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WATER PROBLEMS IN SPANISH COAL MINING

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ABSTRACT

The paper describes and classifies the major hydrological problems affecting coal mining in Spain. Water problems of both surface and underground mines are described. For reasons of brevity the description of the remedial measures used to overcome these difficulties is deliberately excluded.

GEOLOGICAL ENVIRONMENT

The report on Spanish coal deposits, published by the Centre for Energy Studies (1979), identifies a total of 59 coalfields (figure 1) distributed in twelve zones, to which new coalfields discovered in recent years must be added. Some 200 companies are involved in mining activities in these coalfields.

In Spain, the bituminous coal and anthracite deposits are Carboniferous in age. They are mostly situated in the provinces of Austrias, Leon, Palencia, Ciudad Real and Cordoba. The pre-Stephanian paralic deposits are well developed in Asturias where they have been severely deformed by the variscan folding developed there during the Westphalian time. On the contrary, in Southern Spain, pre-Stephanian deposits have limnic characteristics and are not so strongly deformed; they postdate main variscan folding which occurred earlier than in Asturias. The uppermost Carboniferous (Stephanian) coal deposits are everywhere limnic and their tectonic structure is gentle, except in some places where they have undergone intense alpine deformations.

The lignite deposits, in which are included the black and brown lignites, and the peats, with ages ranging up to Cretaceous, Paleogene and Neogene, are located in Galicia, Aragon, Catalonia, the Balearic Islands and Andalusia. Their structural arrangement may be tabular or homoclinal in some areas (f.i. Ebrobasin), whilst within the folded belts (Pyrenees, Iberian Range) of alpine age it is gently or moderately deformed for the deposits predating the foldings. In some intermontane (Granada basin in the Betic Cordillera, Cerdanya in the Pyrenees, f.i.) and foreland (Puentes de Garcia Rodriguez and other, in Galicia), Neogene and or Quaternary lignite and peat deposits occur and show tabular or gently deformed structures.

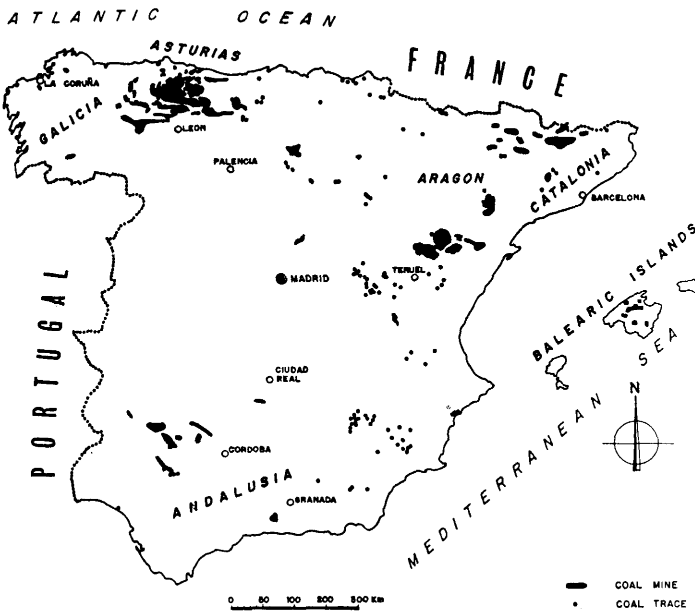

Figure 1: Location of coal mines and coal traces, in Spain (CEE, 1979)

MINING METHODS

Owing to the diversity of structure, seam thickness and dip, and geomorphology, these deposits are mined in many varied ways and consequently in very different hydrogeological surroundings. In addition, a representation of practically all hydrogeological mining problems exists in this country due to the lithostratigraphical diversity and different acquifer behaviour of rock masses affected by the mining operations.

Underground Mining

Steeply Dipping Seams:- In the case of the deposits steeply dipping or sub-vertical seams the most common mining method is the modification of the metalliferous mine stoping system; incorporating a pickhammer, sometimes assisted with explosives, with electrically or pneumatically operated coal cutters. The ground support is obtained as with timber with protection with packing, complete or otherwise and dependant on roof characteristics. Complete packing is becoming general practice, otherwise the caving is protected with timber packs.

