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MINE WATER DRAINAGE

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INTRODUCTION

In general terms, surface mine developments and underground mine workings below the phreatic level invariably changes the hydraulic gradient, thus affecting the groundwater and surface water flow regimes. As a consequence, flow of water may be induced from the surrounding rock mass towards the mining excavations which may necessarily require pumping large quantities of water and creating extensive and prolonged cone of depression. Under these circumtances, hydrogeological, environmental and economic repercussions may take place, requiring to adopt an appropriate water management stretagy in order to reduce the socio-economic impacts of mine dewatering.

In 1978, in the preface of the conference proceedings of the Congress on Water in Mining and Underground Works (SIAMOS - 78), it was stated that water in mining poses a wide variety of problems. Amongst the major problems two issues, concerning the environment and the management of water resources, were considered to be most important factors confronting the mining industry. However, what could be seen as uncertainty fifteen years ago , has proved to be a reality today.

In this paper, the authors have attempted to characterise water inflows, together with techniques to forecast water inflows quantities and drainage methods for various mining excavations. In this methodology, the approach adopted includes different anthropogenic/ natural factors that can influence the yield volumes of inflows to the mining excavations. Taking into account a wide variety of units used by different authors and for the sake of consistancy, the mine water inflow is quoted in units m^3/hour, since this unit is most frequently used by mine operators. It may be noted that for hydrogeologists l/s is more widespread unit.

WATER IN MINING

The presence of water in mining sites creates a range of operational and stability problems and requires drainage to be carried out from the mine workings in order to improve slope stability, avoid oxidation of metallic sulphides and reduce corrosion of mining plant and equipment. The quality of the drainage water depends on a series of geological, hydrogeological and mining factors which can vary significantly from one mine to another.

Mine drainage water can frequently have quality problems, mainly due to the alteration of equilibrium conditions in underground water and, specially, due to the formation of so called acid mine water . This in turn creates a problem of dissolving heavy metals and carrying suspended particles of lithological materials existing in the affected area. For instance, in the anthracite mining region of Pennsylvania (USA), a total drainage rate of 93,960 m^3/hour has reached with an average pH of 4 and 38 mg/l of dissolved iron (Growitz, 1978). Similarly, in the lead-zinc underground mine at Bunker Hill, with a total volume of damaged rock of 21 km^3, created an average discharge of 576 m^3/hour, with a pH ranging from 4.0 to 4.7 (Ralston, et al. 1978).

In many cases the quality of mine water discharge is adequate for domestic, agricultural and industrial purposes. This happens more frequently due to the environmental challenge that mining have to face and due to the procedures established in order to preserve the original quality of the underground water, due to the use of the advance drainage technologies. The overdeveloping pollution control techniques minimise the effect on the physio-chemical balance of the hydrogeological systems.

In many surface mines and underground workings, it is necessary to carry out drainage in quantities mainly determined on the basis of the hydrogeological characteristics of rock mass involved. The quantity of mine water inflow from surface sources or rapid infiltration of rain water to underground workings will depend upon transmissibility of the formations, dimensions of the fractures, hydraulic head, thickness of the protective layers, etc. After analysing almost 1.500 cases of water irruptions in three mining areas affecting on two aquifer formations, Schmieder (1978 a) has presented distribution curves of the percentages inflows rates , fracture opening and transmissibilities (Figure 1). In the case of the Dorog Mine, the inflow variations ranged from 0.18 m^3/hour to 6,600 m^3/hour.

Furthermore, water enaminating from the drainage of the underground aquifer systems, is added the industrial water introduced for drilling operations or for hydraulic filling operations. Thus, in the Neves-Corvo Mine, Portugal, the flow corresponding to the service water is higher than the aquifer water, since hydraulic filling of stopes introduces large volumes of industrial water (Frasa, 1987).

DRAINAGE IN MINES

General behaviour

Although conventional classification divides mines between open pit mines and underground mines but from the point of view of the hydrogeology it is more appropriate to distinguish between mine workings over or below the piezometric level. The latter case has undoubtedly more hydrogeological repercussions; nevertheless, the effects of the former on water is not negligible.

The underground water requires the lowering of the piezometric levels and the depressurization of the underlying aquifers in order to be able to develop the mining activity. This activity undoubtedly includes metalliferous mining, coal mining, salt mining, or the so called industrial and ornamental rocks mining, quarrying, sand and gravels extraction.

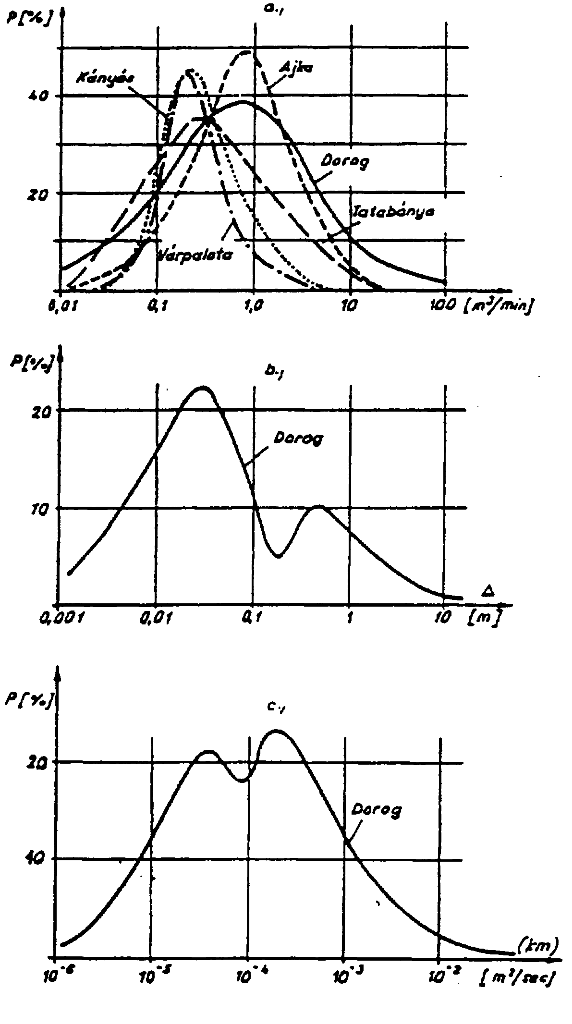


Figure 1. Density functions for (a)water inflow rates, (b) width of slits and caverns intersected by boreholes and(c) the transmissibility of local-faulted zones (Schmieder, 1978 a).

In many of these mines, the aquifer is the deposit itself, while in others it is more or less isolated by protective layers, which can be above or below the aquifers and can accumulate large reserves of water or receive resources by direct infiltration or can be in contact with the surface water. In case of large aquifer system it is normal to carry out certain over-exploitation of the aquifer systems , extracting large volumes of water, with very different rate of flow from one mine to another. In any case, the largest water inflows correspond with the areas of higher rainfall. Thus, in a study carried out in China over 15,750 mining deposits, including 137 types of mines, the conclusion drawn was that the influence of rainfall on drainage in mines is of utmost importance (Pei, 1988). For those who are not familiar with the mining activities, the mine inflows can be surprising high, and even unknown to many hydrogeologists in some cases. As a matter of fact, in many mines, the rate of extraction of water is much higher than that of mineral.

