# The post-minig context at Decazeville-Firmi concession (Aveyron, France) : analysis of impacts resulting from the cessation of pumping at the central shaft. Survey of various scenarios related to the water level of the Pit lake in the Grande Decouverte

Roger Cojean, Nicolas Franco, Jean-Claude Lazarewicz, Agnès Blachere, Dorothée Lefort, Claudia Sorgi

# THE POST-MINING CONTEXT AT DECAZEVILLE-FIRMI CONCESSION (AVEYRON, FRANCE): ANALYSIS OF IMPACTS RESULTING FROM THE CESSATION OF PUMPING AT THE CENTRAL SHAFT. SURVEY OF VARIOUS SCENARIOS RELATED TO THE WATER LEVEL OF THE PIT LAKE IN THE GRANDE DECOUVERTE.

COJEAN Roger[1], FRANCO Nicolas[2], LAZAREWICZ Jean-Claude[3], BLACHERE Agnès[4], LEFORT Dorothée[4], SORGI Claudia[5]

[1] ECOLE des MINES de PARIS, Institut des Géosciences, Centre de Géologie de l'Ingénieur, UMLV, Bât. IFI, 5 Bd Descartes, Champs-sur-Marne, 77454 Marne-la-Vallée, cedex 2. roger.cojean@ensmp.fr

[2] CHARBONNAGES de FRANCE, Direction Technique Nationale, 4 square François Margand, BP 534, 42007 Saint-Etienne, Cedex 1. nicolas.franco@charbonnagesdefrance.fr

[3] CHARBONNAGES de FRANCE, Direction Technique Nationale, BP1, 13590 Meyreuil. jean-claude.lazarewicz@charbonnagesdefrance.fr

[4] Bureau d'Etudes CESAME, ZA du Parc, Secteur Gampille, 42490 Fraisses. cesame.environnement@wanadoo.fr

[5] INERIS, Parc Technologique ALATA, BP 2, 60550 Verneuil-en-Halatte. claudia.sorgi@ineris.fr

*ABSTRACT: Within the frame of the Survey related to the cessation of mine workings in Decazeville-Firmi concession, various impacts resulting from the cessation of pumping at the Central Shaft were assessed. Mainly these impacts are related to groundwater behaviour in the abandoned underground coalmines, hydrochemistry of waters discharged to the environment, ground stability concerns and coal gas emanations. This analysis allowed the choice of the most appropriate elevation of the pit lake level in the Grande Découverte, with the necessity to continue the pumping. Two main objectives were reached. The elected elevation is high enough to result in a permanent chemical stratification, which allows the pumping of the superficial waters and its discharge to natural watercourses without any treatment. The elected elevation is low enough to avoid any problem of inflow of water or ground stability at some particular places which might have been threatened by the rising of the piezometric level of the mining aquifer. Lastly, the elected elevation of the pit lake allows a quality scenery design around the pit lake.*

*KEYWORDS: Coal mine. Impacts of cessation of pumping. Pit lake. Mine groundwaters. Ground stability*

*RESUME : Dans le cadre de la constitution du Dossier d'arrêt des travaux miniers dans la concession de Decazeville-Firmi, différents impacts résultant de l'arrêt du pompage au Puits Central ont été étudiés. Ces impacts sont principalement relatifs au comportement de l'aquifère minier, à la qualité des eaux restituées au milieu naturel, à la stabilité des terrains et aux gaz de mines. Cette étude a conduit à la définition de la meilleure cote du lac minier de Decazeville dans la Grande Découverte, en respectant deux principaux objectifs, avec la nécessité de poursuivre le pompage. La cote retenue est suffisamment élevée pour permettre l'établissement d'une stratification chimique permanente dans le lac minier, ce qui rend possible le pompage par soutirage de la tranche d'eau superficielle du lac et sa restitution au milieu naturel sans traitement particulier. La cote est suffisamment basse pour éviter tout problème de venue d'eau ou de stabilité des terrains en quelques zones particulières qui auraient pu être menacées par la remontée du niveau piézométrique de l'aquifère minier. Enfin, la cote retenue permet de réaliser un aménagement paysager de qualité autour du lac minier.*