Thick vertical seams are also mined using the methods of sub-level stoping and sub-level cavings or stope, mining manually or with explosives. Strengthening is with timber and controlled roof caving is producted to avoid packing. The sub-level method is also used in wide seams with horizontal levels and packing of the rock that is left between each level.

Moderately Dipping Seams:- Seams dipping between 40° and 25° are usually worked by sub-level cavings, sub-level open stoping or stope mining systems. Mining is with a pickhammer (sometimes with the aid of explosives) or with different types of coal cutter. As the inclination of these openings is not suitable for introducing packing under gravity, mechanical strengthening is used for support (powered supports or individual hydraulic or yielding supports). Strengthening is with timber in the roadways, with rubble or wooden packs, but with caving in of the post-workface, on recovering the pillars.

Level Seams:- For gently dipping and sub-horizontal seams a higher degree of mechanization is possible using ploughs or coal cutters with individual hydraulic or yielding supports (powered or movable) but always with post-workface caving. When the seams are more altered, or in the smaller mines which cannot justify mechanization, the sub-level stoping or the rooms and pillars method is used, with variations adapted to each coalfield. Coal mass caving is used for thick seams, employing transverse workfaces up to the side walls.

OPEN-PIT MINING

This is gradually becoming more important, with major examples of workings in Galicia, Asturias, Teruel, Catalonia, Ciudad Real and Cordoba, some of which are of appreciable size and depth. In some cases, cut in the mountain side are worked for inclined seams, although cuts in structural tectonic depressions or in the upper part of outcroping fold structures are more characteristic. The author would like to point out that these cuts make it necessary to excavate both overburden and coal. Therefore, not only mining methods (dredging, excavators, bucket wheel conveyors, blasting) are affected, but also slope stability. All are conditioned by the presence of water and by drainage which are in turn conditioned by the permeability and structure of the seams. From a hydrogeological point of view, both the nature of the overburden and the materials in the excavated slopes internal and/or final, together with the berms, are of great importance in these workings.

HYDROGEOLOGICAL PROBLEMS IN UNDERGROUND MINING

It is important to note that given the large number of mines the diversity morphological and geological conditions, and the variety of mining systems employed, it is inevitable that the workings are affected in very different ways from a hydrological point of view

(a) Mines with no Water Problems

In this first group are included those old or new mines that have no previous or current water problems. For example, this is the case of the strip mine of the Valmisa company in Alcorisa (Teruel), which only has a flow of 3 litres/hour of water (emanating from surface sands), and does not affect mining operations. Also included is the open pit mine of Mine and Railway of Utrillas, S.A. which worked the black lignite seams from a lithological complex of sandstone, lutites, and carbonaceus sediments in Utrillas (Teruel).

(b) Mountain Mines with only Seasonal Flows

Included here are those mountain mines whose strata are more or less subjected to natural drainage through the surrounding valleys. In this case the gravity drainage caused by the mining operations is only seasonally affected with drainage through roadways or transverse access roads. Occassionally rapid drainage of perched water tables may occur. For example, the case of the Minera de Fontoria, S.A. anthracite mines in the Fabero coalfield (Leon), which are normally dry from May to October, but an overall inflow of around 100.000 m^3 (except for some very rainy years) is calculated for the rest of the year. The water is drained by gravity and, for the average annual production over the last 5 years of 81,776 tonnes, involves a small drainage ratio of 1.2 m^3/t of coal.

(c) Mountain Mines Intercepting Aquifers in the Unsaturated (Vadose) Zone

In this category are included those mountain mines that drain under gravity through the access crossroads or roadways which intercept acquifer systems that are partially confined to the mining level. They provide a permanent gravitational flow, as a result of the drainage process due to extension of the mining operations, and to natural or induced recharge of the underground acquifer system. To this water with a slow hydrological cycle, other short-time cycle water may be added as a result of the direct inflow of rain-water or surface runoff in rainy periods, either through old workings that reach up to the surface, or through the fractures caused by the mine roof collapse, or through other structural discontinuities. The water inflow rates in these roadways or cross-cuts and adits usually increase with depth. An example of this type is Antracitas de Velilla, S.A. Mines that operate an underground mine, without stowing, of eight seams of Westphalian-D coal, with thicknesses of between 16° and 35°, with an average of 20°. Mine access is through seven cross cuts located at different levels (between 1,225 m and 1,545 m), with lengths varying between 80 m and 1,500 m. The deposit, whose coal seams do not outcrop at the surface, is affected by a complex fault system. In the stratigraphic sequence both marine and terrestrial layers are represented (in the latter, sandstone of greater or lesser porosity is abundant).