For examples, in many mines the inflow quantities are highly significant: with inflow rates of 50.000 m^3/hour in iron ore mine in Kursk, in the former Soviet Union; an inflow of 62.500 m^3/hour in the open pit lignite mine in Belchatow (Poland) and, inflow of 226.800 m^3/hour in the coal deposits of the former Soviet Union (Fernandez Rubio, 1986 b). In some cases, this inflow means that the high cost of pumping may result in lowering the narrow margins of profit for the mining business and compel temporary closure or definite abandonment of the business. This has been the case of the excavation of Number 2 Shaft in Konkola Mine (Zambia), which had to be abandoned after a pumping of 1.4×10^6 m^3 water during first seven months of operations without appreciably lowering the piezometric level. The mine itself had to be abandoned during six years due to a sudden water inrush flooding the mine (Stalker and Schiannini, 1978). This mine is widely considered as the wettest mine in the world, pumping of more than 15,500 m^3/hour (Sweeney, 1988), with a peak of 17,700 m^3/hour in June 1978 and an average of 13,400 m^3/hour in June of 1990 (Mulenga, 1991) (Figure 2).

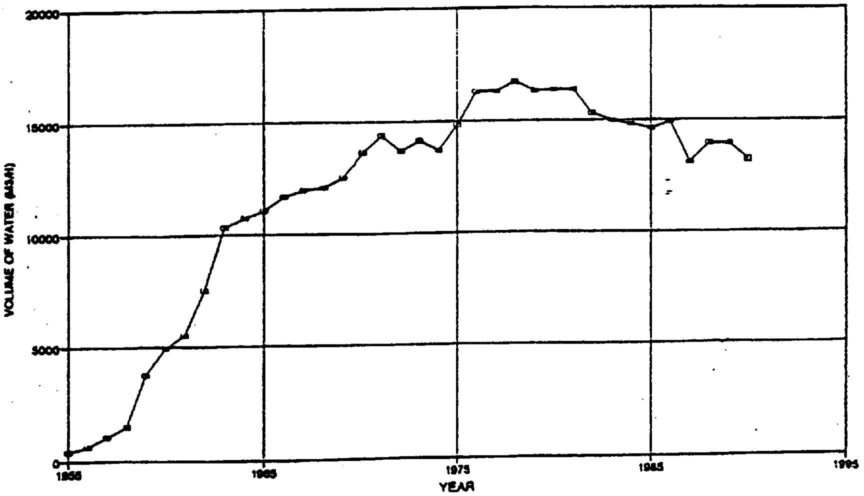


Figure 2. Konkola Mine. Average volume of pumping water (Mulenga, 1991).

In Neyveli lignite mine (India), 40 submersible pumps were used to extract 9,600 m^3/hour of water to reduce the pressure of the underlying aquifer down to 1.5 m below the working level, This means 24 tonnes of water was pumped for each tonne of coal extracted, and during the monsoon period another 16 tonnes of infiltrated water could be added (Banerjee and Shylienger, 1978).

Figure 3 shows,the variation in the ratio of water pumped and the tonnage of coal/mineral extracted in some of the largest mines in the world (Figure 3) ranging from 1:1 to more than 100:1 (Armstrong, 1988 and Mulenga, 1991).

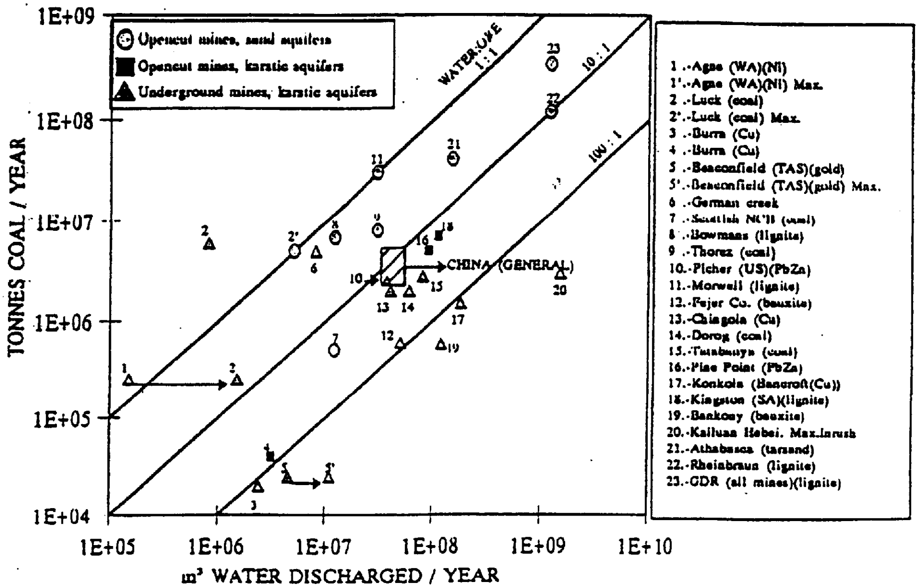


Figure 3. Ratio of mine water discharged to ore extracted in major mining areas of the world (Armstrong, 1988 and Mulenga, 1991).

In Spanish coal mines, an average is 2.5 m^3/tonnes of water is pumped per tonne of clean coal extracted, with values ranging from 1.2 to 4 m^3/tonne (Fernandez Aller, 1981). In Mufulira Copper Mine, Zambia, 5 m^3 of water per tonne of mineral is extracted (Wightman, 1978), while in Konkola, Zambia, the ratio has increased through the time, from 30 to 90 m^3 per tonne (Figure 4) (Mulenga 1991).

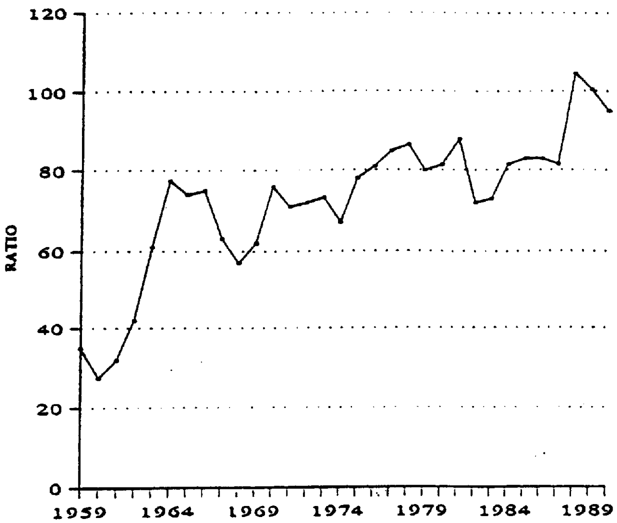


Figure 4. Ratio of volume of water pumped form the mine to tonnes of ore hoisted Konkola Mine (Mulenga 1991).

From the foregoing description, it can be concluded that the energy cost for pumping is relevant to the finacial success of the mining venture. In Pootkee Mine (Jharia Coalfield, India), a total power installed was 4,100 kW,out of which 2,240 kW was used for pumping (55%), with an specific consumption of 25 kWh per tonne of coal extracted (Banerjee and Shylienger, 1978). In Reocin Mine (Spain), drainage cost has been calculated to be 25% of the technical cost of mining (Trilla et al., 1978), with a pumping of 35 $\times 10^6$ m^3 water in 1979 (Fernandez Rubio, 1980).

In the Nchanga open pit mine in Zambia, the underground pumping system has an installed power capacity for pumping 7,200 m^3/h, although in 1976/77 the average amount of water pumped was approximately half of this quantity (Stalker and Schiannini, 1978). In the coal mine of Fengfeng (China), about 7,200 m^3/h of water is pumped (Chih-Kuei and Chang-Lin, 1978). In the copper mine of Nchanga (Zambia), a total of 41 $\times$ 10^6 m^3 had to be pumped during a period of four years, in order to reduce the piezometric level of 30 m/year. In this mine, until 1978, a total of 810 $\times$ 10^6 m^3 of water had been extracted (Stalker and Schiannini, 1978). In the Far West Rand gold mines in South Africa, which has reached the mining depth of three kilometres, below a karstified limestone and dolomites, the inflow of water is extraordinarily high. Thus Wolmarans and Guise-Brown (1978) on referring to the pumping in the Oberholzar Compartment mention a peak inflow of 170 megalitres/day (7,080 m^3/hour).