*MOTS-CLEFS : Mine de charbon. Impact de l'arrêt de pompage. Lac minier. Aquifère minier. Stabilité des terrains.*

## 1. Introduction

The paper is devoted to the analysis of the post-mining context at Decazeville-Firmi concession (Aveyron, France). Complex technical conditions resulting from the past coalmine workings, discussions related to the assessment of various potential impacts and the choice of the most appropriate level of the pit lake in the Grande Découverte are at the origin of a long procedure which took place during four years, from 2001 to 2004. During this time, dialogues occurred between Charbonnages de France, its engineering and technical consultants (mainly Ecole des Mines de Paris – Centre de Géologie de l'Ingénieur, CESAME, INERIS), the Midi-Pyrénées DRIRE (Regional Direction for Industry and Research), the local and regional authorities (Villefranche-de-Rouergue Sous-Préfecture and Rodez Préfecture) and the elected representatives of the concerned communes. After several investigations in the fields of hydrogeology, engineering geology and geomechanics, and presentation of the obtained results to the various concerned authorities, a general technical and consensual agreement was obtained. In a brief way, the paper describes the main steps of the corresponding scientific or technical investigations which allowed to address and solve the impact problems (Cesame, 2000, 2004; Charbonnages de France, 2001; Cojean, 2002, 2003, 2004; Ineris, 2000, 2003; Lefort, 2000).

## 2. Regional geological setting

According to geological investigations mainly due to Vetter P. (1968) and later research works resulting from the coal mining works, the litho-stratigraphic sequence of the coal basin, as well as the tectonic deformation phases are well known (Figures 1 and 2).

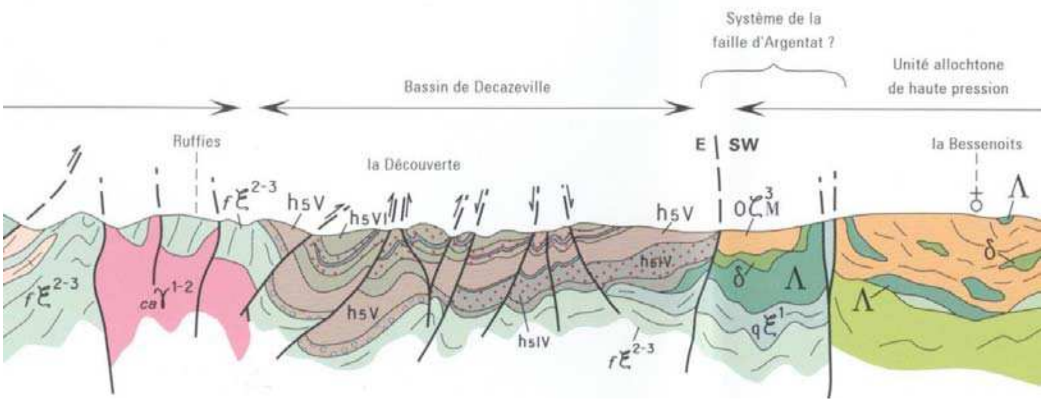



Figure 1. Geological cross section of Decazeville coal basin. The Stephanian series is represented in the central part of the cross section. La Découverte is concerned by the Bourran ($h_{5VI}$) cycle. Old underground coal works are mainly related to the Bourran ($h_{5VI}$) and Campagnac ($h_{5V}$) cycles. (after BRGM. 2001. Decazeville geological map, 1/50000).

The sedimentary sequence consists of several cycles or "assises" dated from Middle Stephanian series (Carboniferous period). In a stratigraphical order, the cycles are arranged as follows: Brayes cycle, Volcanic complex, Auzits cycle, Banel cycle, Campagnac cycle and Bourran cycle.

