# IMPACT OF MINING ACTIVITIES UPON THE AQUATIC ENVIRONMENT WITHIN THE UPPER SILESIAN COAL BASIN /USCB/

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## ABSTRACT

In USCB mining activity have been run for hundreds years, thus creating a significant environmental problems. The main factors affecting aquatic environment and its effects are briefly reviewed. This concerns, impact of mining subsidence on the surface and ground water flow pattern over the area hydraulically separated from the effects of mine drainage, effects of mine drainage within the area where such hydraulic isolation does not occur, discharge of mine water into the surface water bodies, environmental effects of dumping mine spoil on the land surface. Forms of the adverse effects and the measures taken to minimize further degradation in water quality are also presented.

## 1. Main factors affecting natural water conditions in the mining region.

The Upper Silesian Coal Basin (USCB) is the part of Poland which due to the highest concentration of industry and population undergoes strong antropogenic pressure. Mining activities have been run here for hundreds years (mining of lead-zinc ores since half of XIIc., mining of coal since half of XVIIIc.). Annual coal production in the USCB reaches now nearly 190 mil.tons. The region is exposed to unavoidoble effects thereof resulting in various changes of the natural environment. One of the forms under which the environmental changes occur is the disturbance of the natural water conditions caused by:

- subsidence of the ground surface above, and around of the extracted portion of the bed,
- dewatering of the rock mass resulting from the drainage of mines,
- discharge of polluted mine waters into the surface water bodies,
- dumping of waste rock on the surface wherefrom soluble substances are leached by rainfalls into the subsoil.

As it may be seen from the above examples the interference of mining in the water conditions is of both quantitative and qualitative nature and its effects relate to the surface waters shallow ground waters and deep water bearing horizons adjacent to or far apart from, mined area.

## 2. Hydrogeclogical and mining conditions

From the environmental viewpoint, the area of USCB can be divided into two different hydrogeological units. The first one exhibits the geologic structure where there is hydraulic contact between water bearing horizons drained by mines and shallow aquifers. In the second one, impermeable formations in the overburden separate surface and ground water from mining drainage. The first type of structure occurs in the northern and north-east part of the USCB where:
1a - Carboniferous formations outcrop on the surface
1b - Carboniferous formations are overlaid by Quaternary, mainly permeable deposits
1c - Carboniferous formations are overlaid by Triassic formations without continuous layer of impermeable deposits between them and at the roof of Triassic formation.

The second type of structure prevails over the southern, central and western part of the USCB where:
2a - Carboniferous formations are overlaid by thick series of Tertiary deposits which consist of clays interbedded with stringers of fine-grained sand.
2b - Carboniferous formations are overlaid by Triassic formation and the floor of the latter consists of thick, continuous layer of impermeable clays of Bunty Sandstone.
2c - Carboniferous formations are overlaid by Quaternary deposits and the floor of the latter is build-up of impermeable glacial till and clays.

In the region of the first hydrogeological unit, surface and subsurface water are drained by underground workings in the zones of natural hydraulic contacts like outcrops of Carboniferous sandstones, joints and water-conducting faults as well as through postmining fractures. On the other hand, water bearing layers adjacent to extracted deposits are directly recharged by surface and ground waters.

In the region of the second hydrogeological unit, thick impermeable layers deform plastically, when subjected to mining subsidence, so that all overlying aquifers are protected against mine drainage and on the other hand, inflow to the mines is highly limited and consists mainly of static water.

Underground mining of zinc-lead ore deposits results mainly in the drainage of Triassic formations. The areas, where such ore deposits are mined exhibit usually the lack of Tertiary deposits in overburden and the surface water as well as Quaternary aquifers can be separeted only by clays, contained in the floor of Quaternary deposits.

In open sand-pits providing sand for back filling or building industry, only the Quaternary deposits are extracted. Where the sand is mined from below the water table, the surrounding area within depression cone is being drained i.e. a direct drainage of the Quaternary aquifer occurs.

The underground coal beds are mined almost exclusively by the longwall system of which about 80 percent with caving, the remaining part with hydraulic stowing and to very small extent with pneumatic backfilling. The Carboniferous Coal Measures include from one to several dozen of mineable coal beds whose cumulative depth can reach to 80 m or more. Extracting of these beds will produce subsidence of ground surface up to 50 m. Just now subsidence in excess of 20 m is being observed at some mining areas. In many cases the mining operations are concentrated in certain zones. These zones are separated from each other by the areas where no mining is run due to either natural conditions (tectonic disturbances, outcrops or washouts of coal beds) or the necessity of protecting some objects by means of safety pillars. Consequently, the subsidence troughs developing in the mined zones with the winning of subsequent coal beds overlie one another thus causing pronounced deformations of the land surface.