In Fanggezhuang Coal Mine in Kailuan coalfield (Hebei Province), North China, an inrush took place in June 1984 involving a inflow of 123,120 m^3/hour, accompanied by the collapse of a cavity of 60 m of diameter and a height of 313 m (Figure 5) (Baiying, et al., 1988; Pei, 1988). Another catastrophic inrush of 90,000 m^3/h, occurred in August 1966, in the Jiangbei Mine (Pei, 1988; Zhongling, 1988). Both inrushes are considered to be the largest inflow incidences in the world, although many extraordinary inrushes have taken place in Chinese mining industry.

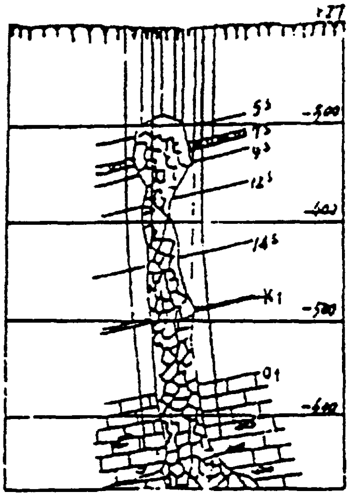


Figure 5. Fanggezhuang Mine. Collapse cavity (Baiying, et al., 1988; Pei, 1988).

From the analysis of more than a hundred water inrushes in Chinese mines in the karstic areas, Zhongling (1988) has established the type and distribution details of mine water in rushes in the Table 1.

Table 1. Types and distribution of water inrushes in Chinese mines in karstic areas Zhongling (1988).

Type	Discharge m³/h				Number (%)	
	Enormous >7.200	Large >3.600	Moderate > 1.800	Small < 1.800		
Cavity	4	1	3	10	18	17.1
Collapse	1	0	0	1	2	1.9
Underground river	1	1	0	0	2	1.9
Fault zone	5	8	11	13	37	35.3
Contact zone	0	0	2	4	6	5.7
Hangingwall aquifer	1	1	0	7	9	8.6
Footwall aquifer	3	7	3	16	29	27.6
Surface water inrush	2	0	0	0	2	1.9
Total	17	18	19	51	105	100.0

Forecasts for inflow of water in the Megalopolis Lignite open pit (Peloponnese, Greece), was 13 m^3/t of lignite during the first eleven years, afterwards, it was predicted to be reduced to 4 m3/t, with an estimated cost of US $ 0.33 per lignite tonne produced (1978 value)(Spiliotis, 1978). In this 500 million tonnes lignite deposit, the pumping of 245 $x10^6$ m^3 water was estimated, in order to reach the final depth (70 m). It would also be necessary to increase this estimated pumping capacity to $35x10^6$ m3/yearly of water resources.

All the data presented here, prove the relevance of the inflow of water that, in many cases, have to be drained to the mining operations. However, in any case, the greatest inflow rates in mining are related to karstic aquifers.

MODES OF INFLOW

The mode of inflow of water to mine workings can be classified into the following categories:

- o Variation of inflow rates as a Gaussian distribution.
- o Increasing inflow with time.
- o Constant yield.
- o Decreasing inflow with time.
- o Mixed inflow rates.

Rates of water inflow as a Gaussian distribution

In many large water inrushes, it is frequent to find a sudden increase in initial inflow for a short period that reduces gradually with time, reaching a certain stable state flow. This behaviour is typical in heterogeneous hydrogeological systems and, can be considered normal when water comes from the following sources:

- o Interception of prominent channels in a heterogeneous environment,
- o Access to confined and water-tight compartments,
- o Roof collapses with an effect on overlaying aquifers,
- o Water inrush of footwall aquifer through a protective layer,
- o Sudden inrushes of surface water associated with severe rainfall periods.

These are turbulent flows that can carry a significant quantities of suspended solid. When the irruptions occur in mine workings without leaving a protective layer, the flow rate is usually increased at a lower pace than in cases where the protective layer does exist. Likewise, in case of no protective barrier, the representation of the inrush percentages for the different flows has the form Gaussian distribution,when there is no protective layer (Schmieder, 1978 a) (Figure 6).

A typical example of this can be found in the Far West Rand gold mines, South Africa, which has a 1200m thick karstic aquifer in the hangingwall in pre-Cambrian dolomites, containing estimated groundwater volume of $2{,}200 \times 10^6$ m^3 (Schwartz and Midgley, 1975 in Wolmarans and Guise-Brown, 1978). The interception of the syenite dykes (between five and sixteen kilometres away, which isolated this aquifer, have caused frequent irruptions of water with high peak flow rate of 4,500 m^3/hour. For example, in the West Driefontein Mine, at a depth of 874 m, in a sector which had been previously found to be free of fissures, taking into account that the reconnaissance bore holes which indicated hardly any significant amount of water. The drainage of West and East

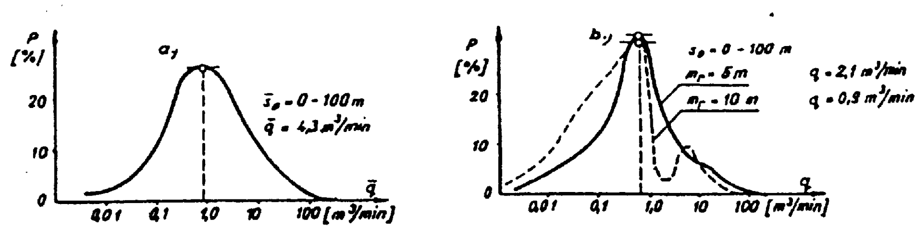


Figure 6. Density functions for water inflow rates (a) without protective layer effect and (b) the rates of water inflows influenced by the effect of protective layer (Schmieder, 1978 a).

Driefontein mines exceeded the yield of 14,000 m^3/h and stabilized at 3,500 m^3/h after seven years (Figure 7). In four mines in this area, with 25 years of average activity, a total of 1,997 . 10^6 m^3 had been pumped till 1976. Under these conditions, it seems logical that all attempts to drill mine shafts were unsuccessful between 1898 till 1930, when the grouting process was introduced enabling the completion of the first shaft in 1934 (since then, more than twelve mine shafts have been drilled.(Wolmarans and GuiseBrown, 1978).

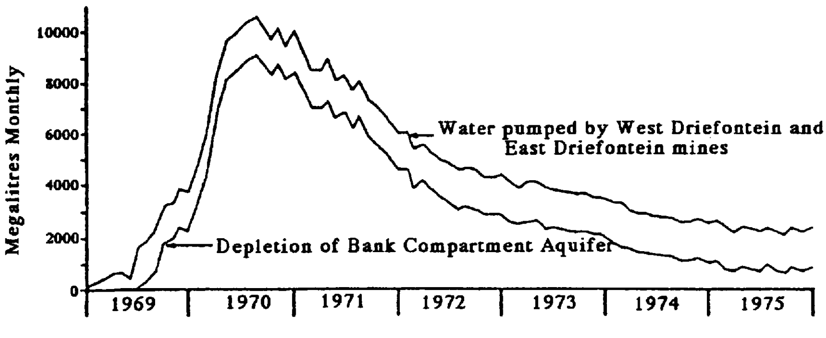


Figure 7. Progress made in depleting the aquifer by pumping in West Driefontein and East Driefontein mines (Wolmarans and Guise-Brown, 1978).