Rainfall for 1984/1985 was 975 mm, and the total water inflow from the different levels over this period was between 21 and 126 l/s, with an average of 74 l/s, so that with an average annual production of 160,000 gross tonne in the last five years, this means a drainage ratio of 14.5 m^3/t of coal.

It is important to emphasize that the minimum flow rates, drained away by the different floors, are very similar (from November 1984 to October 1985 the minima have varied between 181 and 390 m^3/day, with an average of 257 m^3/d). These inflows, to a certain extent must respond to the "base flow rate" of the acquifers. The average flow rates in these roadways, as is typical in this type of mining, show a regular increase with depth. It is a consequence of the inflow to the base flow rate of the water corresponding to the fast rainfall infiltration cycle through the mine working, as is confirmed with the maximum flow rate trend (Fig 2) of 2900 m^3/d.

(d) Underground Mines Below Piezometric Level

This category comprises underground mines that are worked below the piezometric level, where access is by pit shafts or descending ramps. In these cases, it is necessary to pump out the water drained by the mine working. Some working areas in these mines may correspond to the previous two categories.

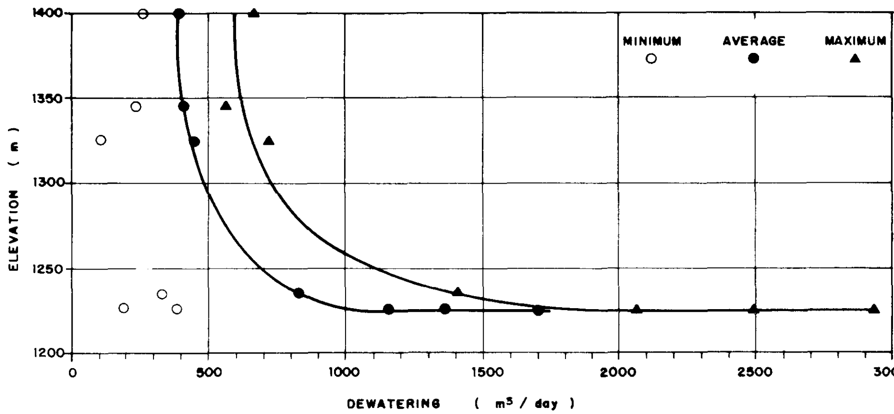

Figure 2: Dewatering trough the access galeries at different underground mining levels in Antracitas de Velilla mine (November 1984 to October 1985)

The water inflow to the mine may come from the storage in aquifers affected by the cone (in which case the flow rate falls if the mine development involves a drainage greater than the water released from the storage). It may also come from renewable resources, by means of natural or induced recharging of surface or ground water.

This is the most common hydrogeological category of underground mines. They may be classified in sub-groups as a consequence of the mining-hydrogeological environment in which they are located, and of the mining methods employed. It it therefore of interest to describe some typical cases in this category.

(i) The first sub-group includes those mines that involve relatively plastic materials with low permeability and little recharging, contributing a small amount of water to mine workings. For example the underground lignite workings of Minas y Ferrocarril de Utrillas, S.A. in the province of Teruel, which has a total dewatering of 1,000 to 1,200 m^3/d (12 to 14 l/s), which is a low yield despite the great size of the underground workings. In this case the water comes from sandy sections inter bedded with clays and marls intersected by the mine shafts (3.8 l/s contributed by the San Just Shaft and 2.5 l/s by the Pilar Shaft); or by point inflows from dripping from gallery roofs in production levels and from old workings (with flow rates below 0.5 or 1 l/s). If we take into account that, in this mine, average lignite production for 1980-84 was 440,000 tonnes/year (with variations between 392,000 and 501,000 tonnes), the average drainage ratio is 0.8 to 1 m^3/t of lignite.