Impact of underground mining on the surface and subsurface hydrology depends also on mining progress and depth. The regions with the greatest mining progress i.e. mainly within the main anticline area exhibit the rock mass, which has been almost entirely dewatered. The water inflows to the mines are low, of a couple of cubic meters per minute and originate mainly from the dynamic resources. The observations have shown that the water inflow to the mining excavations in the USCB generally diminishes as the depth of extraction progresses. At the same time, however, the mineralization of water entering the mine openings increases.

## 3. Impact of mining subsidence on ground and surface water systems.

### 3.1 Subsidence - induced changes of the water levels.

The observations show that the changes in water level above the travelling subsidence trough are caused mainly by the changes in the inclination of aquifer base involving alterations of hydraulic gradients as well as by the changes in stress distribution within particular aquifer. The former factor is of greater importance as far as the water-table conditions are concerned. Where the vectors of subsidence tilt and of pre-mining hydraulic gradient are in the same direction and add to one another the water table gets lowered in relation to the ground surface whereas in the opposite case the water table rises in relation to ground surface. The changes in aquifer base inclination, however, are not always decisive for the changes in hydraulic gradients. Where water confined conditions occur the changes in piezometric pressure are significantly influenced by the distribution of stresses in the aquifer. The pressure rise will be observed when the observation point is situated within the zone of maximum compressive stresses (i.e. in the central portion of the trough). Then the pressure drops after the mining area has moved away and the rock mass is subjected to decompression and eventually the quasi-equilibrium conditions are regained after the rock-mass movements have ceased.

Hitherto conducted observations show that in quasi-equilibrium conditions the relationship between the magnitude of surface subsidence and the changes in absolute levels of ground water within the given basin can assume the following forms:

- no changes in water level occur ($\Delta H = 0$) with $w \neq 0$ (where: $w$ = surface subsidence),
- water levels are lowered by a magnitude smaller than that of subsidence ($\Delta H < w$),
- water levels are lowered by a magnitude approximating that of subsidence ($\Delta H \cong w$),
- water levels are lowered by a magnitude greater than that of subsidence.

According to what was said above the ground water level will be either relatively raised in relation to subsiding site surface (first two cases) or relatively lowered (the last case).

The first form of the changes has been noted close to the subsidence trough edge at the outflow side where the threshold as formed raises the ground water in the trough to its initial level. The second form of the changes has occurred inside the concave morphological depressions developed above the subsidence trough. The third form of the changes was found within the basin area with no pronounced alterations in the water flow pattern and in this case the changes were mainly attributable to the lowering of the recharge zone. The last form of the changes was observed at the edge portions of deep subsidence troughs at the water inflow side.

A similar mechanism of changes resulting from the mining subsidence can be observed in the case of surface run-off. The longitudinal profile of a river (or stream) extending over the subsidence trough can be divided into three sections. In the lower section the subsidence tilting is counter to the inclination of the river bed whereby the water table rises, the central section exhibits backwater effect whereas in the upper section subsidence induced gradient is in line with water flow direction. Response to the induced changes in the profile is tending toward the maintenance of hydraulic equilibrium state and manifested by such phenomena as an accelerated flow of water and erosion in the upper section as well as reduced water flow, raise in water level and sedimentation in the central and lower sections.

Where on the ground surface occur semi-permeable or nonpermeable deposits the changes in ground configuration result in disturbances in overland flow and interflow.

The concave morphological depressions as formed, retain water replenished by rainfalls or snowmelts.

With the volume of water flowing into the depression being large enough to balance or exceed the evaporation and infiltration losses the soil can become permanently waterlogged and the area can get marshed.

### 3.2 Forms of adverse effects.

The disturbances in the ground and surface water run-off as hitherto described result in spatially differentiated changes in water levels. One of characteristic effects attributable to these changes is the formation of subsidence- induced ponding and flooding. Despite of largely developed preventive measures the average total area of pondings in the Upper Silesian Coal Basin is about 8 sg km.
The worst situation is observed in the western part of the USCB where subsidence - induced overflowing of Bierowka and Kłodnica Rivers together with their tributories resulted in permanent flooding at the rivers' valleys. Large pondings were formed on flat sites due to disturbances in the ground water run-off. The area of floodings represents up to 4 percent of the total surface of mining ground belonging to certain coal collieries. Pondings resulting from the disturbances in surface run-off can be encountered in the southern region of the USCB where the surface is predominantly covered with semi-permeable deposits.