Another historical case is one of the deepest levels in Berga collieries, Spain, where the water pressure of the footwall karstic aquifer caused the irruption of the underlying confined aquifer. In this incidence the breakage and upheaval of the footwall occurred in the caved areas of the mine, with impossibility to reduce such large inflows. In this mine, other quick and important inflows were related to severe rainfall infiltrations coming from surface open pit through underground abandoned levels.

A sudden inflow of water occurred in two sections of the Jukta Tunnel (Sweden), after blasting, reaching flow rates of 648 m^3/h and 306 m^3/h respectively, and stabilizing after a short period to 126 m^3/h in each case (Figure 8). These irruptions took place in 20m and 35 m long sections of the tunnel intersected by pronounced subvertical fractures (Carlsson and Olsson, 1978).

The case of the La Oportuna colliery, Spain, is also included in which a series of irruptions have occurred as a consequence of the hangingwall collapse and the resulting interconnection with the multilayer aquifer system. The drainage has erroded plastic clay and sand that have finally replenishment the collapsed void.

In Indian coalfields, same as in other areas affected seasonally by severe tropical rainfall, the increase of flow are typical in those seasons. This is the case, in Nothern Bihar during the monsoon period, when rainfall can reach 800 mm in 24 hours, a number of mines were flooded during the severe rains of 1975 (Banerjee and Shylienger, 1978) It has been verified in the underground zinc mine of Vazante, Minas Gerais, Brazil, that the mine drainage, in spite-of its intensity, does hardly reduce the piezometric levels in the years of severe rainfall.

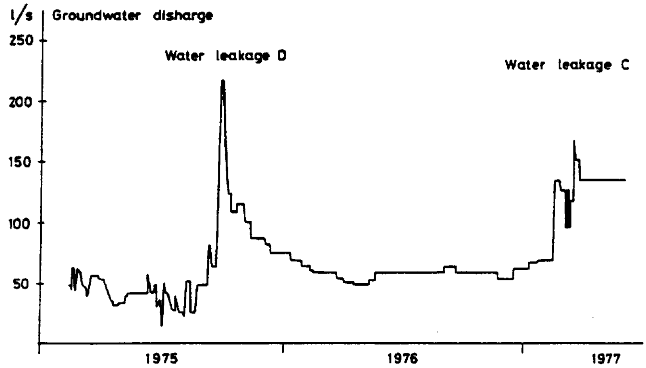
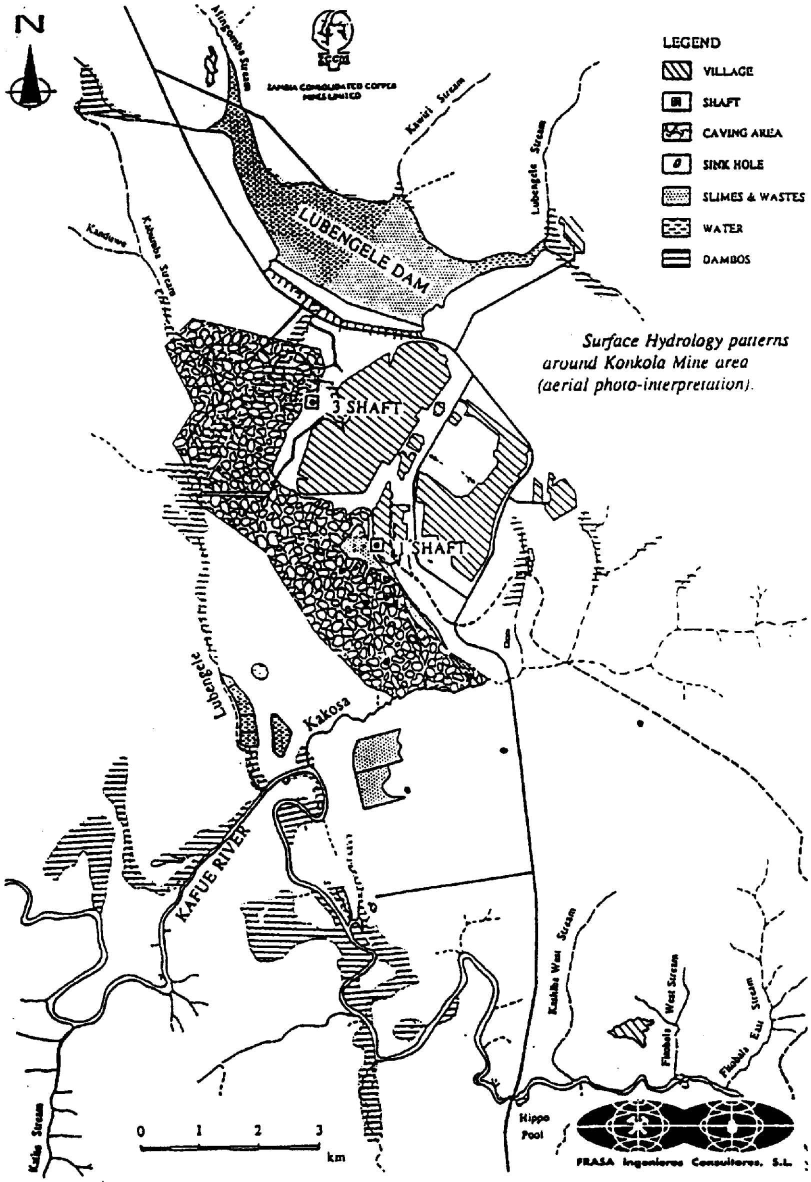


Figure 8. Water discharge in the measuring station at the intermediate access tunnel in Jukta Tunnel (Sweden) (Carlsson and Olsson, 1978).

In the chromite mine of Domokos (Greece), water irruptions at the rate of 500 m^3/h have been recorded during the summer, with almost immediate increases in rainfall, to reach normal flows of 320 m^3/h. The orebody mainly occurs in peridotites, with subvertical tectonic fractures that reaches the surface, through which this water enters the mine workings to the upper levels of the mine. For an annual pumping of 3.5 10^6 m3, 75% was pumped from the shallow workings less than 80 m deep (Marinos et al., 1978).

In 1973, as a consequence of heavy rainfall and following the flooding the bottom of the open pit an extraordinary rate of pumping had to be carried out over the period several month in the Marquesado open pit iron mine, Spain. Such catastrophic rains resulted in the breakage of the docks that byepass the surface mine workings in case of torrential rain. Similarly, in many underground mines with caving processes which provoke large scale surface subsidence, sudden water inrushes in rainy periods, producing important peaks in the water inflow. In these cases, inrushes can correspond directly not only to rainfall on the collapsed areas but also in the pouring intercepted by them and on the hydrographic pattern flowing on the surface. For example, in Konkola



Fgure 9. Caving area affecting the Lubengele and Kakosa stream in Konkola Mine (Frasa, 1993)

Mine, the subsidence affected the flow of Lubenguele and Kakosa streams and permitted water leakage into mine workings through the subsidence trough (Frasa, 1993) (Figure 9).

In this sense, the information provided by Pei (1988) is really impressive: ninety-four mining areas affected by mine subsidence (mainly in the South of China). Worth mentioning is the mine of Enkou with six thousand and one hundred collapses since 1986, affecting houses in a surface area of 18.3 km^2, and 9,500 arable lands, destroying eight small dams. The entry of water from the surface, through the subsidence zone, increase from an inflow of 1,300 m^3/h to 4,250 m^3/h. The lead-zinc mine of Siding, with more than six thousand collapses in an area of 1 km^2, flooded during the summer storms of 1976 due to the entry of the rivers through the collapse cavities. The coal mine of Meintanba, with more than two thousand collapses discovered since 1983 and more that twenty inrush of water and mud have taken place.