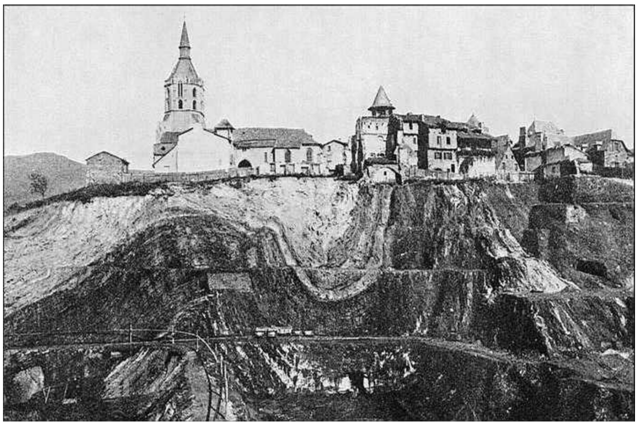


Figure 2. Elisabeth open pit, Firmi. Photo dated 1896. Saint-Eugène anticline, Campagnac cycle. (in Vetter P., 1968).

Each cycle is made up of conglomerates, sandstones, shales and coal layers. The major tectonic phase occurred at the end of the Paleozoic era and resulted in a general compression of the coal basin, with the folding and faulting of geological strata (Figures 2 and 3).

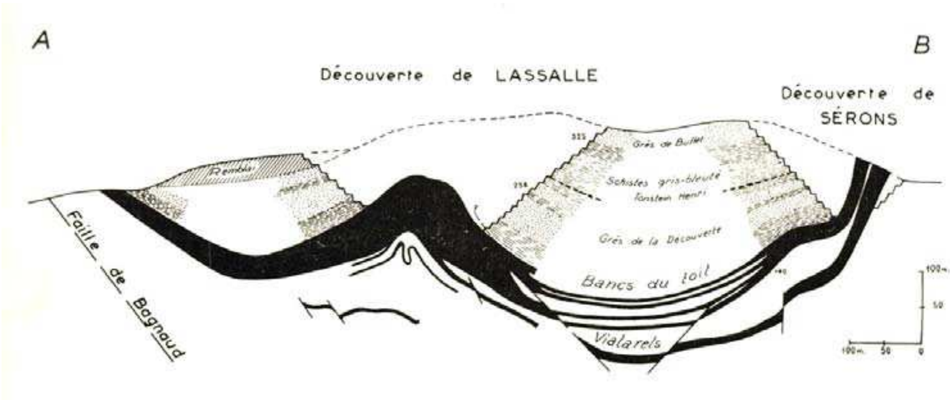
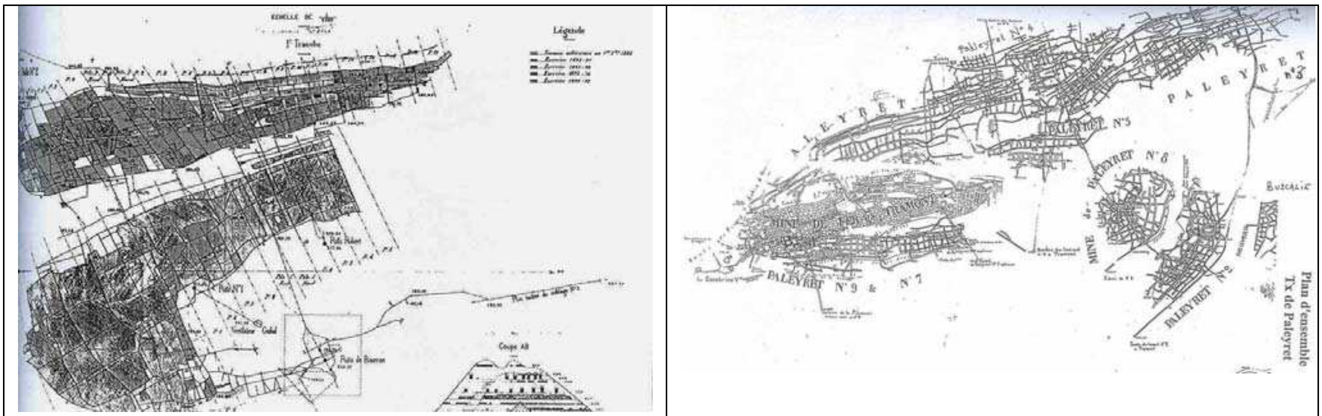