Another effect of the change in water level is observed in the form of local reductions in water resources. This type of damage is frequently underestimated where there is no mining drainage, but the areas affected thereby are not less than those of floodings. Such situations occur close to the floodings where a part of the flow is being diverted towards the subsidence trough. In the farmers' wells located at these sites a drop in water level is observed including temporary or permanent shortage of water supply.
More or less direct effect of water-flow disturbances occur in the form of soil erosion, landslides and suchlike. They are usually initiated by surface deformations and particularly by the horizontal strains. Mostly exposed to these forms of damage are the southern regions of the USCB exhibiting rugged morphology and containing loess-like deposits in the subsoil.

### 3.3 Preventive measures to be taken and mitigation of effects.

The countermeasures preventing the adverse effects of mining subsidence and in particular the formation of floodings can be categorized into three groups as below:
1. Planning and managing the mining activities so as to minimize their effects, through the coordination of mining schedules and plans, designing of large long wall parcels and suitable direction of mining, application of backfilling.
2. Preventive and current hydro-technical operation tending toward the limitation of mining effects and including dredging and rising of river banks to provide for an unrestricted flow, filling of depressions with mining-waste followed by land reclamation, correction of the gravitational drainage gradients, installation of vertical and horizontal drainage systems, pumping stations etc.

Management and utilization of existing floodings for the purpose of recreation or as storage reservoirs providing water supply for industrial purposes.

4. Mining impact on underground and surface water connected with aquifer drainage.

4.1. Actual water inflows to the mines.

The average total volumes of underground waters being drained due to excavations at the USCB broken into open-pit sand extraction, zinc-lead ore mining and coal mining are as follows:

| | |
|---|---|
| - open-pits for backfilling sand extraction | 265000 $m^3$/day |
| - zinc-lead ore mines | 480000 $m^3$/day |
| - hard coal mines | 960000 $m^3$/day |
| Total | 1 705000 $m^3$/day |

Open sand-pits are fed with fresh waters mostly suitable for municipal utilization. The inflows to the individual pits vary from a dozen or so to about 100 $m^3$ per minute depending upon the size of the pit, mining progress therein as well as upon local hydrogeologic conditions.
Waters flowing into zinc-lead ore mines are mostly the Triassic waters with generally low mineral content.
Due to fissure - karstic nature of the water bearing formations the volumes of inflows are different, the greatest one of about 200 $m^3$/min being recorded at "Pomorzany" mine situated near Olkusz.

A large differences from several to several dozen cubic meters per minute are also noted in the water inflows to the various hard coal mines. The greatest volumes are observed in the mines situated in the eastern part of the USCB this being due to the thick layers of strongly porous and permeable sandstone of Cracow Sandstone Formation occuring in this region.

4.2 Drainage effects.

Mining drainage results in partial or complete depletion of static water resources in the aquifer being drained within the produced depression cone. The impact of drainage is often transferred onto other aquifers hydraulically connected with that being drained. The general effect thereof is manifested by the drop in Quatenary and Triassic water level whereby water supply by farming wells and community intakes can be disturbed.

The extent of the mining drainage impact over the USCB region has beem generally well investigated. Resulting damage is counteracted by the development of water-pipe network. The costs of the latter are covered by the colliery which had caused the damage.

Drop in the underground water level is frequently accompanied by side-effects of geologic-engineering nature, such as piping of fine-grained soils, non-uniform compacting of loose soil, changes in consistence of cohesive soil etc. Such phenomena cause frequent damage to buildings. They are hard to investigate and often controversial in evaluation.

5. Discharges of saline water from hard coal mines in the Upper Silesia Coal Basin.

5.1 Mineralization of Carboniferous waters at the USCB.

The waters occuring in the Carboniferous formations exhibit the mineral content varying from several hundred milligrams to 250 grams per cubic decimetre. The regular rise of mineralization with the progressing depth is observed over the whole USCB area, but the gradient of mineralization increase is not the same and depends mainly on local lithologic-structural conditions determining the possibility of supply and circulation of underground water.

