ENVIRONMENTAL IMPACTS OF DEEP OPENCAST LIMESTONE MINES IN LAEGERDORF, NORTHERN GERMANY

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ABSTRACT

Deep opencast mines for limestone of Upper Cretaceous age in the northernmost state of Germany, Schleswig-Holstein, greatly impact the local environment. In three pits with depths of nearly 100 m, mine pumping affects deeper aquifers and sometimes shallow ones as well. The total amount of mine water pumped ranges up to $6*10^6$ m^3/year. Due to the relief of hydraulic pressure, saline water is ascending from deeper parts of the limestone and infiltrating into the pits via the minefloor. The salt content of the deep ground water exceeds that of the sea in some places. The saline water causes process engineering problems and adversely affects the water quality of a receiving channel. Shallow aquifers are affected by dewatering due to hydraulic connections to the limestone. In places with organic soils (mostly peat of Holocene age), this is followed by ground subsidence, which damages buildings and agricultural drainage systems.

INTRODUCTION

In northern Germany, the opencast mining of Cretaceous limestone, or chalk, has caused problems as the material is extracted from below the natural water table. Intensive pumping is necessary and large volumes of mine water are discharged into local rivers and channels. Due to the salinization of the deeper ground water, this influences the water quality of the receiving streams.

History of the Mining Industry at Laegerdorf

Records indicate that mining was occuring in the area of Laegerdorf, Germany in 1737, and it is likely that mining was going on even earlier than that. The so-called "white earth" was mined manually below an overburden of less than 1 m in some places and transported to Hamburg and local villages and towns. It was used for white paint, as mortar and as agricultural lime. First industrial use of this raw material started in 1827; in 1842, nine lime plants exploited the deposit. In 1860, a British investor built the first cement plant. Subsequently, cement plants were established in the village using local pits. Now only one cement plant, the "Alsen AG" is producing cement and burnt lime, while a smaller plant produces agricultural lime. Three large pits are still being exploited, whereas a fourth pit has been refilled. Other smaller quarries have also been partially filled with the overburden of the large pits. The location of these quarries is unknown in most cases. Figure 1 shows the location of the pits.

Geologic Situation

The exploited chalk strata are of Upper Cretaceous age. Elsewhere, these sediments are

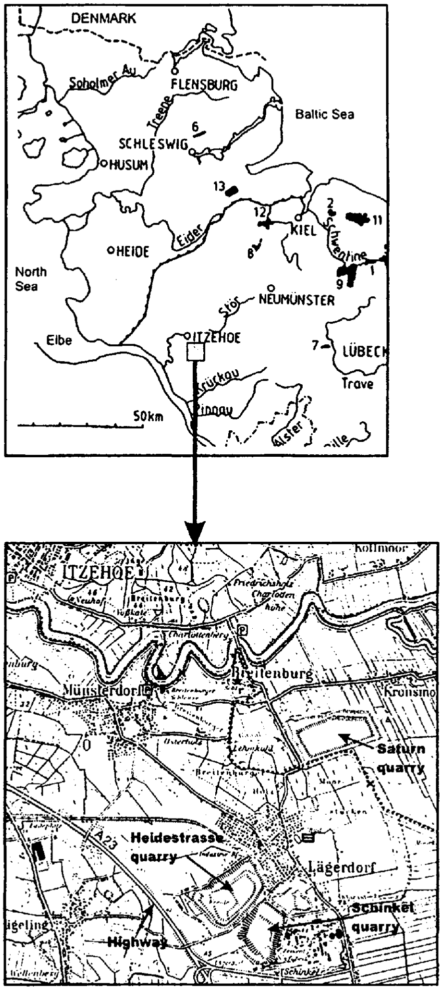

Figure 1: Location of the pits

found at depths of over 2000 m, but the thickness of the overburden at Laegerdorf reaches minima of less than 1 m. The chalk has been uplifted by the movements of a saltdome in the subsurface, which took place mainly during Tertiary times (Jaritz, 1973).