Figure 3. NE-SW geological cross section. Lassale (Grande Découverte) and Sérons open pits. Bourran cycle. (after Vetter P., 1968).

## 3. Past coalmine workings

Decazeville coal mining basin experimented three major mining periods. From 1360 to 1744, numerous private exploitations developed. Then, from 1744 to 1946, the period of large mining companies took place. In 1946, nationalization of mining companies and creation of Charbonnages de France occurred. It was a period of intense mining activities, with peak productions, then decline due to the international economic coal context and progressive lowering of the regional coal resources (Charbonnages de France, 2001).



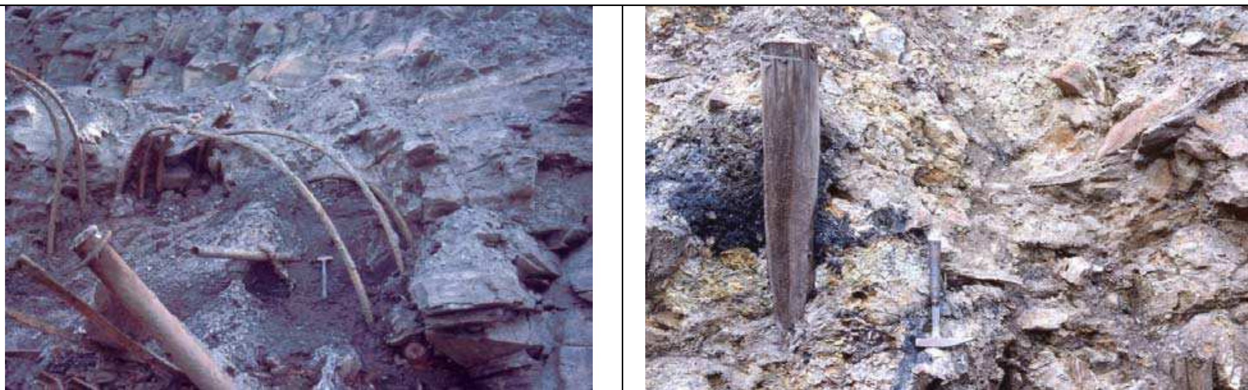

a) Bourran underground coalmine workings

b) Paleyrets underground coalmine workings

Figure 4. Detailed old mining maps. a) The Bourran map is related to mine workings dated before 1893, with detailed drawings concerning backfilled horizontal slices during the period 1893-1897. b) The Paleyrets map is related to mine workings dated from 1830 to 1947, with detailed drawings concerning exploration galleries, abandoned coal chambers and pillars. In addition, the old Tramont abandoned iron chambers and pillars can be noted down. (after Charbonnages de France archives).

Underground mining works were performed according to a large variety of mining methods (Figure 4). Some of them were partial exploitations such as the method of *chambers and pillars* that left important residual voids at the end of the exploitations in case of abandonment. Other ones were total exploitations with an integral void treatment such as the stoping methods by successive horizontal slices: the *cut and fill method* that is working upwards or the *undercut and fill method* that is working downwards.

During the recent period of large opencast exploitations and especially the progressive deepening of the Grande Découverte, as well as other open pits in the surroundings, old mining works were partly intersected. Field analyses allowed to investigate the old backfilling operations as well as the mechanical behaviour of grounds after mining subsidence.



a) Old gallery backfilled by slime materials

b) Old timbered and backfilled mining works

Figure 5. Intersections of old mine workings during the deepening of the Grande Découverte.