Another effect of the subsidence is the variation of flow recorded in the Pennsylvania coal mines, which can be correlated to the variation of flow in the rivers (Figure 10) (Growitz, 1978).

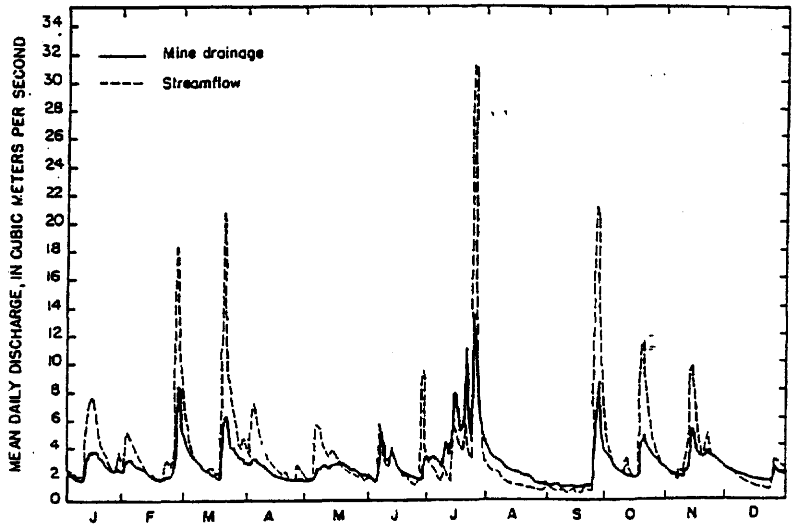


Figure 10. Hydrographs of mine drainage and streamflow in Pennsylvania coal mines. (1975) (Growitz, 1978).

In this sense, the drainage of the mines with its corresponding piezometric decrease can cause the rivers to lower its flow on passing over the area of subsidence. In any case, these variations of flow require building deposits for the store and regulation and an extra pumping capacity to cover the peakflows. Thus, in the coalfield of Jharia, India, the variations of pumping between the peak periods and the low periods are around 4 to 1. This becomes clear by looking at the relationship between monthly rainfall records and energy consumption, with a gap about one month between both peaks (Figures 11 and 12), but with pumping that last longer due to the infiltration of the last rainfall (Banerjee and Shylienger, 1978).

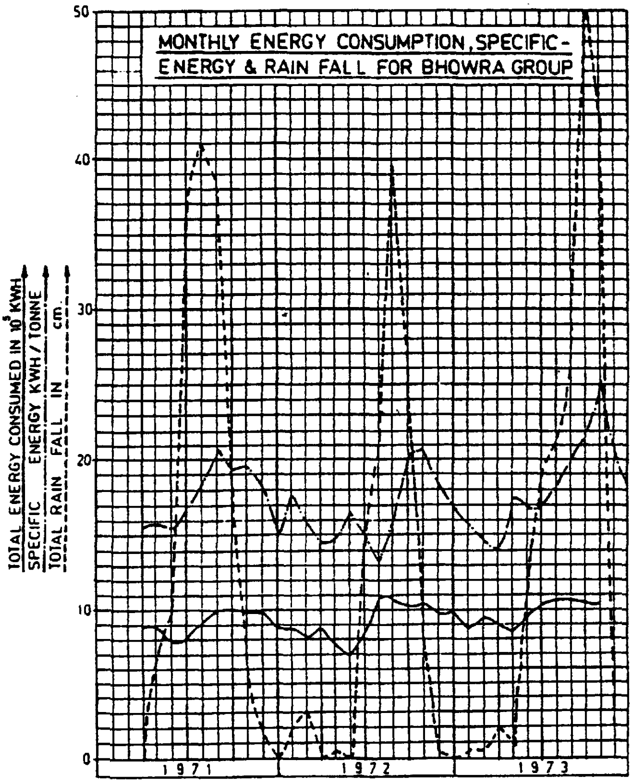


Figure 11. Monthly energy consumption, specific energy and rain fall in Bhowra Group, Jharia Coalfield, India (Banerjee and Shylienger, 1978).

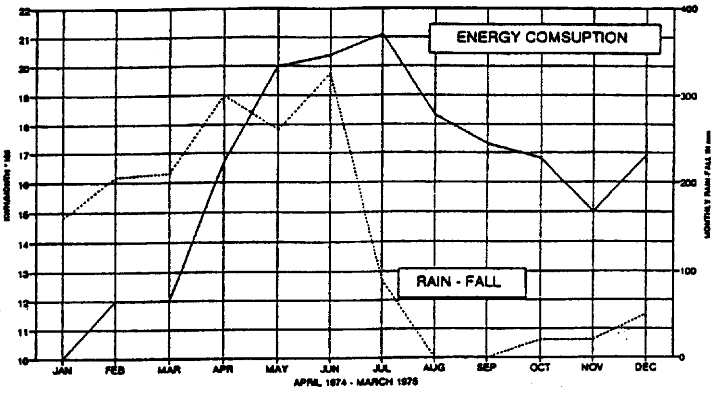


Figure 12. Monthly energy consumption and rain fall in B.C.C.L. Collieries, Jharia Coalfield, India (Banerjee and Shylienger, 1978).

It can also be observed in the response of the average monthly pumped water in the underground zinc Mine of Reocin, Spain compared to the monthly rainfall accumulated (Figure 13) (Fernandez Rubio, 1980).

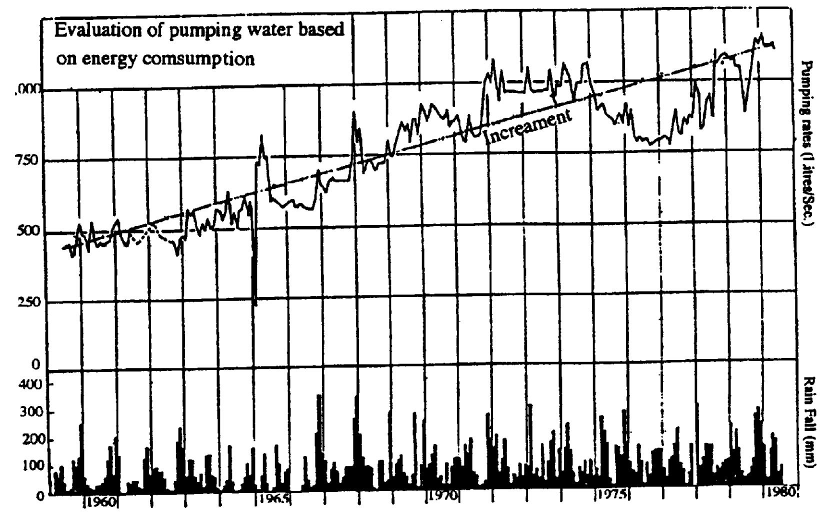


Figure 13.Variations of pumping rates at Reocin Mine, Spain (Fernandez Rubio, 1980).

Increasing flow in time

The drained waters can undergo a gradual increase in time, mainly as a consequence of the deepening of mine workings and the increase of the surface affected (both in the open pit mines and in the underground mine galleries. These raises the extent of the cone of depression , possibilly affecting the surface run off and induces recharge from other aquifers. This case can lead to the previous flow regime, after a longer or shorter period of time, if the extent of the mine-workings are reduced both laterally or in depth;. A typical example of this behaviour can be found in the underground mine of Reocin, Spain, where an average annual increase of flow of 126 m^3/h was noticed over a long period of time (Figure 13). A detailed examination of rainfall records indicates that the variation of inflow rates can be correlated to rainfall (the infiltrations are produced through a very developed karstic system and through old mine openings), on the interception of draining faults and on the regulation coming from the storage of water in the mine openings.

