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Project Summary

Impact of Coal Refuse Disposal on Groundwater

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This study examines the extent of groundwater quality deterioration when coal mine refuse is disposed of in open pits. Disposal methods are also developed, and procedures for planning and designing disposal sites are formulated.

The study was conducted from 1975 to 1979 at an abandoned sand pit near Boguszowice, Poland. Groundwater was monitored, and laboratory testing was conducted on wastes and leachates. These studies determined the physical-chemical character of the waste material and its susceptibility to leaching of particular ions in a water environment. Also examined were the influence of precipitation on the migration of pollutants to the aquifer, and the level of groundwater pollution in the vicinity of disposal sites and its dependence on local hydrogeological conditions (particularly on hydraulic gradients). Recommendations are made for improving waste storage technology to limit the effect on groundwater and for designing a monitoring system.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The increased mining of coal and its processing for combustion during the 1970's has resulted in large quantities of coal solid waste. One common disposal method for this waste is placement in previously exploited open pit mines, but this method creates potential hazards to the groundwater.

The influence of coal waste and ash disposal on groundwater quality was investigated between 1973 and 1976 by the Central Research and Design Institute for Open-Pit Mining (POLTEGOR) as part of the U.S. Environmental Protection Agency's (EPA) overseas activities. A small test disposal site with a capacity of 1,600 m^3 was used to investigate the influence of ash and refuse disposal on groundwater quality. Similar tests were also conducted for a short period on a large disposal site with a total capacity of 2 million m^3. Tests were also performed on groundwater and analog models to investigate pollutant migration in groundwater.

Upon completion of the project, EPA published the final report in the Interagency Energy-Environmental Research and Development Series (Effect of the Disposal of *Coal Waste Ashes in Open Pits;* EPA-600/7-78-067, NTIS No. PB 284-013). This report presented a number of conclusions relating to the pollution hazard and a number of recommendations on methods for reducing the hazard.

In 1976, EPA and POLTEGOR agreed that it was important to verify the conclusions of the report by further studies at the large disposal site. A 5-year study was undertaken from 1975 to 1979. This report presents the results of the study on the large refuse disposal site and its impact on groundwater quality. Recommendations for groundwater monitoring and coal waste disposal are included.

Disposal Site

The test disposal site was located in an old sand pit situated in Boguszowice, about 200 km southwest of Wroclaw, Poland. The sand was exploited for backfilling of underground bituminous coal mines until 1969. The site comprises three pits that have a total capacity of about 3 million m^3. The main (central) pit had a capacity of about 1.5 million m^3 and has been abandoned for nearly 6 years. The western and eastern pits were smaller. Beginning in 1975, coal wastes from a bituminous coal mine located in the vicinity was disposed of in the central and western pits.

The disposal site is situated on a morphological elevation. The natural surface elevation varies from 275 to 280 m above sea level, and the terrain slopes away in all directions. The surrounding area is covered with meadows and arable fields, and a forest lies about 1 km to the east.

The central pit, where wastes were disposed first, was about 500 m long and 170 m wide, with an average depth of 16.5 m. The pit bottom and slopes were sand, which sometimes contained clay and silt. The sand layer was about 7.5 m thick in the northern part of the disposal area and about 9 m in the southern part; but in some places it decreased to zero. The groundwater table was 0 to 2 m below the pit bottom.

The western pit, planned as a reserve disposal area, was about 580 m long and about 150 m wide, with an average depth of about 7 m. The bottom and sides were sand, which sometimes contained clay and silt. The thickness of the sand layer in the pit bottom varied from about 1 m in its eastern end to about 6 m in the western end. The groundwater table was 0.5 to 3 m below the pit bottom.

Climate

Since the disposal site was above the groundwater table, the amount of precipitation (which is the source of the aquifer recharge as well as the medium for pollutant leaching and transportation into groundwater) was vital to the investigation. These data should be helpful for applying the research results to other regions of the world.

The average precipitation for the region during the investigated period was 788.0 mm per year, varying from 633.0 mm in 1979 to 958.6 mm in 1975. The highest monthly precipitation was observed in August 1977 (156.5 mm), and the lowest was in February 1976 (3.6 mm). The maximum daily precipitation (62.5 mm) occurred in August 1975. The average temperature during the investigation was + 8.5c. The coldest month was - 4.2c and the warmest + 19c.