## 4. Post-mining conditions

The post-mining context was analysed in a detailed way, considering the following causes for concern and corresponding impacts on the environment and constructions (Feuga, 2005; Fabriol, 2005):

- Type and behaviour of the mining aquifer;
- Ground stability concerns;
- Impacts of various scenarios related to the cessation of pumping and the water level in the pit lake;
- Risks resulting from mining gases, surface mining facilities, waste dumps and tips, specific equipments.

Only the first three items are presented in this paper.

*4.1. The mining aquifer*

The question of underground waters was investigated considering the different types of aquifers as well as their properties by reference to the problem of discharges and the question of water pressures and ground stability (Cesame, 2000; Cojean, 2002; Younger et al, 2002; Schmitt et al, 2003). The Carboniferous rock masses can be considered as made up of three different hydrogeological units that were more or less intensively modified by the mining works and associated mining subsidence. The Table 1 summarizes the characteristics of these units.

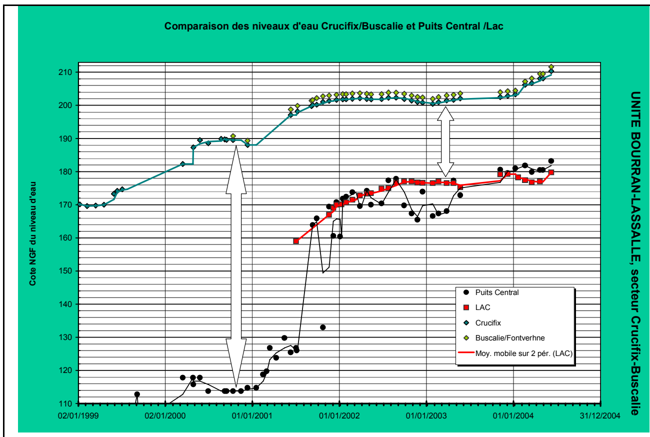
As a matter of fact, the water-bearing formation can be considered as mainly determined by the old coalmine workings, generally backfilled by permeable materials, while discharge questions and water inflows are concerned. However, for underground water pressures and stability problems, the hydraulic continuity has to be underlined as the major concern and may result from continuous water paths through low or very low permeability formations. So, in order to completely investigate these questions, very detailed consultations of old mine working drawings were performed in order to understand the connections between different mining works or to identify the presence of dams in particular cross-cut drifts.

In addition, a piezometric network was installed to get a good understanding of the underground water behaviour and improve the knowledge of water pressure distributions in some specific places.

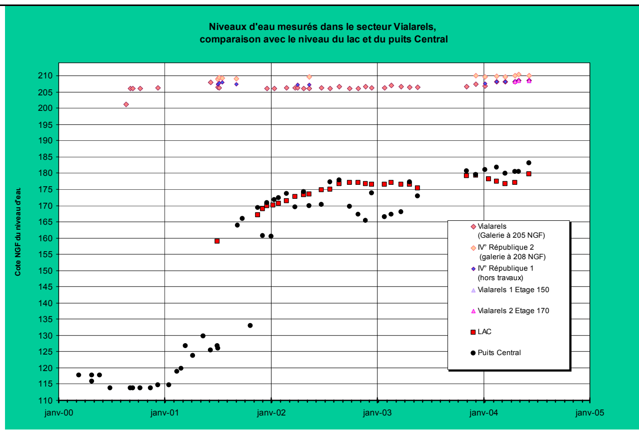
Table 1. Hydrogeological behaviour of the mining aquifer. Storativity and transmissivity are highlighted. In addition, the exchange function related to interactions between underground water and storage rocks has to be considered for physico-chemical, hydro-biological and thermal processes. It controls water quality.