On the contrary, in Nchanga copper mine (Zambia), with a pumping of 870×10^6 m^3 from period from 1953 to 1978, an average increase of only 25 m^3/h is mentioned. This is despite of the expansion of drainage basin both in lateral direction and in depth; this is to be interpreted as the consequence reaching the maximum flow of the hydrogeological basin. In this mine, the drainage drilling reveals rapid increases in inflow rate immediately after the beginning of rain, suggesting an easy recharge from the surface (Stalker and Schiannini, 1978).

In the Mufulira copper mine (Zambia), records over a period of about twenty years reveal an increase in trend of inflow, with certain fluctuation, between 3,000 m^3/h and 4,250 m^3/h (Figure 14) (Wightman, 1978).

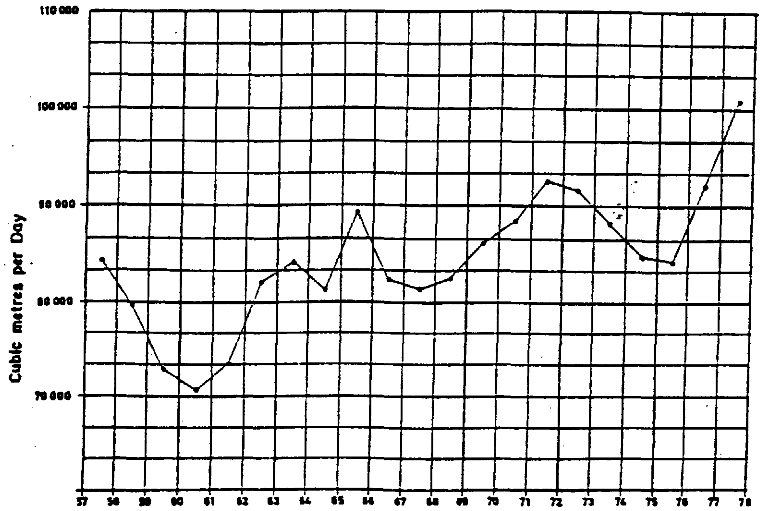


Figure 14. Average pumping rates per day in Mufulira Mine, Zambia (Wightman, 1978).

In the underground lignite mine of Aliveri (Greece) a sudden irruption of water occurred in a crosscut leading to 38m Sublevel. After two hours, the initial rate of inflow of 120 m^3/h was doubled, reaching 900 m^3/h after two days (Figure 15). It was necessary to seal the cross-cut with a concrete dam, and inject the galley walls downstream and finally to inject concrete through the drainage pipes placed in the dam in order to isolate the water. The mining operations were resumed in the rest of the mine twenty-seven days later (Marinos, et al., 1978).

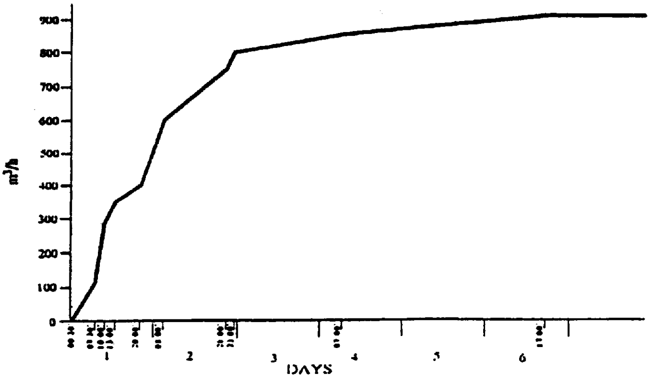


Figure 15. Water inrush development in Aliveri Lignite Mine, Greece (Marinos, 1978).

An increase in pumping rate with time is also deduced on comparing the mine water discharges of Pennsylvania mines which increased from 68,220 m^3/h in 1941 to 93,960 m^3/h in 1975 (Growitz, 1978); these are thought to be the effect of the increase of the surface area affected by open pit mining. This increase of flow has been accompanied with an improvement of the quality of the pumped water.

Constant yield

The drainage of mines in which the flow is actively constant during long periods of time are more frequent than supposed. This can occur on account of different circumstances:

- it can be consequence of the regulation of flow from drainage bore holes closing of valves to match the installed pumping capacity,
- it increased a combined effect of the exhaustion of the water reserves and corresponding to a drainage from consequence of the extension of mine workings, it can be derived from the drainage in a multilayer aquifer system with leaking effects through intermediate aquitard, and
- it can be a consequence of the reduction of groundwater reserves compensated by the increase of source water used for various mining operations.

In this sense, it should be taken into account that the normal decrease of permeability with depth has notorious incidence in the reduction of water inflows as the exploitation gets deeper. A very didactic example is the one exposed by Schmieder (1978 a) for several Hungarian mines in different hydrogeologic contexts (Figure 16). A similar behaviour has been observed in mines developed in karst areas in Minas Gerais, Brazil.

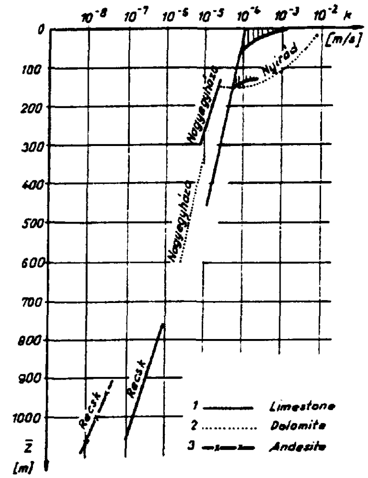


Figure 16. Variations of the seepage factor with depth for fractured karstified rocks in Hungarian Mines. (Schmieder ,1978 a).

Typical examples of this behaviour can be those of the pumping from Konkola Mine, Zambia, with a total pumped flow regulated by means of the control of valves systematically installed in the underground drainage holes (controlled water) (Mulenga, 1992).

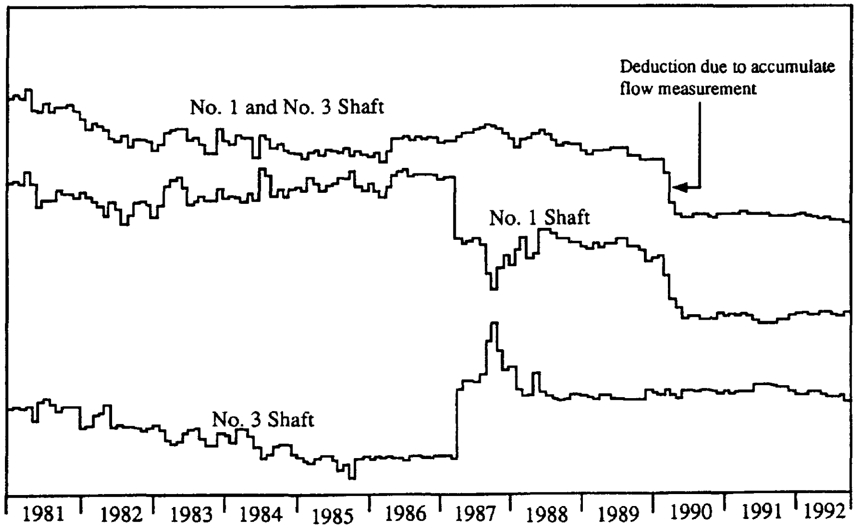


Figure 17. Water pumped from Number 1 Shaft, Number 2 Shaft and total water pumped in Konkola Mine, Zambia. (Mulenga, 1992).

