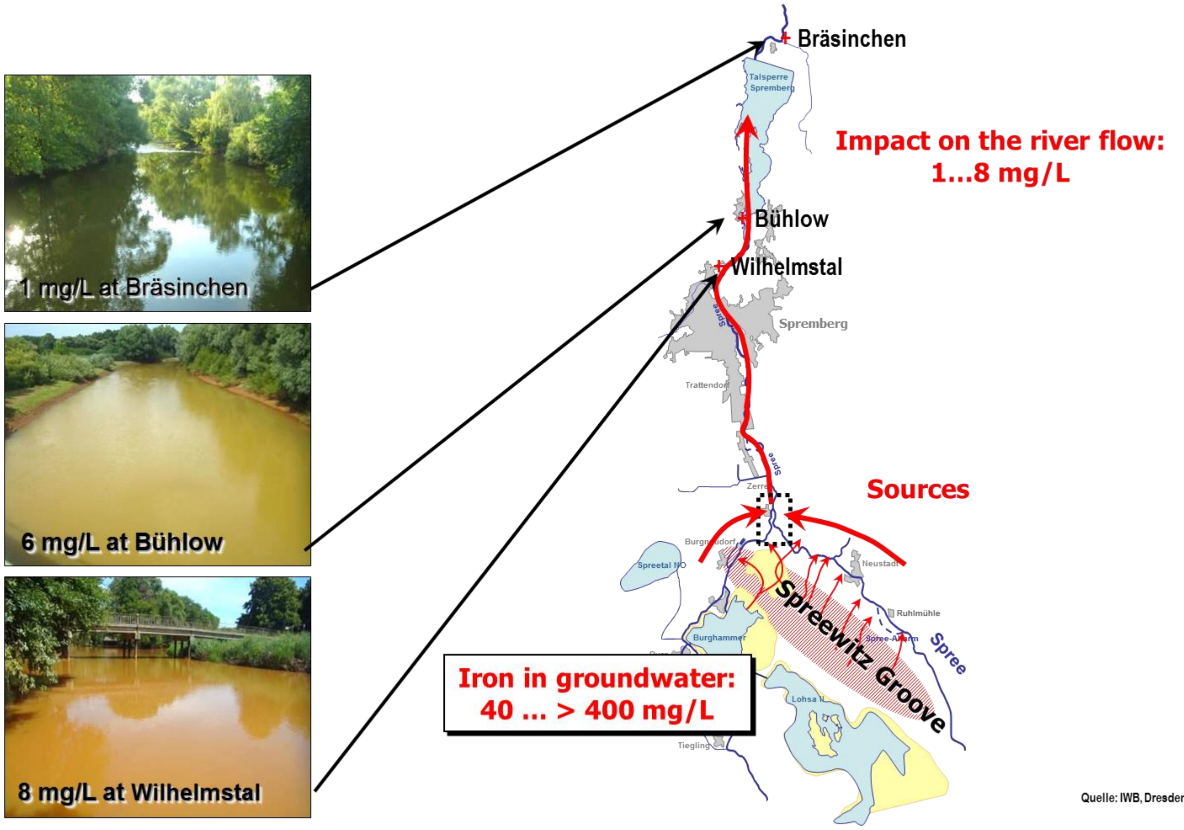

Figure 6 Iron sources and impact along the river Spree

In the "Kleine Spree" river, the volumetric flows of the diffuse groundwater inflow into the River Spree cannot be measured directly. Taking the regional water balance into account, and applying the values of a geohydraulic groundwater and runoff model, the volume of flow is estimated to be between 300 and 700 L/s (Fig. 4). The concentration of iron can be captured here at a few selected locations where groundwater monitoring wells have been installed.

A few local surface tributaries to the River Spree can be reliably measured. An oxbow parallel to the River Spree drains groundwater over a stretch of about one kilometer. The groundwater inflow into the oxbow is most stable during low and medium water periods. At an inflow between 100 and 130 L/s; here the iron concentration is about 150 mg/L. Another 600-metre long ditch for lowering local groundwater draws off about 20 L/s of groundwater containing over 350 mg/L of iron.

Planning preventive measures it is important to know the diffuse groundwater peak inflows into watercourses. This issue has both a hydraulic and a hydrochemical aspect. The maximal groundwater inflow into watercourses is expected when the groundwater rise will be completed in some years. Groundwater hydrographs show that the increase in groundwater levels has progressed far, but is not yet complete in all parts of the area under investigation.

In most places where groundwater is monitored the iron concentration has been stable for a long time. In some monitoring wells near the river the concentration of iron increases as the groundwater level rises. Reverse trends of a diminishing concentration of iron have not yet been observed. Consequently it can be assumed that the iron load in watercourses will continue to increase for some years.

At present, about 600 to 1,200 L/s of iron-loaded groundwater flows into the river "Kleine Spree". Only about 150 L/s of which stems from newly-formed aquifers in the catchment area. The remainder is produced by permeation losses from the Lohsa and Burghammer post-mining lakes. The volume of iron-loaded groundwater in the Spreewitz groove is estimated to be between 600 and 800 million m^3. The balance also shows that flows of iron-loaded groundwater into the watercourses must be expected to continue at least for the next 15 to 40 years.

REMEDIATION APPROACHES

To reduce the iron loading in the River Spree different approaches are followed:

- water treatment in or near the river
- water retention, drainage, and treatment

A water treatment plant and a natural wetland area in or near the river are being examined as potential solutions. Such treatment plant on the River Spree would have to be dimensioned for a volume flow of 12 m^3/s at initial inflow values of between 4 and 8 mg/L of iron. An appropriately dimensioned technical plant of this size and for these inputs would be very expensive to build and operate. A natural retention wetland on the other hand would require an area of between 30 and 60 hectares for treatment by sedimentation. Such areas at the end are not available in the intensively used landscape of the River Spree.