| Mining aquifer | Storativity function | Transmissivity function |
|---|---|---|
| Carboniferous rock masses directly related to the old coalmine workings.<br>*Very high permeability.*<br>*Very high porosity.* | Very significant role | Very significant role |
| Carboniferous rock masses altered by the old coalmine workings and subsidence phenomena.<br>*Medium to low fracture permeability.*<br>*Medium to low porosity.* | Moderately significant role | Poor role |
| Carboniferous rock masses unaltered by the old coalmine workings.<br>*Low (subsurface zones) or very low permeability.*<br>*Low (subsurface zones) or very low porosity.* | Very poor role | Very poor role |

As an illustration, conclusions resulting from the analysis of data related to two piezometers are presented in Figure 6. In the two cases mining connection was existing, but it can be seen that the hydraulic connection does not have the same reaction while the hydraulic gradient is lowering due to the rising of the water level in the Central mineshaft (Puits Central) which is used as a pumping shaft.




a) The drawing illustrates the very close piezometric levels for two nearby piezometers (upper dots and curve: Buscalie and Crucifix), the correlation between these piezometric levels and the level of water in the Central mineshaft and the adjacent pit lake (lower dots and curves)




b) The drawing illustrates the very low correlation between the piezometric levels of different piezometers in the area of Vialarels (upper dots) on one hand and the level of water in the Central mineshaft and the adjacent pit lake (lower dots) on the other hand.

Figure 6. Hydrogeological connections between several coalmine workings and the Central mineshaft (Puits central).

Taking advantage of these different investigations a synthetic map was provided (Figure 7) which illustrates the different hydrogeological units and connections with the Central mineshaft.

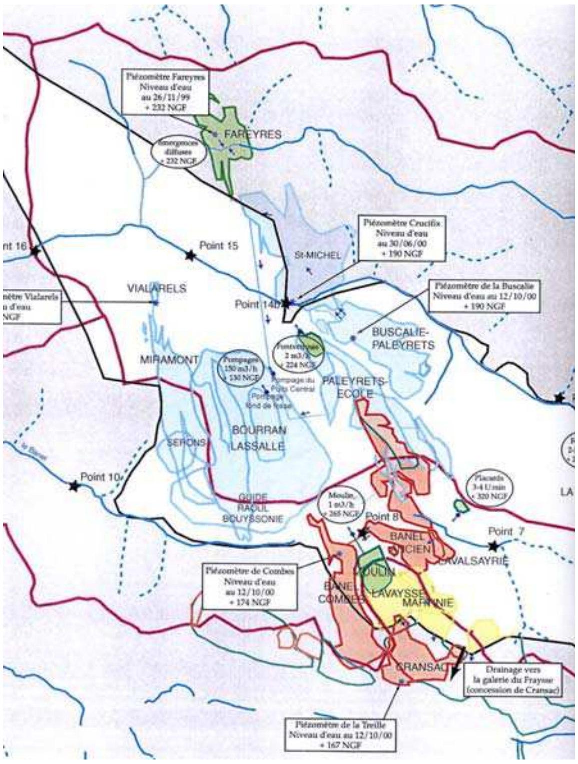



Figure 7. Synthetic map showing different mining aquifers connected to the Central mineshaft (Bourran-Lassalle, Paleyrets and Buscalie sectors) and other mining aquifers with no connection to the Central mineshaft (Banel, Placards, Martinie-Moulin and Firmi sectors). (after Cesame, 2000).