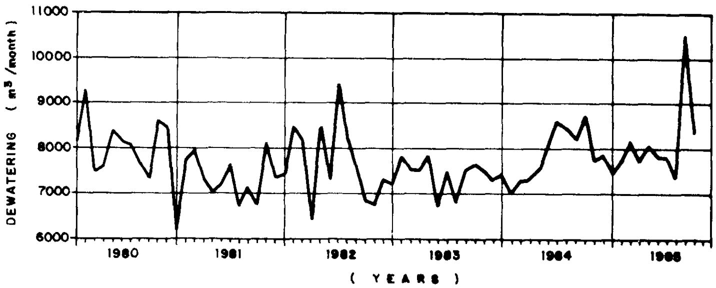

Figure 3: Dewatering in underground workings, Lieres Mines (Asturias)

A similar case is the Minas de Lieres, S.A. in Asturias, although there is a greater variability in drainage flow rates here. For the period between January 1980 and September 1985 the monthly volumes varied between a minimum of 6,425 m^3 and a maximum of 10,513 m^3 (Fig 3). This is equivalent to 207 m^3/d (2 l/s) and 339 m^3/d (4 l/s), with a daily average of 252 m^3/d (3 l/s) and a variation of only 1/1.6. For the average production over this period of 157,335 tonnes/year (with a minimum of 151,072 tonnes and a maximum of 166,169 tonnes), the drainage ratio was only 0.6 m^3/t of coal.

(ii) A second sub-group contains those underground workings, below the piezometric level, with temporary cyclic variations as a result of direct access of rainfall or surface runoff in rainy periods. This subgroup has significative variations from even day to day, month to month, or year to year. For example, the San Jose and San Rafael Shafts (Fig 4) of the Empresa Nacional Carbonifera del Sur, S.A., in Penarroya-Pueblonuevo (Cordoba), with reduced inflows, that largely arise in old surface and underground workings, totalling a drainage ratio of only 1 m^3/t of coal for the annual average production of 220,000 tonnes of coal, although dewatering of 654,000 m^3 of water was necessary in 1974.

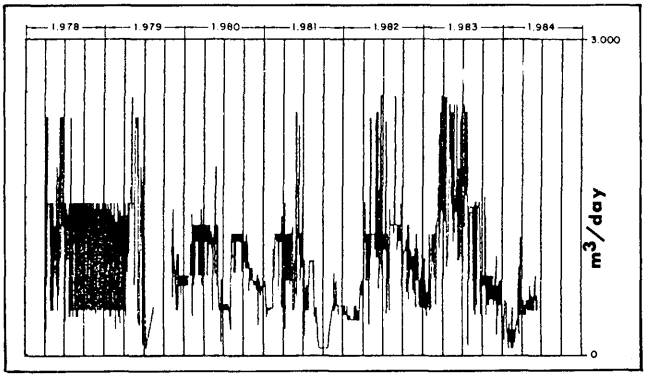

Figure 4: Dewatering in San Rafael Shaft (Cordoba)

This group also includes the workings of Antracitas de Gaiztarro, S.A., in Leon, with three underground collieries (and one strip mining operation) in regular seams, throughout all of the panels. These are mined with mechanical longwall faces and with total caving. The strata in the roof and floor adjacent to the coal seams comprises slates and lutites of variable thickness, with thin layers of coal that grade laterally to sandstones, microconglomerates and conglomerates of different grain size (lacustrine and fluvial deposit environments). One of the three mining collieries (Escandal) recorded a minimum inflow of 373 m^3/d (4 l/s) for the period April 1984 to November 1985, compared to a maximum of 3,000 m^3/d (35 l/s), with an average of 970 m^3/d (14 l/s). This means a variation of 1/8. For the output of 472,000 gross tonnes, in those 19 months, implies a drainage ratio of 1.2 m^3/t of coal.

A special case with these seasonal variations is shown by mines located in areas where a substantial part of precipitations occurs as snow, so that the maximum arise when the snow melts in spring. This is the case, for example, for the underground mine of Antracitas de Montebismo, S.A. in Santa Maria de Redondo (Palencia), in the southern slope of the Cantabrian Mountain Range, where the peak flow rates occur towards old mountain workings that reach the surface, as well as along a fault connecting the access ramp with the Lombatero stream.

The direct access of water through mine workings that reach the surface is also the case of Minas de Figaredo, S.A., underground mines in the river Turon basin (Asturias), in which, despite all of the streams being channelled and concreted, there is a net increase due to surface runoff and rain water infiltration that is added to the abundant inflows from the acquifers intercepted by the mining work. Thus dewatering, which is carried out from two shafts, gives the extreme figures shown in table 1.