Waste Characteristics

A total of 2.09 million m^3 of waste was deposited in the two pits. The central pit received 1.51 million m^3, and the western pit 0.58 million m^3. About 96 percent of the waste consisted of coal refuse, and about 4 percent was of power plant ash.

Between 1975 and 1977, the surface area of the waste exposed to precipitation and percolation gradually increased from 30,000 to 100,000 m^2. Reclamation of the disposal site began in 1978 and decreased the exposed surface area in 1979 to about 78,000 m^2, despite the fact that the volume of wastes increased. The surface area is an important factor in determining the amount of water that can contaminate the groundwater by percolation.

To determine the leachability and pollution potential of the waste, representative samples were taken every 4 to 6 months from recently disposed material. About 10 kg of waste was delivered to the laboratory for each leaching test.

Samples were placed in glass columns 100 cm high and 12 cm in diameter. These were equipped with valves that regulated the rate of water flow through the waste. A sample was placed in the column on a layer of sand taken from the disposal area. The ratio of waste-to-sand thickness was about 4:1. The material was washed using a peristalic pump with distilled water in a closed cycle.

Three successive leachings were performed until 5 dm^3 of water had been used. Each leaching lasted 24 hours. For the first test the leaching rate was 1 dm^3/hr, and for the others it was 0.5 dm^3/hr. These rates could theoretically be compared with 88 and 44 mm of rain per hour, respectively.

Leachates were analyzed from a total of 11 samples to determine the pollution potential of the refuse (Table 1). The data indicate that the contents of the samples varied considerably but that the variations were within acceptable limits.

Groundwater Monitoring

In March 1974, 14 monitoring wells were installed to monitor the aquifer surrounding the disposal area. All monitoring wells were drilled by the dry method down to the roof of the continuous clay layer. The depths of the wells varied from 7 to 27 m. The lithology of all layers found in each well was described in detail, and samples were taken for laboratory analysis to determine permeability and specific yield. In 1977, three additional monitoring wells were drilled in the area northeast of the disposal site because a model analysis of the hydrodynamic network suggested that the groundwater flow might run in that direction.

Water samples for physico-chemical analyses were taken from the monitoring wells from 1974 (one year before disposal

Table 1. *Summary of Leaching Tests of Coal Solid Waste*

Designation	*Unit*	*Maximum*	*Minimum*	*Average*
pH		9.9	7.3	8.4
Conductivity	*μs/cm²*	2140	500	1500
TDS	*mg/dm³**	3372	548	1600
Cl	"	479	51	209.2
SO_4	"	230	50	164.6
Na	"	357	44.5	243.7
K	"	48	4.1	26.3
Ca	"	355.9	5.2	75.9
Mg	"	21.85	0.42	7.3
Mn	"	2.995	0.035	0.729
Fe	"	75.8	0.11	24.65
NH_4	"	4.46	0.32	1.733
PO_4	"	3.140	0.036	0.522
CN	"	0.066	0.003	0.0252
Phenols	"	0.088	0.008	0.0282
Al	"	38.5	0.175	11.71
Zn	"	3.085	0.360	0.883
Cu	"	0.925	0.019	0.1974
Pb	"	0.271	0.034	0.1956
Cr	"	0.089	0.011	0.0364
As	"	0.133	0.008	0.0581
Sr	"	2.050	0.037	0.406
Hg	"	10.9	0.6	5.17
Cd	"	0.056	0.005	0.024
Mo	"	0.029	0.003	0.017
B	"	3.600	0.095	0.855

$*mg/dm^3 = mg/L$

began) until the end of 1979. Sampling was performed on a regular 3-week interval. Until October 1976, every fourth sample was taken for full analysis (42 parameters), whereas all others were taken for simple analysis (14 parameters). After October 1976, every third sample was taken for full analysis. A total of 85 sets of water samples were taken for physicochemical analysis between 1975 and 1979; of these, 26 sets received full analysis.