*4.2. The ground stability concerns*

Ground stability questions were investigated by reference to potential mining subsidence, collapse of abandoned rooms and pillars exploitations and sinkhole processes (Ineris, 2000; Piguet and Wojtkowiak, 2000; Cojean 2002; Wojtkowiak et al, 2002; Al Heib et al, 2003).
The areas which formerly were affected by mining subsidence were delimited. Presently, no residual subsidence can be expected in these places. However, reactivation of mining subsidence as a response to the rising of the general water level in the mining aquifer had to be considered. Different observations in the world show that some low uplift process can be expected. It has to be noted down that these processes occur at a regional scale. On the contrary, at a local scale, the rising of underground water level can result in local reactivation of settlement due to the washing out of infilling materials in sloping galleries for shallow exploitations.
The collapse of partial exploitations such as rooms and pillars is a concern for exploitations with a depth lower than 50 meters. The present stability conditions were investigated using the data provided by colliery archives. Long term stability conditions were analysed, taking into account the lowering of strength of pillars due to the rising of water levels in the exploitations. It was necessary to carry out additional boreholes in some places in order to clarify particular situations where safety problems were at stake.
The sinkhole hazard was also investigated considering possible scenarios of cavities at the crown of an underground mine working turning into successive bell holes reaching to the surface. For this purpose, additional boreholes have allowed to precise the risks associated to these processes and gave some essential data for stability calculations.
Lastly, ground stability questions were also analysed for underground iron mines, connected to the coalmine workings, which would be concerned by the rising of the regional piezometric level as a response to the cessation of pumping at the Central mineshaft.
As it can be noted down, any ground stability problem is closely connected to underground waters and corresponding water pressures. That is the reason why it is necessary to analyse the roles of mining aquifers in post-mining conditions by respect to discharge and water inflow questions, as well as by respect to piezometric levels and water pressures.

## 5. Election of the most appropriate water level in the pit lake

At the beginning of the Survey related to the cessation of mine workings in Decazeville-Firmi concession, comparative scenarios were analysed. At the beginning of the investigations, the scenario of a lake level at the 211 m elevation was considered. It was corresponding to a total cessation of pumping and made it possible to have a gravitational flow of water towards the surface watercourses, but consequences concerning ground stability concerns and water inflow in some places were not completely solved. Then a scenario of a lake level at the 170 m elevation was analysed. It allowed to cancel any ground stability problem, but long term pumping had to be taken into account as well as water treatment.

Finally an intermediate solution appeared to be appropriate. It was established according to the following thinking. The option had to make it possible to discharge water towards the surface watercourses without any treatment. But potential ground stability problems had to be limited and residual cases to be solved, especially for two cases related to Vialarels area in the town of Decazeville and Combes area in a nearby village. A consequence was that pumping had to continue.

Some world expertise concerning the behaviour of pit lakes is available as well as French expertise concerning coalmining works, especially at Blanzy (Saône et Loire). Pit lake evolution is complex and depends on geometrical parameters related to the watershed, hydro-chemical parameters concerning the lake supply from surface and underground flows, characteristics of the connection between the lake and the mining aquifer and climatic parameters. The seasonal thermal stratification is well known for lakes in general. But for mine lakes, a chemical stratification can also take place. A permanent confined and mineralized body of water appears at the bottom of the lake and does not participate to the seasonal thermal convection processes. This zone appears below a narrow transitional zone called the chemocline, the corresponding lakes being described as meromictic lakes. According to the expertise coming from Blanzy (Paquette et al, 2000), three main factors seem to control this chemical stratification with threshold values:

- The maximum depth of the lake has to be larger than 25 m;
- The mean depth (ratio volume/surface: V/S) has to be larger than 15 m;
- The hollow index ($1000\times V/S^{3/2}$) has to be larger than 50.

In addition, two additional factors may play a significant role: the ratio watershed surface/lake surface (BV/S) and the age of the lake.

As a consequence, in a first step, various scenarios concerning the water elevation in the pit lake were studied and led to the results presented in Table 3.