The deposit consists of soft, white limestones, the so-called chalk, which is built up of microfossils. The $CaCO_3$ content usually exceeds 90%, and in parts of the deposit, exceeds 95%. The overburden consists of Quaternary deposits of sand and gravel, marl and clay. Near local rivers, extended layers of Holocene peat and tidal muds are found.

RECENT QUARRIES

The Heidestraße and Schinkel Pits

The location of these pits is shown in Figure 1. Both pits are separated from each other by a steep dam of chalk that has not yet been mined. At present, the Schinkel pit is not exploited for cement production, but is only used by a neighboring plant that produces agricultural lime. The pit has a depth of nearly 100 m, and the present water surface of the pit lake lies about 70 m below the surrounding soil surface, due to dewatering associated with the mine.

The Heidestrasse pit is being exploited for the production of cement and burnt lime. The depth of this pit is also approximately 100 m. Due to the fact that its deepest sections are not currently being used, the pit lake surface lies at a depth of nearly 80 m below the soil surface.

During the last decade, a lot of investigation and planning has been done to extend these opencast mines. The final position of the northern border of the present Heidestrasse quarry will be about 1 km northward. The dam between the two quarries will also be mined, which will leave a single pit at a depth of 100 to 110 m below the soil surface. Pumping will cease, which will lead to the development of a large, deep lake with very steep slopes below the base of the overburden.

The overburden in the vicinity of both mines consists mainly of sand and marl. The marls, which cover nearly the entire surrounding area, have a very low permeability. They prevent the infiltration of rainwater into the chalk itself and separate the chalk aquifer from some unimportant sandy aquifers above it. The geologic situation changes near the western borders of these pits. There the surface of the chalk shows higher inclinations and the overburden becomes significantly thicker. In this area, sandy outwash aquifers lie directly on the chalk and show direct hydraulic connections. Ground water movements in the chalk strata, which are observed and expected due to recent and planned mining activities, could influence the higher parts of the overburden and the soil in this area.

In an isolated location with a very special geologic history, many drillings have shown the existence of peat in the overburden with a thickness of up to 25 meters. Because of hydraulic connections between the chalk, the mineral overburden and the peat itself, any lowering of the water table in the chalk, which is expected due to the intended extension of the mines, would cause subsidence of the soil surface in this area. However, subsidence cannot be tolerated there because a federal highway traverses the area.

The Saturn Quarry

The Saturn quarry (see table 1) is located northeast of the village of Laegerdorf and the cement plant, in a marsh near the river Stoer, a major tributary of the river Elbe. The pit is presently exploited for the production of cement and burnt lime. At present, the pit has a depth of nearly 60 m. Because the mining starts directly at floor level, there is no lake within the pit, only very small sump basins for pumping purposes.

The sediments of the marsh, which entirely surrounds the pit, consist mainly of peat or organic clay. Below these very young formations of Holocene age, extended layers of sand can be found. In many places, they lie directly on the surface of the chalk strata. In other places, these sediments are separated by nearly impermeable marl. This means that the pumping of the pit can influence the overburden up to the surface of the soil, potentially causing:

1. ground subsidence and associated damage of buildings near the pit;
2. lowering of moisture contents of the agriculturally used soils during dry periods; and
3. damage of some drainage systems used by local farmers.

It should be mentioned here that dewatering of this area has been going on locally for centuries to make farming possible. This means that the mining didn't cause all of the problems curently being observed in the shallow groundwater table, but these problems have increased significantly with the existence of the open cast pit.

HYDROLOGIC SITUATION

Mine Pumping

At present, nearly $6*10^6$ m^3 of mine water must be be removed from the pits. Approximately $3.5*10^6$ m^3/year are pumped from the Heidestrasse and Schinkel pits; the rest ($2.5*10^6$ m^3/year) is from the Saturn pit. The water is pumped either from basins (Saturn pit) or from lakes in the deepest parts of the quarries (Schinkel and Heidestrasse pits). The mine water from the Saturn pit flows directly into the river Stoer. The water from the Schinkel and Heidestrasse pits reaches the Stoer via a channel that had been used for cement shipping some decades ago.