Many-year hydrogeologic and hydrochemical investigations have proven the occurence of vertical stratification in the chemistry of the Carboniferous waters manifested by their mineralization increasing and their chemistry varying with the depth. In general three zones can be classified:
- zone of infiltration waters which are usually fresh and are characterized by the minimal content below 1.5 $g/dm^3$, differentiated ionic composition as well as by distinct predomination of calcium bicarbonates and calcium sulfates over the remaining salts,
- zone of mixed waters with mineral content up to 35 $g/dm^3$ being mainly of $HCO_3$-Na, $HCO_3$-Cl-Na and $SO_4$-Cl-Na type, the latter one tending toward Cl-Na type,
- zone of relic waters with a general mineral content varying from 35 to more than 250 $g/dm^3$, of Cl-Na and Cl-Na-Ca type.
The depths at which these zones are occurring in the both hydrogeological units differ from one another. In directly water-recharged area slightly mineralized waters (with salt concentration from 1 to 3 $g/dm^3$) are mainly of $HCO_3$-$SO_4$-Ca-Mg and Cl-$HCO_3$-Na type and can be encountered down to about 400 m, converting into Cl-Na type as the depth increases. In the restricted water-recharged area, slightly mineralized waters occur generally at a depth not exceeding 100 m, below that depth highly salined waters of Cl-Na type occur.

Hence the chemical composition of waters flowing into the mines depends on the hydrogeologic conditions in the overburden and also on the depth and development of mines excavations network as well as on the winning duration period. It should be emphasized that the mineralization of waters entering the excavations varies with the individual phases of mining development. In the first stage of entries development and winning of coal bed, the excavations drain water from static resources, whose mineralization depends in general upon the type of hydrochemical zone being drained. As the winning progresses the network of excavations gets extended and subsequent postmining fractures appear, whereby the zone of active exchange of waters is growing in depth and width. The hydraulic contacts development is also controlled by the tectonic structure of the rock mass since the mining operations often increase water conductivity of the fault fractures and associated joints network.

## 5.2. The present and anticipated salt loads in mine waters

According to the data for the year 1980, the natural inflow to the mines situated within the USCB totals about 960000 $m^3$/day, of which about 735000 $m^3$/day comes within the Vistula river drainage basin and 225000 $m^3$/day - within the Odra river drainage basin. According to the degree of mineralization the waters were classified into four groups.
Water shares in the separate quality classification groups are presented in Table 1.

Table 1

Volumes of waters pumped from hard coal mines broken into classification groups.

| Group | Content of $Cl^- + SO_4^{2-}$ kg/$m^3$ | Volume of pumped water | Percent |
|---|---|---|---|
| I | 0,6 | 427 | 45 |
| II | 0,6 - 1,8 | 232 | 24 |
| III | 1,8 - 42,0 | 278 | 29 |
| IV | 42,0 | 23 | 2 |
| Total | - | 960 | 100 |

The volume and mineralization of water pumped out hard coal mines vary with the individual river basins.
Table 2 shows the volumes of water and their salt load being drained from the mines to the rivers over the USCB territory.

Table 2

Salt discharges in mine waters shown for Odra and Vistula river drainage basis.

| Basin of: | Average low flow $10^3 m^3$/day | Volume of mine water $10^3 m^3$/day | Average NaCl content kg/$m^3$ | NaCl charge t/day |
|---|---|---|---|---|
| Odra River | 1800 | 225 | 12,3 | 2780 |
| Vistula River | 2350 | 735 | 5,3 | 3887 |
| Total | 4150 | 960 | 6,9 | 6667 |

Note: The Odra river flow was measured down Kłodnica river outlet whereas the Vistula flow was measured at Oświęcim.

The forecast on the inflow and mineralization of mine waters was prepared in 1982 on the basis of analysis of relevant documentation obtained from individual mines. According to its conclusions for the major part of basins the volumes of water flowing into the mines up to the year 2000 would not be significantly changed but the water salinity will increase thereby raising salt load in mine waters.
In Odra River basin the water inflow to mines will rise by about 16.000 $m^3$/day and the average concentration of $Cl^-$ ion and the salt load will be increased by about 15 kg/$m^3$ and 3589 t/day, respectively. In the Vistula River basin the present values of water inflow, average concentration of $Cl^-$ ion and salt charge will rise by about 34 000 $m^3$/day, 7 kg/$m^3$ and 8890 t/day, respectively. The share of IV group-water in the cumulative inflow to mines will rise from 2 to 15 percent, but on the other hand the share of I group-water will drop from 45 to 26 percent. The shares of waters classified into the II and III groups will also increase.