Results

The leachability of pollutants in the column studies may be divided into three groups: The components most easily leached (Cl, SO_4, Na, K), the components of medium leachability (Cu, Zn, Hg, Sr, Cd, B, Mn, Mo, CN), and the components characterized by the slowest leaching (Mg, Al, Cr, As, Pb, NH_4, Ca).

The glass column leaching experiments showed that on the average, the following masses of particular pollutants were leached from 1 kg of coal wastes:

Item:	Amount (mg/kg)
TDS	320
Cl	41.8
SO_4	32.9
Na	48.74
K	5.26
Ca	15.18
Mg	1.46
Mn	0.146
Fe	4.93
NH_4	0.347
PO_4	0.104
CN	0.005
Phenols	0.0056
Al	2.34
Zn	0.177
Cu	0.0395
Pb	0.0391
Cr	0.0073
As	0.0016
Sr	0.081
Hg	1.03
Cd	0.005
Mo	0.003
B	0.171

Data developed in this manner could be used to forecast the amounts of leachable pollutants contained in stored coal wastes (see Table 2).

It was observed in the column studies that colloidal sediments were flushed from the coal waste and settled on the sand layer. This material caused a gradual and then complete sealing of the sand and column.

Table 2. *Comparison of Actual Groundwater Pollution Versus Glass Columns Leachate*

Designation	*Ratio of Groundwater Values/Leachate Column Values*		
	Maximum	*Average*	*Minimum*
pH	0.82	0.75	0.70
Conductivity	0.53	0.307	0.20
TDS	0.34	0.20	0.12
Cl	0.35	0.19	0.09
SO_4	1.28	0.72	0.36
Na	0.34	0.14	0.04
K	0.43	0.21	0.10
Ca	0.71	0.45	0.23
Mg	2.38	1.40	0.74
Mn	1.08	0.36	0.15
Fe total	0.355	0.152	0.013
NH_4	1.43	0.705	0.32
PO_4	0.10	0.047	0.017
CN	0.68	0.23	0.09
Phenols	0.23	0.13	0.07
Al	0.038	0.02	0.02
Zn	0.56	0.19	0.09
Cu	0.5	0.16	0.01
Pb	0.24	0.13	0.05
Cr	0.21	0.15	0.06
As	0.98	0.47	0.08
Sr	0.53	0.36	0.23
Hg	0.25	0.12	0.05
Cd	0.24	0.15	0.09
Mo	1.41	0.49	0.13
B	0.11	0.08	0.06

This research confirmed that coal refuse disposal in an abandoned open pit in which the refuse may have contact with an underlaying aquifer deteriorates groundwater quality. The level of groundwater contamination depends first of all on the leachability of the wastes. Other significant factors include (1) the amount of precipitation percolating into the disposal site (which depends on the area of disposal surface exposed to precipitation and the amount of precipitation), and (2) the self-sealing of the disposal site bottom by the fine clays washed out from the waste that settled at the aquifer roof. This process was observed in the column studies, but could not be proven at the field site because the waste aquifer interface was not sampled and water levels in the waste pile were not measured.

The first indications of groundwater pollution occurred in the form of singular waves of pollution in specific wells in 1976 (i.e., 12 to 18 months after disposal operations had begun). But, these developments were difficult to monitor. Continuous pollution began in early 1977, 2 years after the commencement of storage operations (Table 3).

The waste caused significant pollution of the aquifer only in the direction of the greatest declination in the groundwater table. The pollutants did not migrate in the form of a wide, uniform front, as predicted by hydrodynamic net analysis; rather, they migrate in the form of narrow veins. This finding has been proved by comparing pollutant concentrations of particular wells in the potentially polluted zone. Results were not very uniform, demonstrating that local differences in aquifer permeability determine pollutant concentration (i.e., the higher the permeability, the higher the pollution), especially after 3 years.

Heavy pollution persisted for 2 ½ years and then decreased. This phenomenon could be explained by two factors: First, the surface area of the disposal site exposed to rain infiltration was reduced by careful reclamation of 30% to 40% of the total disposal surface; and second, the inferred self-sealing of the bottom of the disposal site when the silty wastes were washed from the disposal body and settled at the bottom of the pit.

According to the model developed earlier, the sequence and duration of pollutants occuring in particular wells from the beginning of storage could be predicted with 80 percent accuracy.