Surface Water

The meteorologic data from 1960 to 1997 has been summarized in Table 1. The evapotranspiration was calculated from meteorological data collected nearby (Bretschneider et al., 1993). Runoff was calculated as the difference between rainfall and evapotranspiration. Negative minimal runoffs occur during periods of high evapotranspiration and low rainfall, when the water budget becomes negative and the river flow principally consists of ground water base flow.

GROUND WATER SITUATION

Ground Water Recharge

The average ground water recharge can be determined simply by recording the low-water discharges of the nearby rivers. The annual recharge of the upper aquifers ranges as low as approximately 30 mm/year in the marsh and does not exceed 130 mm/year in other areas.

In general, variations in the water budget in the catchment areas do not greatly influence the pumping rates, except during extremely heavy rainfalls. Up to 1000 m^3/h of rainwater reaches the basins of the Saturn pit as a result of a net rainfall of 1.6 mm/h. Events like this cause major problems in the Saturn pit, because the small basins there do not allow any retention of rainwater.

Table 1: Basic data of water budget from 1960 to 1997 in mm/year

	Minimum	Average	Maximum
Rainfall	529	814	1102
Evapotranspiration	371	511	830
Runoff	-67	302	710

Ground Water Budget and Hydraulics

The ground water in the catchment area of the pits circulates in different , highly permeable aquifers of Pleistocene or Cretaceous ages.The uppermost and youngest aquifers are those of the valley of the river Stoer on the one hand and of extended older glacial outwash deposits on the other. When they are unconfined, the storage coefficient of the sediments reaches values of 0.15 or slightly more. This means that the upper parts of the mine slopes that consist of these sediments are responsible for a high level of ground water flow into the pits.

The limestone itself shows overall permeabilities between approximately 10^{-5} m/s and 10^{-7} m/s. It is known that the permeability of the limestone is anisotropic in the subsurface: horizontal permeability is assumed to be 10 times as high as in the vertical direction. The reasons for this are the stratification of the chalk and the the inclination of the strata, which very rarely exceeds values between 5/ to 7/. Most of the water in the chalk moves along the deposition planes, with relatively little moving through the relatively rare steep fissures or faults. Ground water flow in the chalk aquifer is related to recharge from the sediment; pumping tests show that the storage coefficient of the chalk is about 0.001.

The mean range of the ground water depression cannot be calculated by using one of the established formulas because of anisotropic permeability, different flow rates from the overburden into the chalk and inhomogeneous as well as anisotropic distribution of bedding planes, fissures and faults. Ground water monitoring in over 60 wells indicate that ground water depression ranges between 600 m and 1.5 km.

The influence of the pumping in the zones below the mines has not yet been observed. Some hydraulic models have been calculated assuming that the characteristics of the chalk at greater depths are the same as in the mining areas. The results of these models show the uplift of ground water from the base of the chalk strata, at 400 to 500 m depth (Koestler and Ehrmann, 1986). Confirmation is provided by briny water in the mine floor of the Saturn pit.

As mentioned earlier, the recharge of the shallow aquifers ranges from 30 mm/year to 130 mm/year. Only a minor component reaches the chalk aquifer; the ground water recharge of the chalk aquifer itself is less than 30 mm/year. This means that under steady-state conditions, a pumping rate of approximately $6*10^6$ m^3/year and the above-mentioned recharge rate of 30 mm/year requires a subsurface catchment area of nearly 200 km^2, which simply does not exist. This leads to the conclusion that there are still unsteady conditions in the chalk aquifer, without equilibrium between pumping and recharge, so that the chalk shows a net loss of ground water.

CHEMISTRY OF GROUND WATER AND MINE WATERS

The ground water shows high concentrations of calcium and bicarbonate (as expected), as well as high amounts of sodium and chloride, positively correlated with depth (Table 2). The dominance of calcium and sodium as well as chloride and bicarbonate is clear. Due to the fact that no nitrogen-containing minerals exist in the chalk deposit, ammonium, nitrate and nitrite concentrations reflect the minor influence of the shallow ground water.