## 5.3. Social and economic effects of saline contamination of the rivers.

The pollution of main Polish rivers with saline mine waters results in the degradation of natural water habitat. No advantage can be taken of rivers in water supply for municipal and agricultural purposes. The industrial plants supplied with river water incur tremendous costs of its treatment, inestimable losses are suffered caused by increased corrosiveness of polluted water and many other adverse phenomena are observed.

Saline mine waters being discharged into rivers contain large amounts of valuable raw materials such as sodium chloride as well as iodine, bromine, potassium and magnesium salts. These substances are irretrievably lost, but on the other hand the construction of new salt mines is being planned for the needs of chemical industry.
To illustrate the scale of the problem some figures are quoted below. Water for cooling and drinking purposes is taken from Odra and Vistula river by 26 and 31 industrial plants, respectively. The total consumption pf Odra River water is 0,6 x $10^6 m^3$/day whereas that from Vistula River is 17,3 x $10^6$ $m^3$/day. According to its final destination the river water is freed from suspended matter, decarbonized and often subjected to demineralization, the latter process covering about 5,7x$10^6 m^3$/ /year and 157 x $10^6 m^3$/year of water from Odra and Vistula River, respectively. According to current estimations failure in protecting the rivers against salinity will result in about 60 milliard zloty costs being incurred every year for the treatment of Vistula and Odra River waters at the end of the 1990s.

Lack of solution to the problem of discharge or utilization of saline mine waters raises a serious obstacle for the development of mining at the Upper Silesia Coal Basin. For example, the construction of new coal mines in the so called Vistula region is at present impossible, because of aboundance of brackish waters accompanying coal beds in this area. In connection with the above, large inflows of saline water to any future coal mines are expected.

5.4. Implementation of, and anticipated methods for, protection of rivers against salinity.

On the basis of technology worked out at the Central Mining Institute of Katowice, the Mine Water Desalination Plant was installed at the "Dębieńsko" Colliery. The Plant has been operating for a dozen or so years and it processes every day about 2,4 x $10^3$ $m^3$ of water taken from the "Dębieńsko" Colliery and produces salt and pure water.

The programme now under implementation provides for the construction of:
- 12 desalination plants intended for the utilization of saline waters being discharged into Vistula and Odra River,
- intercepting collectors on Olza and Kłodnica River and two dosing storage reservoirs with storage capacities of 8 and 16 million $m^3$ for hydrotechnical protection of Odra River,
- "Bojszowy" reservoir with a storage capacity of 1 million $m^3$ and "Vistula" intercepting collector for hydrotechnical protection of Vistula River.

Investment outlays for meeting the targets as foreseen in the above programme figure out about 120 milliard zlotys. The economic effect of the programme implementation is estimated at about 11,5 milliard zlotys per year which should provide for the outlay refund within 11 years.

The implementation of the programme will result in significant improvement in the quality of surface water but it will not provide full protection of rivers against salinity. In particular, the postulated water quality standards will not be met for Odra River up-stream Glogów locality, for Vistula River over the section from Dunajec River outlet to Warsaw and for Czarna Przemsza River.
Despite of the implementation of the programme the costs of treatment of water taken by industrial plants from Vistula River will amount to 44,4 milliard zlotys per year whereas the fines paid every year by the coal industry for discharging saline water into rivers will amount to about 14,3 milliard zlotys.

To ensure an effective protection of rivers against salinity a full utilization of saline and moderately saline (III and IV group) waters is proposed. This solution will call for the construction of 64 desalination plants, 6 concentration plants and one heating plant of about 1400 MW capacity, either nuclear or fired with a smokeless fuel.

The investment outlays for the implementation of the above concept concerning full utilization of waters belonging to the III-rd and IV-th group are estimated at about 350 milliard zlotys.

The economic effects of operation of the above mentioned plants consisting in the dales of produced salts and elimination of demineralization of water taken from Vistula and Odra River by industrial plants is estimated at about 60 milliard zlotys per year which ensures the repayment of the investment outlays within less than 5 years.
Additional economic effects of implementation of the above conception will consist in:
- renunciation of the construction of new salt mines,
- saving of steel consumption due to the reduction of corrosiveness of river waters,
- saving of hydrotechnical building work under the "Vistula" programme due to the reduction of corrosiveness of water against concrete,
- protection of natural habitat in rivers,
- retaining of suitability of water for irrigation purposes.