The Neves Corvo Mine, Portugal, has also experienced constant rate of flow of water, as a consequence of a equilibrium reached between the reduction of flow caused by the drainage of stored reserves and the increase caused by deeper mine workings and lateral access to new mining areas (Figure 18) (Frasa, 1987).

The open pit iron mine of Marquesado, Spain, drainage through vertical pumping well, reaches a semi-equilibrium yield for each drainage depth, as a consequence of an induced recharge, coming from aquifers partially isolated by aquitards (Medina Salcedo, et al. 1977).

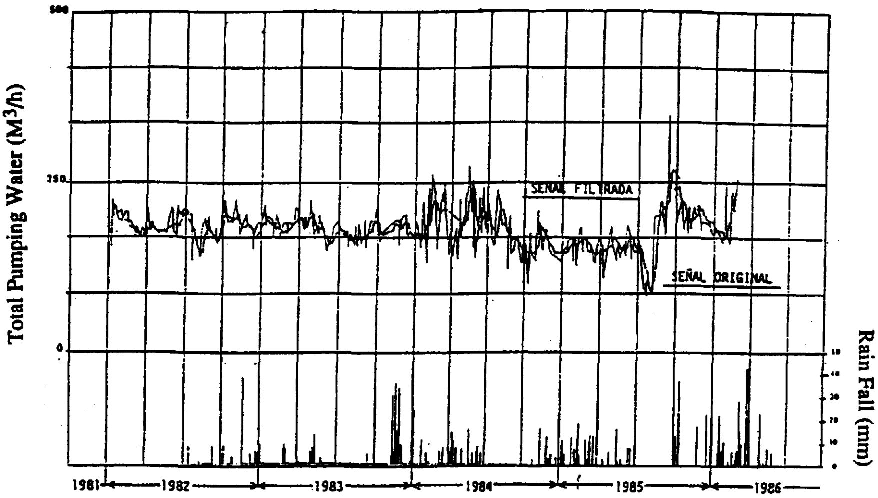


Figure 18. Total water pumped in Neves-Corvo Mine, Portugal. (Frasa, 1987).

Decreasing flow in time

This behaviour is normal when the drainage or the inrush takes place in the following circumstances:

- o unsteady flow regime, by means of constant drawdown pumping through vertical wells characterized by the depth of the pumps,
- o drainage with an initial phase in which predominates the water resources together with the accumulated storage. It is gradually-affected by the decrease of the water reserves and the maintenance of the resources, sudden inrush of water for any other cause.

The first and the second cases can occur during the life of the mine or by stages, when new drainage levels are periodically developed. This has been the behaviour of the open pit iron mine of Castilla, Guadalajara-Spain, drained by means of vertical wells placed in the periphery and within the pit, whenever it was required to depress the water table in order to reach a lower mining level (Fernandez Rubio, 1974).

A further example is of the open pit mine of Marquesado, Granada Spain, in which, whenever it was required to reduce the dynamic level in order to deepen the pit bottom, it was necessary to intensify the pumping in order to lower the core of depression below a new mining level.

The third type of sudden irruption can take place in any of the circumstances previously shown in Table 1 (Zhongling, 1988) and its time dependent pumping rates are similar to the depletion curve of springs yield:

$Q_t = Q_0^{-\alpha t}$

$Q_t = Q_0(1 + \alpha t)^{-1}$

where Q_t is the flow in time t,
Q_0 is the initial flow (time 0), and
α is the exhaustion coefficient.

The total discharge (ΣQ) is the result of the integration of Q_t till the end of the irruption:

$\Sigma Q = Q_0$

$\Sigma Q = Q_0 \alpha^{-1} \ln (1 + \alpha t)$

After studying seventy-four water irruptions with records of the peak flow of the irruption and the initial hydraulic pressure, Zhongling (1988) establishes the following relationship:

$Q_{max} = \alpha (H_t^{1/2} - H_i^{1/2})$

where Q_{max} is the peak flow of the inrush (m^3/h),
α is the irruption coefficient (approx. 3,600 m^3/h),
H_t is the total hydraulic pressure on the inrush point (Atm.), and
H_i is the beginning of the hydraulic pressure (Atm.).

This equation is similar to the hydraulic flow through pipes. H_i varies depending on the type mine, and Zhongling (1988) established three different categories for coal and iron ore mines, karstic environments in China:

- o Category A: Large karstic aquifers with sufficient recharge (abundant surface run off). Well developed cavities, with open canals and few fillings. If the mine is not very deep (200 to 250 m under the piezometric level), H_i can be considered about 4 atmospheres, for mines or tunnels belonging to this category.

  The equation to be applied is: $Q_{max} = 3600 (H_t^{1/2} - 2.00)$

- o Category B: Non outcropping deep karstic aquifers, but large and thick. Sandy filling in solution cavities and many of the transmissive canals completely open. If the mine is at 200 to 400 m below the piezometric level, Hi can be considered to be between 7.5 and 8 atmospheres.

  The equation to be applied is: $Q_{max} = 3600 (H_t^{1/2} - 2.75)$

- o Category C: Similar conditions to Category B, with the difference that in Category C the water is transmitted through faults or thin limestone layers or some aquifugous existing between the mine and the aquifer. When the water flows through such obstacles, the hydraulic pressure undergoes large loses, and H_i has values between 12 and 13 atmospheres.

The equation to be applied is: $Q_{max} = 3600\ (H_t^{1/2} - 3.50)$.

For these seventy-four well-documented inrushes the time dependent inflow characteristics is shown in Figure 19, Zhongling (1988).

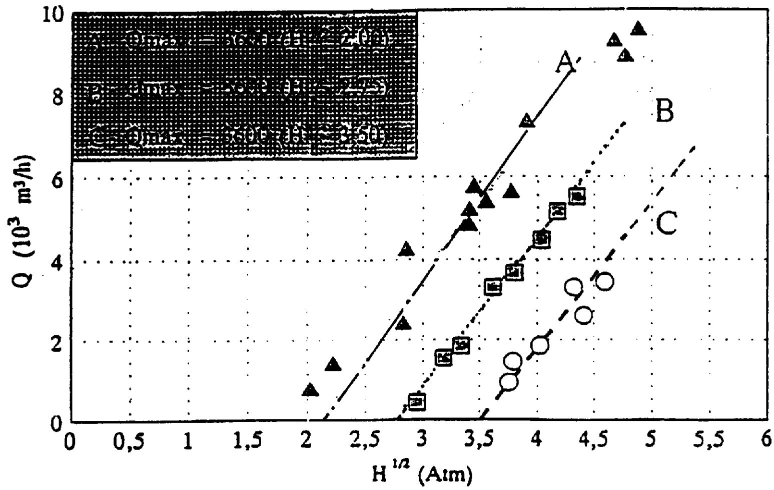


Figure 19. Coal and iron mines in karstic environment in China. Sudden water irruptions Zhongling (1981)

Mixed flow charactertics

In many cases, the time dependent flow characteristics is a combination of the pattern previously described. For example, the underground zinc mine of Vazante in Minas Gerais, Brazil, in which pumping test on real scale were carried out with a gradual increase of the drained flow, until the maximum pumping flow was reached with the available equipment. In this case, the full rate of inflow has reached equilibrium state drainage by boreholes controlled by valves (Figure 20) (Frasa, 1991).