Table 1

Shaft	Depth (m)	Pumping August-September	Pumping April-May
San Inocencio	496	3,442 m^3/d (40 l/s)	8,445 m^3/d (98 l/s)
San Vicente	356	4,320 m^3/d (50 l/s)	7,320 m^3/d (85 l/s)
Total	-	7,762 m^3/d (90 l/s)	15,765 m^3/d (182 l/s)

These shafts are provided with three and seven pump units, respectively, with a total installed power rating of 1,900 and 1,550 HP.

In this mine, in accordance with the average production for the last five years (451,140 tonnes with extreme figures of 421,597 and 474,546 tonnes), an average drainage ratio can be estimated at 10 m^3/t of coal.

Table 2: Coal production and water statistics in some Spanish coal mines

Pozo	Production (Tm Coal) 1980	1981	1982	1983	1984	Ratio de Desague (m^3/coal raise) 1980	1981	1982	1983
San Antonio	339.062	275.397	274.816	279.047	245.262			22	26
Santiago	253.926	290.324	312.890	287.052	279.497				
Aller	236.252	278.919	263.594	266.401	229.474				
San Jose	278.625	280.663	301.552	298.239	253.806	6	5	3	6
Santa Barbara	207.585	204.174	265.324	222.688	214.466	14	11	6	14
Barredo	239.575	228.277	244.557	235.924	210.840				9
Polio	230.324	204.906	234.169	220.243	214.010		14	11	15
Tres Amigos	189.213	190.530	196.036	177.063	173.070			4	6
San Nicolas	393.005	436.650	453.788	453.626	407.763	7	6	5	7
Montsacro	351.307	319.660	368.878	347.421	355.099	3	4	3	5
Olloniego	0	0	0	0	45.610	-	-	-	-
Pumarabule	287.878	305.218	336.937	308.319	281.270				
Mosquitera	165.386	141.145	123.371	144.928	136.961	7	7	7	8
Candin	740.300	466.684	432.817	390.527	388.638	3	4	4	6
Fondon		279.396	314.640	293.558	219.929		6	3	5
Soton	362.038	372.030	385.334	273.724	353.720	9	8	7	12
Venturo	200.967	206.528	206.139	216.298	203.454	2	2	2	2
Maria Luisa	456.255	447.585	445.843	382.559	402.914	10	8	7	11
Samuno	368.179	408.857	345.584	392.719	372.712	5	3	2	4
Carrio	194.276	211.516	218.518	200.557	186.204		16	14	22
San Mames	242.157	234.937	237.554	237.173	216.768		6	5	7
Entrego	238.198	252.165	234.926	220.312	229.962		9	7	10
Cerezal	142.946	138.532	144.132	145.874	144.848		16	14	21

This sub-group also includes the majority of the collieries operated by Empresa Nacional Hulleras del Norte, S.A. in the Asturian coal fields (table 2). The dewatered volume trend over the last five years of 1980 to 1982, followed by a net increase in the wet year of 1983, with a slight trend to reduction or stabilization in the year of normal rainfall 1984 (all without a direct relationship to coal output).

This trend can be followed in greater detail by considering monthly figures, such as, for example, in the San Antonio Shaft in this coal field (figure 6) that not only shows this difference between a dry year (1982) and a wet year (1983), but also the repercussion of rainy months on the pumping operation (sometimes with a delay of one month).

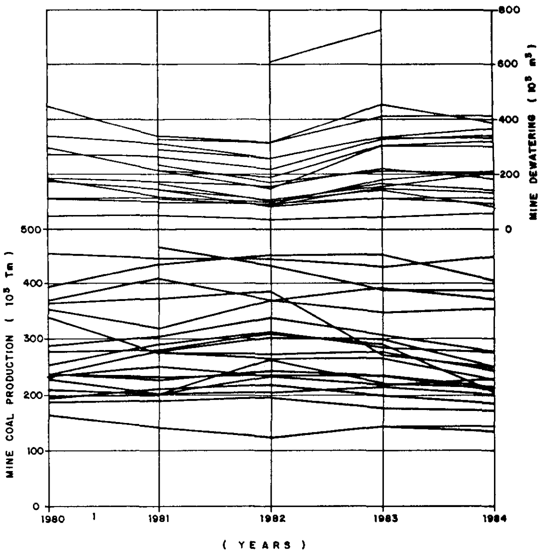

Figure 5: Mining dewaterings and shaft coal productions in Hunosa Collieries (Asturias)

This influence of external water inflows in a rapid cycle superimposed on the slow cycle of acquifer drainage is also shown when comparing the minimum and maximum inflows. Thus, for example, with data from eight HUNOSA shafts from the Modesta Group (five years) and from the Carrocera Group (four years), there is a minimum dispersion in the Maria Luisa Shaft (ratio 1/2.5) and a maximum in the San Mames Shaft (ratio 1/6.98), which seems to provide evidence of the lesser influence of the fast cycle inflows on the former shaft.