## 6. Environmental effects of dumping the mine-spoil on the land surface.

In terms of qualitity the hard coal mine-spoil constitutes the largest group of industrial waste in Poland. The contamination of underground and surface waters by substances being leached out from dead rock coming from the coal mines and dumped on the surface causes very serious problems at the Upper Silesia Coal Basin. Said contaminations, known as "local pollutions" are hardly controllable among others because of lack of homogeneity of the material. The importance of the problem is borne out by the fact that the Carboniferous spoil produced at the USCB in 1975 constituted more than 42 per cent of the total industrial waste recorded in Poland.

The present level of utilization of the Carboniferous spoil at the USCB is about 21 per cent. The remaining part thereof is directed to about 100 local dumping grounds close to collieries and to 5 central dumping grounds both of sublevel (31%) or overlevel (48%) type. These dumping grounds are dispersed over the whole USCB area. The total spoil in absolute figures is estimated at about 80-90 mil. tons in 1986. Their volume shows a growing tendency due to a greater degree of mining mechanization, expansion of mining areas, intensified output from thin beds and deeper cleaning of coal.
The present trend to remove the tips and to expand the sublevel dumpings being more suitable for reclaiming and further management intensifies the hazard of pollution of surface and underground water. Such a situation results from the enlargement of dumping sites on the one hand and from the contact with ground waters on the other hand this contact being easier many a time. This is particularly the case when the excavations with permeable base are filled with waste rock. The actual trend of building large dumpings from several dozen to several hundred hectares in area intensifies the impact of waste on the quality of underground- and surface waters within the dumping site.

Until recently the impact of dumpings on the contamination of waters at the USCB was disregarded. It is since the recent years that their increasingly contaminating effects have received due attention in Poland and the potential impacts of dumpings to the water quality have been taken into consideration in their siting. Research work was commenced and its results were presented in some publications /e.g. Libicki (1977), Twardowska (1981), Herzig and al.(1986), Szczepańska, Twardowska (1987)/. It is from these publications that the data as given herein are taken.
Taking into consideration the annual production of coal mine spoil in the USCB and the mean sulphate production estimate at the rate of 20,8 g/tonne of spoil/day the total annual sulphate production in the spoil deposited within the tips has been found to amount some 740 000 tonnes $SO_4$/year. The annual chloride load has been estimated to be about 65 000 tonnes/year. Also the heavy metals which are present in spoil in trace concentrations, are the essential factor of water contamination in the vicinity of tips.

The basic processes occuring in the course of chemical and biochemical decomposition of the spoil as well as during its leaching by atmospheric precipitations and underground water include:
- oxidation of iron disulfides (pyrite, marcasite),
- neutralization of sulfuric acid being formed due to the buffering ability of the spoil as well as the removal of the products of sulfide oxidation and neutralization beyond the system,
- dissolution and leaching of carbonate minerals,
- ion exchange,
- dissolution and leaching of chlorides.

At the same time micro-components are being leached including those of heavy metals exhibiting a high degree of toxicity for the aquatic environment.
Of the chemical components leached from the coal spoil, chloride ions are most important because of their high mobility. As to the origin of the presence of saline waters in the Carboniferous limnic formation of the USCB different opinions have been published by the authors interested in this problem. This question is the subject of a special paper published in this volume.

As to the scale of water contamination caused by coal mine spoil tips we can use the example of the Smolnica tip in the USCB. The data referring to this example have been recently published by Szczepańska and Twardowska /1987/, who carried out long-term investigations of water quality in the vicinity of this tip.
The mentioned authors have come among others to the following conclusions. "Total dissolved solids concentrations in waters beneath the tip have increased from 6 to over 14 times, in comparison with those in adjacent natural waters flowing towards the tip on its uphill side. Sulphate concentrations increased from 11 to more than 33 times, and chloride content from 2,5 to over 25 times. The chemical type of water changed from $HCO_3$- Ca- Mg for natural waters flowing towards the tip to $SO_4$- Na or $SO_4$ - Cl - Na in waters bene-

ath the tip. The quality of natural waters flowing towards the tip fullfill the standards for tap water, water quality in drainages, water-courses and ponds below the tip exceeds not only the standard limits for tap water, but also the standards for the lowest quality class for the inland waters." As to the distance from the tip in which the contamination can be observed no detailed data are available by now.

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