Table 2: Chemistry of the groundwater in the chalk aquifer from wells and springs on the surface of the mine slopes. Units in mg/l, except conductivity, which is in TS/cm.

constituent	minimum	average	maximum
pH	6.10	7.10	7.84
conductivity	120	913	2570
dissolved oxygen	0.3	5.5	11.6
sodium	7	88	647
potassium	1.0	4.3	11.3
calcium	55	138	233
magnesium	0.0	9.4	25.8
iron	0.0	0.2	1.4
ammonium	0.00	0.25	1.50
chloride	18	105	655
sulfate	9	128	286
bicarbonate	79	194	659
nitrate	0	3	19
nitrite	0.00	0.07	0.29
phosphate	0.00	.06	.3

Water collected from the lakes and basins in the mine or from the mine pumps show higher salt contents due to ascending groundwater that reaches the reservoirs via the mine floor. Chloride concentrations up to 1232 mg/l have been observed. Multivariate statistic evaluations show a strong and highly significant positive correlation between both chloride and sodium with magnesium. This indicates that magnesium is also transported upwards with ascending ground water from deeper parts of the subsurface.

In some samples, taken mainly from springs at the chalk slopes, calcium and bicarbonate are oversaturated with respect to calcite. This is due to contact with the atmosphere and its low partial pressure of CO_2, which affects the equilibrium of dissolved calcium bicarbonate and CO_2.

The high degree of oversaturation of dissolved iron with respect to hematite and goethite leads to intense formations of ochreous coating around nearly all springs on the slope surfaces.

SALT CONCENTRATIONS BELOW THE MINE FLOORS

Three boreholes were drilled from the floor of the Saturn pit to a maximum depth of 50 m to investigate the chemical composition of the chalk and the ground water. Salinity increased significantly with depth. The chloride concentrations rose from 0.028% as a minimum to a maximum of 0.363 % at the bottom of a drillhole. The sodium concentrations showed similar characteristics, increasing from 0.05 % to 0.17 %.

The increased salt content at greater depths has important consequences for mining, process engineering and the environment. The usually immobile saline pore water has to be removed from the raw material in a primary step of the production process, which leads to a significant increase in waste water salinity.

The salinity of the ground water has been measured in drillholes on the floor of the pit. This was done several weeks after the drilling to allow the water in the drillholes time to equilibrate with the surrounding ground water. In a drillhole very near the center of the mine floor, the chloride content increased from 19896 mg/l at the water level to 22420 mg/l at the hole's bottom at a depth of 29 m. In drillholes at the periphery of the mine floor, the chloride concentrations ranged from 9401 mg/l to10723 mg/l, showing the same tendency at greater depths.

As a second step, the ground water was completely removed from one borehole and replaced with freshwater with a conductivity of 679 TS/cm. During one and a half months, after which the borehole collapsed, samples were taken at specified depths and the conductivities were measured on site. Figure 2 shows the development of the conductivities as a function of depth and time. The intrusion of ground water with high salinity, especially at greater depths, is clearly visible. The slight decrease of the conductivity at the end of the investigation period in the upper parts of the borehole was caused by the infiltration of freshwater due to intense rainfalls.

As previously mentioned, the base of the chalk layers occurs at a depth of 400 to 500 m below the surface. The relief of hydrostatic pressure (approximately 5 atm) is believed to be responsible for the ground water movement. Models indicated that such a pressure loss would have such an effect at this depth and even in deeper strata, if their permeability allows such movement.

The vertical permeability of the chalk itself is not known. Vertical or nearly vertical ways for the ground water to ascend exist in joints or faults, which are significantly less frequent than bedding planes. As a result of a few pump tests in the Saturn quarry and its surroundings, the vertical permeability of the chalk below the minefloor is estimated to range between 10^{-7} m/s and 10^{-8} m/s. This means that under the present conditions, it would take between a few years and approximately a decade for the deep ground water to move up from the base of the chalk strata to the floor of the Saturn quarry. The fact that the ground water salinity is higher in the Saturn quarry than in the other quarries may be explained by the assumption that the total thickness of the chalk strata is much smaller.