In the group of HUNOSA shafts the higher drainage ratio also occurs with the Maria Luisa Shaft at 26 m^3/t of extracted coal (50 m^3/t of washed coal). For the series of 20 shafts with available data (excluding the San Antonio, Aller and Olloniego shafts), a total of 46.7 Hm^3 of water has been pumped out in 1984 that, for a total output of 5,245,901 gross tonnes, gives a drainage ratio of 8.90 m^3/t.

Similar situations arise in the underground lignite mines on the Island of Majorca, operated by Lignitos, S.A., in an area with an average rainfall of 808 mm (for 1961-70), with a daily maximum of 112 l/m². The surface runoff here is only temporary, but when a torrent crosses the mine workings it has a maximum flow rate of 100/200 l/s. All the water is infiltrated, so that there are major variations betweeen the daily flow rates raised through the ramp (table 3), with a maximum ratio of

Table 3: Variation in the amount of water pumped per tonne of coal for a 5-year period in an underground lignite mine.

Year	Pumping dewatering (m^3/day) minimum	maximum	average	Production coal t	Ratio m^3/t
1981	675	5,425	1,703	43,490	14
1982	425	2,000	1,116	66,102	6
1983	408	1,869	2,264	57,599	14
1984	727	3,093	7,129	67,748	38
1985 ()	575	3,928	6,242	61,442	37

() Until October

Perhaps it is even more significant to point out that the increase in recent years of the dewatering ratio of these mines (with minor variations in coal output) has risen from a figure that could be considered as low, of 6 m^3/t in 1982, to a high value of 37 m^3/t in 1985.

Another underground mine that would belong to the same sub-group is that of Hulleras de Sabero y Anexas, S.A., in Leon, that is presently working 440 m under the pit surface.

Since mining started most production has been by caving and a large part of the rainfall (recording averages of between 1,000 and 1,200 mm per year) and some of the surface runoff reaches the mine through subsidence zones and accounts for the majority of the inflow. Despite the many roadways, no aquifers have been intercepted that would involve significant increases in the overall flow rate.

Table 4: Dewatering statistics for Hulleras de Sabero y Anexo in Leon.

Year	Pumping dewatering (m^3/day) maximum	minimum	average	Production coal t	Dewatering m^3/t
1980	6,768	456	3,408	309,064	4,047
1981	4,728	336	2,400	312,819	2,799
1982	10,032	576	2,664	320,865	3,020
1983	11,184	1,008	4,248	316,070	4,893
1984	8,904	1,008	3,816	310,874	4,490

In this way the dewatering over the last five years (table 4) has varied between a minimum of 336 m^3/d (4 l/s) up to a maximum of 11,184 m^3/d (129 l/s), with an enormous maxima to of 1/ and with an average of 3,307 m³/d (38 l/s) that, for an average output of 313,937 tonnes, a mean drainage ratio of 3.8 m³/t of coal.

Also included in this sub-group are mines of Minas de San Cebrian, S.A., in Palencia, that work four bituminous coal seams in the Westphalian-D. The lithological succession, from the bottom to the roof comprises sandstones or sandy lenses, with interbedded limestones, sandy slates which include the coal seams, and are covered by slates and sandstones.

The volume of water drained from this mine varies little from one year to the next but does share major variations from some months to others, with maxima in the months from February to April with flow rates of around 4,000 m³/day (46 l/s) and with an annual average of 2,385 m³/day (28 l/s). Thus, for an average output over the last five years of 64,650 gross tonnes raised, means a dewatering ratio of 13.5 m³/t of coal.