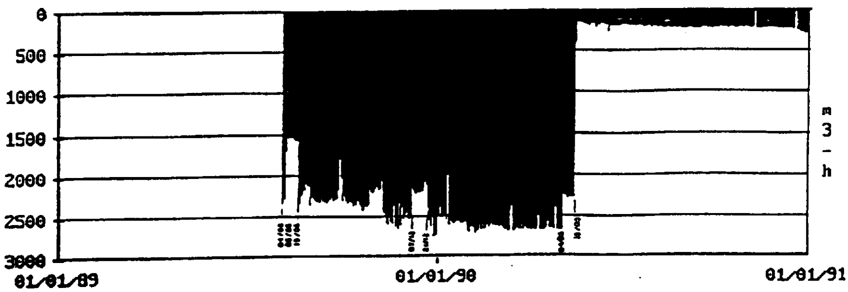


Figure 20. Total pumping water evolution controlled by a tight door ,Versant Mine, Brazil (Frasa, 1991).

MINE WATER MANAGEMENT

The rate of drainage of mine workings is usually determined by the necessity of avoiding high risks of inrush and improving economic yield. In many cases, it involves a higher cost, which can make the mining venture economically unviable. However, this management has difficulties derived from the physical environment, from the mining activities therein developed, apart from a series of technical, socioeconomic and political factors (Fernandez Rubio and Pulido, 1978) In this sense, it has to be take into account that mine drainage has to meet the requirements of mining activity, that can be different from the desirable from the management point of view, and therefore this water has to be considered together with the other water resources on which can be operated with a higher degree of freedom. On the other hand, mine drainage can modify the water balance in the region, and can seriously affect the existing water sources, the natural wetlands and the balance of aquiferous systems. That is the case in a series of coal, bauxite and manganese underground mines in the Transdanubian Mountains (Hungary), with an estimated ground water volume of 100 × 10^6 m^3 (Schmieder, 1978 b), or in Llanos del Marquesado in the neighbourhood of the open pit iron mine of Marquesado (Granada, Spain)l or in an wide area around Belchatow open pit lignite mine (Poland).

Schmieder (1978 b) has reported that the parallel drop of natural flows in springs, marshlands and lateral drainage, against mining drainage quantities (Figure 21) has shown an increase of 1000% between 1940 and 1975 (Figure 22).

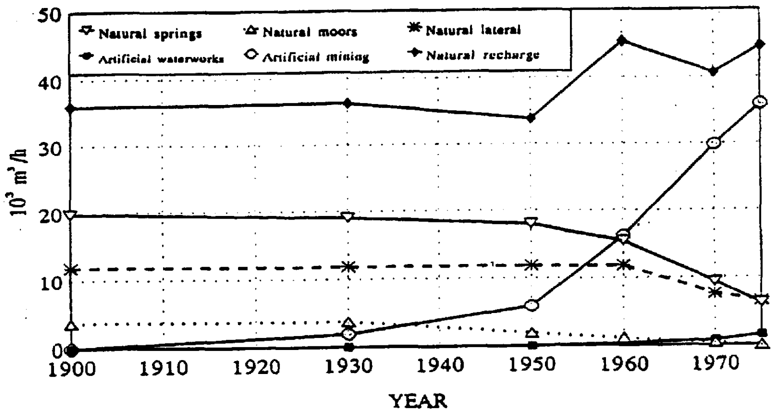


Figure 21. Karstic water budget in Transdanubian Mountains(Schmieder, 1978 b).

To compensate costs and in many cases to meet demand, the pumped water from the mine can be used for different purposes, like a non conventional hydrogeological resources, although this water is frequently deviated directly to the natural hydrographic system, to be integrated in the surface run off.

For examples, mine drainage water from the iron mine of Sierra Menera (Teruel, Spain), was used for the water supply of the mining town, and the surroundings villages, as well as for land irrigation and industrial usage in the mine. Likewise, the water from the iron mine of Marquesado (Granada, Spain) is used to supply the mining town as industrial water and irrigation water and, more recently for the artificial recharge of Llanos del Marquesado aquifer, affected by the mine drainage.

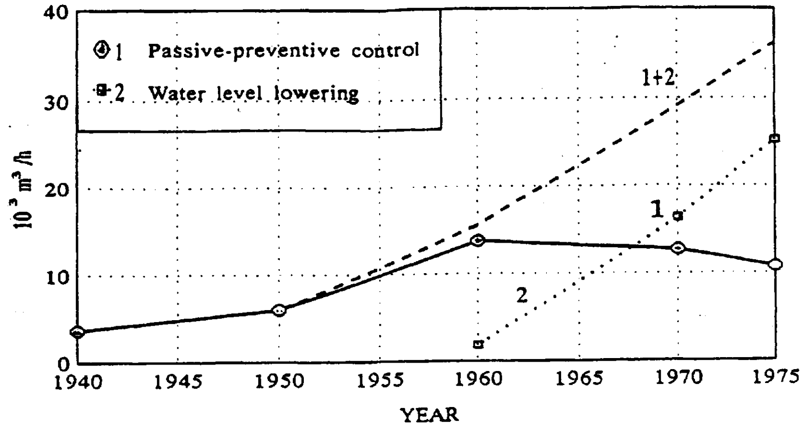


Figure 22. Karstic water withdrawal from mines in Transdanubian Mountains (Schmieder, 1978 b).

The water pumped through the peripheral drainage wells is also used in the Thermal Power Plant of Megalopolis, for cooling and services purposes. In this case, although the pumping capacity reaches 2,700 m^3/h, and it has been operating during several years, no remarkable influences on the underground water has been observed. In this same area, the exploitation project for the Kiparissia open mine was planned including drainage wells with a total pumping capacity of 7,200 m^3/h, and a total volume of 630 × 10^6 m^3 to be pumped in eleven years (Spiliotis, 1978). An important part of this water will be used for the Thermal Power Plant and the Megalopolis municiple water supply.

In a series of Hungarian coal and bauxite mines, located in a karstic domain, in north Balaton Lake, with a pumping amount over 2.0 × 10^6 m^3, a part of the water is used in trout fish-hatchery, although most of it is used for water supply to a disperse population of around half a million inhabitants (Fernandez Rubio, 1991). In these mines, the water yields are estimated to be between 7,200 m^3/h and 10,800 m^3/h (Bagdy, Kocsanyi, and Kesseru, 1978). Similarly, in the iron mines of Lorena, France, 4,000 m^3/h of water is used for industrial potable water supply. As some of the water is pumped from the abondoned mining operations to regulate the flow rate ,the quality of mine water presents some problems. The mine water is known to contain sulphate, that can reach over 800 mg/l (Herve, 1978).

It is remarkable that in some cases, the inertia of underground aquifers can modulate the drainage, to make easier the integration of this water resource in the general hydrological management.

In many circumtances, the abandoned mine can be used as a large reservoir of water , that can be integrated into water resources management. Foster and Price (1978) have mentioned that service water at the rate of 42 m^3/hour was supplied from an old abandoned coal mine to a newr mining operation in the same deposit. Similarly, in India, abandoned mines are used as a water reservoirs for supply and cooling of Thermal Plants, especially during the Monsoon season, when surface water flow is extremely turbid (Banerjee and Shylienger, 1972). In some cases, these water can require pre-treatment, as consequence of the presence of iron or other heavy metals, as well as ammonia from explosives usage.

Finally in relation to quality, there are many references to mine drainage water that does not comply with the standards required for its usage, especially in those cases where acid water is present. This happens frequently in coal and complex sulphur mining. Nevertheless, even in this case quality improvement can be achieved through appropriated treatments such as engineered wetlands.

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