ENVIRONMENTAL EFFECTS

The most important environmental effects of the mine pumping is caused by the discharge of mine water into the local rivers and channels. The salt content of the mine water is increasingly causing salinization of the receiving streams.

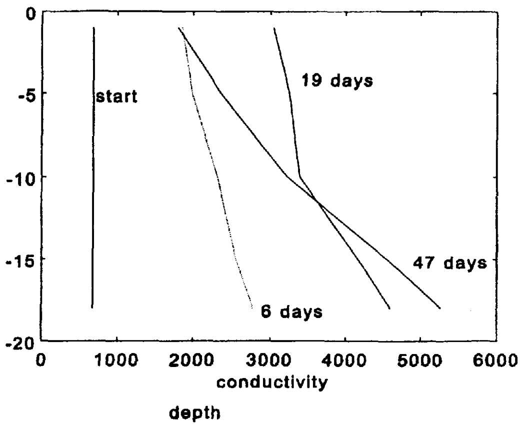

Figure 2. Conductivities of water in a borehole following its filling with freshwater.

The mine waters of the Heidestrasse and Schinkel pits discharge into a local channel (the "Breitenburg Channel") that flows into the river Stoer. The average annual runoff of this channel has been calculated to be $11*10^6$ m³/year, which equals approximately 350 l/s (minimum: $5*10^6$ m³/year or 160 l/s, maximum: $18*10^6$ m³/year or 570 l/s). The mine water is discharged at a rate of $3.5*10^6$ m³/year, equal to approximately 114 l/s, and has a chloride content that ranges from approximately 1000 mg/l to 1200 mg/l, whereas the natural background concentration of chloride in the rivers and channels does not exceed 100 mg/l. During dry periods, the volume of mine water exceeds the channel's baseflow, and the salinity of the channel increases strongly.

The mine water of the Saturn pit is pumped directly into the river Stoer. The salinity of the mine water is not significantly higher than that of the other quarries, despite the extremely high salinity of the water below the mine, due to the amount of fresh ground water that flows into the quarry from the overburden.

The river Stoer is not strongly influenced by the mine water's salinity. As a tributary of the river Elbe, the Stoer shows tidal effects in the Laegerdorf area. A single 24-hour flow measurement as well as evaluations of the regional water budget (Siefert, 1976) indicate flows of approximately 20 m^3/s with mean-minima not lower than 4 m^3/s during summer and mean-maxima of 86 m^3/s during wet and cold periods. A simple comparison of the dimensions of the runoff of the river Stoer and the annual volume of mine water ($6*10^6$ m^3/year which equals 0,19 m^3/second) shows that the saline mine water cannot significantly influence the water quality of the Stoer except during periods of extremely low flow.

The salt content of the river Stoer in this area lies between 50 and 70 mg/l. Where the mine waters run into the river, measurements had been made to evaluate the extent of the zone of influence of the salt water. The saline mine water cannot be identified by conductivity measurements at the opposite bank of the river, which is only 30 m away. Downstream, it can be observed that after a distance of only 60 m, a complete mixture of fresh and salt water takes place, after which conductivities and chloride contents reach their normal values.

In the future, following the extension of the Heidestrasse and Schinkel pits (see above), it is anticipated that the total amount of mine water discharged will total approximately $10.1*10^6$ m^3/year (0.32 m^3/second). If the mining extends below 80 m, the salt content of the mine water will increase too. Models indicate that this combination would cause the salt content in the river to increase to a maximum between 120 mg/l and 250 mg/l, depending on the river level.

SUMMARY

The influences of three big open-cast limestone mines in Northern Germany on water economy and environment have been described. Pumping of approximately $6*10^6$ m^3/year of mine water,in total, causes ground water depressions around the mines. The salinization of the ground water from below the mines, which is ascending due to relief of hydrostatic pressure, influences the water quality of the receiving streams

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