Finally, a problem associated with this type of mining operation, if unconsolidated sand is located nearby, is that of water inrush with large quantities of solid material. This is the case at the Innominada and Oportuna underground lignite mines in Teruel operated by the Empresa Nacional de Electricidad, S.A., and using caving and longwall mining methods. The thickness of the lignite seams is from 6 to 10 m in the former and 10 to 20 m in the latter, with Albian clays and sands in the roof. The sand layers (with an average permeability of 2×10^{-4} m/s and overall porosity of 20%) constitute confined acquifers between clay aquicludes with a hydrostatic head over the workings that varies from 110 to 230 m, and that has been the cause of sudden inbursts of large volumes of water and sand.

(e) Underground Mines with Rising Inflows

In this fifth category is included a mine with special problems due to the presence of a footwall aquifer with a high hydrostatic head, where the water inrush into the mine rises through the protective barrier of interbedded material.

This is the underground mine of Carbones de Berga, S.A., in Barcelona, that mines Cretaceous lignites by 250 m mechanised longwall faces with total caving.

The mined coal seams are interbedded with limestones and sandy carbonaceous marl beds, are 2 to 2.5 m thick, of which 65% is coal. The roof is formed by a thick overburden in which marls prevail (over 500 m thick). At the footwall, below 7 metres of sandy limestones with carbonaceous marls, there are 9 metres of fissured marly limestones and, below again, 35 metres of sandy marls and nodular marly limestones, followed by more than 800 m thick limestone, sandy limestone and sandstone formation of upper Maestrichtian age, in thick beds. Fracturing is conspicuous in these rocks.

The water reaches the mine rising from the footwall limestones due to the high hydrostatic pressure. This occurs in faulted area, where the 32 metres of limestone, sandstone and marlish materials are insufficient to provide an impermeable protection layer.

The rising inflow, comes from the storage of the aquifer, together with the fluvial infiltration (river Llogregat), and from direct rainfall infiltration in outcrops through the faults. To these continuous inputs must be added the sudden direct inputs due to infiltration through abandoned workings reaching the surface in rainy seasons.

Table 5: Pumping statistics for Carbones de Berga, S.A.

Year	Coal production clean ton	Pumping dewatering m^3/day	l/s	Ratio m^3/t
1980	240,445	2,880	33	4.4
1981	372,385	4,320	50	4.2
1982	248,974	5,760	66	8.4
1983	278,889	8,640	100	11.3
1984	433,326	18,720	217	15.8
1985	410,000 ( )	23,040	267	20.5

( ) Forecast

Under these conditions, the mine was flooded and mine workings stopped from November 1982 to April 1983 and unfortunately the inflow of water through the deep faults shows a continuous increase, as can be seen in table 5, with a considerable rise in the drainage ratio, that has grown by five times in five years. The problem is particularly serious because the inflow takes place when the mine workings have advanced, as the roof caving combines with wall decompression caused by the hydrostatic pressure of the underlying aquifer system, a condition that will become increasingly unfavourable as the mining work goes deeper.

(f) Recovery of Flooded Abandoned Underground Mines

The reinitiation of workings in abandoned mines requires dewatering beforehand both the water accumulated in the underground mine system and in the acquifers connected to it.

Such an example is the Belmez Shaft of Empresa Nacional Carbonifera del Sur, A.S., in Cordoba where 220,740 m^3 of water had to be pumped out in the year opening, although in normal operations with a production of 43,000 t/year it has a drainage ratio of only 0.6 m^3/t of coal.

WATER PROBLEMS IN SURFACE COAL MINES

(a) Open Pit Mining without Relevent Water Problems

Frequently this is the case in the initial phases of many mining operations, or where the working level is not too deep. The only water inflows come from superficial acquifers or from the weathered zone.

In this category are included the black lignite open cut of the Empresa Minas y Ferrocarril de Utrillas, S.A., in Utrillas (Teruel), where water inflow is associated with colluvial overburden, excavated as the mine advances. For a total inflow of 77 m^3/day, and an average yearly production of 409,439 t of lignite (during the last five years 1981-82), the corresponding drainage ratio is only 0.68 m^3/t of coal. However this ratio probably will become higher in the future in some areas where increasing thickness of the coluvial occurs (with risks of frontal landslides).

Also included in this category is the new Cervantes open-cut, of the Empresa Nacional Carbonifera del Sur, S.A., in Penarroya-Pueblonuevo (Cordoba) which has no significant water problems now but which may arise in the future in faulted and dip-slope excavation areas.