Nevertheless the technical effort is considerable. The technology includes four stages: extraction, raising the ground water, transfer it to a treatment plant, cleaning the iron-loaded groundwater, and finally treating the iron sludge.

Cleaning the iron-loaded groundwater is ideally carried out in a water treatment facility using alkaline and polymer flocculants. As an alternative to a treatment plant, the iron-rich groundwater can be pumped (no. 6) into the deep, anoxic area of a nearby post-mining lake. Because the surrounding post-mining lakes are acidified and therefore require long-term chemical treatment anyway, the sludge treatment can be dealt with in the process.

A remediation of the entire Pleistocene aquifer contaminated with iron is out of question because of its enormous costs. Quite apart from the fact, there is no state-of-the-art groundwater treatment technology for dealing with the iron load mentioned. It is acknowledged that there are possibilities for developing subsurface water treatment using heterotrophic sulphate reduction (no. 1). The significantly greater expense characteristic of this process is partly made up for by the absence of drainage, water treatment, and iron sludge treatment. Large-scale field trials in this context are being undertaken at present.

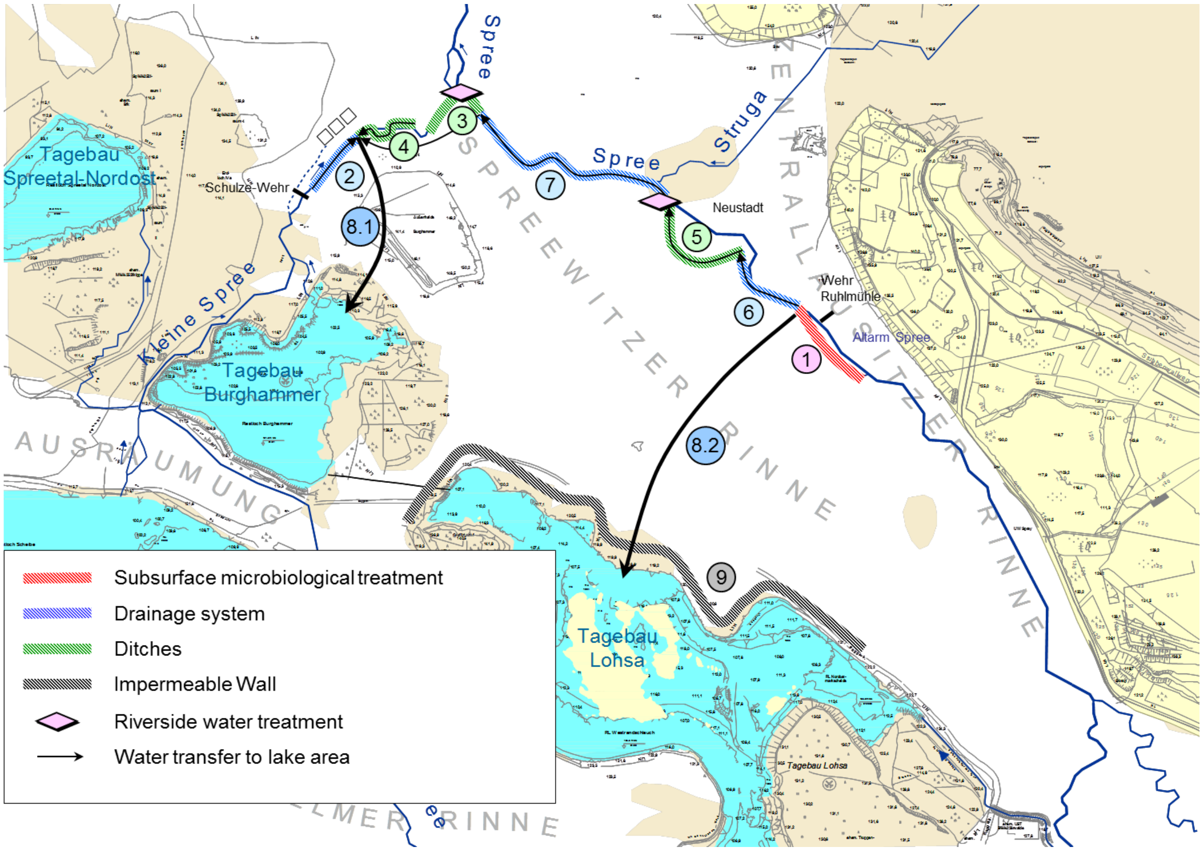

Figure 7 Measures to reduce iron discharge into the River Spree

As an hydraulic alternative the installation of a barrier wall on the northern border of the Lohsa post-mining lake (no. 9) is being examined. The intention would be to achieve a substantial reduction of the groundwater outflow, and thus of the iron loads being carried to the River Spree. A barrier solution could reduce measures near the river in the medium term.

SUMMARY

The Tertiary and Pleistocene strata in the Lusatian soil contain Pyrite which oxidised following the groundwater lowering in previous decades. This has resulted in the formation of groundwater that contains up to 400 mg/L of iron in places. This groundwater is now diffusely flowing into the watercourses of Spree river. A specific exploration scheme has been implemented to determine the loads along the river flow. Hydrochemical surveying of the groundwater at numerous monitoring well near to the river permits local differences in load levels to be determined. Varying loads were identified by repeating monitorings in summer and winter on specific days.

Depending on the varying loads along the course of the river flow a barrier concept had been developed to reduce the diffuse inflow. A substantial reduction of these discharges can be achieved economically over the medium term.

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