The system of monitoring wells in the shape of five radial lines was sufficient to monitor the aquifer for potential pollution. In practice, however, a smaller number of wells would be sufficient.

Three-week intervals for groundwater sampling and measurements were suffi-

Table 3. *Comparison of Groundwater Quality Before and After Waste Storage*

Designation	Unit	Average Concentration Before Disposal	Average Concentration During Disposal	Maximum Concentration During Disposal
pH		6.66	6.25	6.88
Conductivity	μs/cm^2	247.1	460.72	801.0
TDS	mg/dm^3*	169.2	329.13	550.07
Cl	"	15.08	40.84	72.73
SO_4	"	54.1	117.98	209.89
Na	"	7.84	33.50	81.99
K	"	2.77	5.51	11.31
Ca	"	16.26	34.11	53.60
Mg	"	4.95	10.23	17.39
Mn	"	0.24	0.266	0.79
Fe total	"	4.60	3.7433	8.75
NH_4	"	0.43	1.22	2.47
PO_4	"	0.014	0.0244	0.053
CN	"	0.0049	0.0059	0.0172
Phenols	"	0.0034	0.0036	0.0066
Al	"	0.16	0.181	0.444
Zn	"	0.360	0.1672	0.497
Cu	"	0.023	0.0102	0.0313
Pb	"	0.0165	0.0246	0.047
Cr	"	0.0064	0.0056	0.075
As	"	0.0168	0.0274	0.057
Sr	"	0.130	0.1472	0.216
Hg	"	0.630	0.6294	1.300
Cd	"	0.0024	0.0037	0.0058
Mo	"	0.0148	0.0083	0.024
B	"	0.032	0.0685	0.095

*mg/dm^3 = mg/L = ppm

cient, and in practice, measurements could be reduced to once a month.

The schedule of physico-chemical analyses (i.e., measuring 19 parameters for every set of samples and 42 parameters for every third set of samples) is appropriate.

Recommendations

The full report recommends methods for the design and monitoring of coal refuse disposal sites. Subject areas discussed are: (1) waste classification and examination; (2) site classification; (3) planning and designing disposal sites; and (4) design of monitoring wells and sampling systems.

Coal waste is divided into two subgroups —dry and wet wastes. Of the two, the wet waste has a greater potential for creating groundwater pollution because of its fine granulation. Disposal methods are thus discussed in relation to this subgroup. Chemical analysis of the refuse is not recommended as means for characterizing it. Column leaching tests are preferred because the results are more representative of the chemical character of the leachate that will be found at the disposal site.

The following criteria should be considered when classifying and evaluating open pits for the storage of coal refuse and the protection of groundwater:

1. The hydrogeological criteria based on the relationship of the disposed material and the threatened aquifer.

   Two situations are recognized—the dry disposal site, in which waste is situated above the groundwater table, and the wet site, in which waste is situated below the groundwater table. The four dry site subgroups discussed are waste located within (a) the impermeable layer, (b) the permeable layer, (c) the impermeable layer underlined with an unsaturated permeable layer, and (d) the unsaturated permeable layer and underlined with an impermeable layer. The four wet site situations are waste located within (a) the impermeable layer underlined with an aquifer with hydrostatic pressure, (b) the permeable layer underlined with impermeable layer, (c) the impermeable layer directly underlined with an aquifer with hydrostatic pressure, and (d) the permeable layer.
2. Hydrogeological criteria based on the relationship of the disposed material and aquifer permeability.
3. Criteria for aquifer protection based on aquifer use.

Planning the storage of refuse in an open pit should be preceded by a knowledge of the coal refuse characteristics (including its leachability), detailed investigation of the hydrogeological conditions, and assessment of aquifer use. The full report discusses methods for surveying the site and aquifer situation and the design of a monitoring system.

The full report was submitted in fulfillment of Contract No. J-5-537-1, by Poltegor, Powstancow SL.95, Wroclaw, Poland, under the sponsorship of the U.S. Environmental Protection Agency.

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The complete report, entitled "Impact of Coal Refuse Disposal on Groundwater," (Order No. PB 83-193 649; Cost: $17.50, subject to change) will be available only from:

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