The last example in this category is the San Antonio open-cut mining by Cavosa in Belmez (Cordoba) which also has few water problems, but where the latest deep working level may have slope stability problems, due to the hydrostatic pressure in confined acquifer layers.

(b) Open Pit Mining below the Piezometric Level

In this category are a series of mines in which the problems of working under the piezometric level are combined with the problems of direct water inflow from rainfall or surface runoff common to all open-pit mines.

In general, this involves installing slope drainage in order to improve stability conditions. Consequently large volumes of water do not always have to be drained, as the unfavourable conditions are created more by the head of water than by the amount of water stored. Nevertheless, other mine-hydrogeological problems may exist.

An example of this type of mine is the As Pontes mine in La Coruna, worked by Empresa Nacional de Electricidad, S.A. with a yearly lignite production of 12 x 10^6 t, raising over 40 x 10^6 m^3 of waste. This strip mine is located in an area with an average rainfall of 1,650 mm per year (with extreme values over a period of records going back 35 years of 1,021 and 2,604 mm). A pumping capacity of 5,000 l/s has been required (518,400 m^3/day), with the construction of perimeter channels for peak flowrates, with a return period of 25 years, of 80 and 180 m^3/s in the North and South sectors, respectively.

The strata consists of alternating lignites, clays, sandy clays, sands and some gravel which were deposited in a terrestral basin of tectonic origin, in Neogene times. The bottom of the sequence consists of palaeozoic rocks. Thrusts and reverse faults are significantly developed in some of the basins borders. As a result Palaeozoic rocks can locally overlap the Tertiary sediments. During excavation large volumes of rock became unstable so that complex drainage operations are required in order to improve the safety factor and to prevent landslides. Drainage is required in both the Palaeozoic heterogenous rock system, (permeable due to fissuring) and in the Tertiary multi-layer system, where the acquifers are the detrital levels and the lignite itself.

A case with similar aspects to As Pontes is that of the Meirama lignite mine, also in La Coruna province.

A different mining-hydrogeological approach is that of the Emma Mine, of Empresa Nacional Carbonifera del Sur, in Puertollano (Giudad Real), where the small water inflow is presently connected by fracturing to surface runoff. Thus for an average production over the last five years of 700,000 tonnes per year gives a drainage ratio of only 0.2 m^3/t of coal. However, these conditions may change in the future, as mining will be reaching deeper levels and intercept abandoned flooded underground workings.

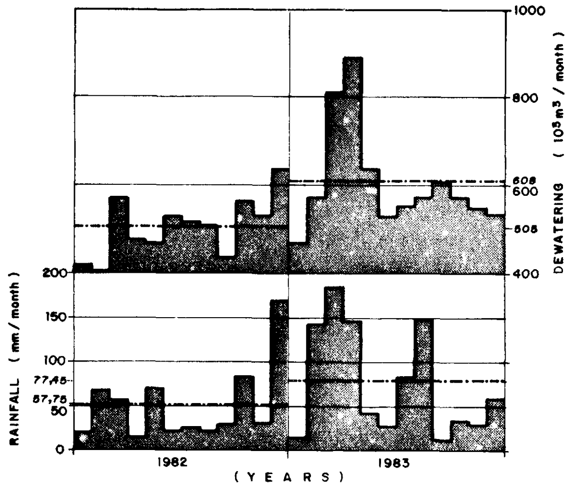

Figure 6: Dewatering evolution compared with the rainfall in San Antonio Shaft, Asturias (Hunosa Coal Mine)

A future mine in which water is expected to cause special stability problems is that of Lagoa d'Antela (Orense), of Empresa Nacional de Electricidad, S.A. The lignite here is below 100 metres of a multi-layer hydrogeological system, with unconsolidated clays and sands, and with palaeo-channels, and over a similarly confined artesian system with a hydrostatic pressure of over 100 metres. Similarly but with lesser problems, will be the Padul (Granada) peat mine, where the deposit is located on a confined detrial system, also under artesian conditions, and limited laterally by major carbonate acquifers, that close off the tectonic depression in which the deposit has organised.

CONCLUSIONS

Before ending this classification of the water problems in Spanish coal mining, I should mention that the cases described here can only be considered as examples of the hydrological problems arising in the coal mining exploitation. Many other cases have not been included because they do not provide new information.

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