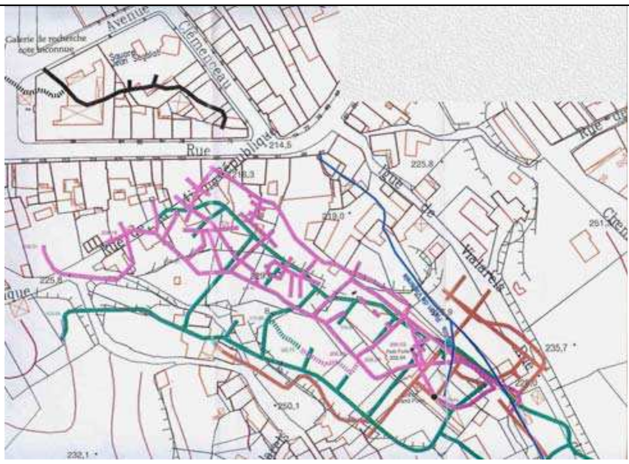
According to the accepted threshold values, it appears that the most appropriate water elevation is 195 m, taking into account a small safety margin (Figure 10). Then it will be possible to pump a superficial water slice within a specific structure designed to pump water with no disturbance of the chemical stratification of the lake.

Table 3. Analysis of factors controlling the chemical stratification in the pit lake.

| Water elevation in the pit lake | 170 m | 185 m | 190 m | 195 m | 204 m | 211 m |
|---|---|---|---|---|---|---|
| Maximum depth (m) | 16 | 31 | 36 | 41 | 50 | 57 |
| Volume V ($m^3$) | 220 000 | 920 000 | 1 330 000 | 1 800 000 | 2 800 000 | 3 750 000 |
| Surface S ($m^2$) | 33 000 | 77 000 | 87 000 | 97 000 | 124 000 | 155 000 |
| Mean depth V/S (m) | 6,7 | 11,9 | 15,3 | 18,6 | 22,6 | 24,2 |
| Hollow index $1000\times V/S^{3/2}$ | 36,9 | 42,9 | 51,9 | 59,7 | 64,2 | 61,5 |
| Ratio BV/S | 47 | 20 | 18 | 16 | 12 | 10 |

In a second step, the consequences related to ground stability problems resulting from the 195 m elevation were considered.

The Vialarels area in Decazeville was closely analysed. This area consists in three different levels of galleries (Figure 8-a), the highest voids being locally at a 6 meters depth. These mining works were completed in 1916, and different small mining damage occurred during and after mining: small settlements, gas emanations, minefires. Infilling and reinforcement works were carried out. The hydraulic connection between Vialarels area and the mining aquifer connected to the Central mineshaft (where pumping was taking place) was specifically analysed using maps and additional piezometers which were progressively set up. The hydraulic connection appeared to be very poor (Figure 6-b), especially due to the presence of a permanent dam erected across the single cross-cut gallery connecting Vialarels area and the rest of the mine. In fact the water table in this area is mainly dependant on the recharge corresponding to direct meteoritic waters, but there is also a small flow which leaks (probably through the dam) to the mining aquifer connected to the Central mineshaft. This leak can probably be influenced by the level in the pit lake if it is upper than 195 m. That is the reason why a pumping station will be designed to pump water out in case of heavy rainstorm on this area.



a) Mining works at Vialarels area. Three different levels of galleries can be observed.

b) Rooms and pillars iron mines at Combes area. These exploitations are connected to the Central mineshaft thanks to coal galleries.

Figure 8. Mining works at Vialarels area and Combes area.

Also the Combes area was analysed in a detailed way. In this place, old underground iron mines are connected to the coal mines and the Central mineshaft. The three dimensional characteristics and location of the chambers and pillars iron mines were studied thanks to the colliery archive documents (Figure 8-b) and knowledge related to the mining aquifer. It resulted that only a few houses were potentially concerned by modifications of stability conditions due to a variation of water level up to 195 m in the rooms and pillars of iron mines. Appropriate decisions will be taken for this particular case.

Finally additional analyses were performed about some other places, limited in extension, were similar impacts were identified.

Figure 10: Aerial view of the pit lake in the Grande Découverte. The Central mineshaft is on the right of the lake. In the top left corner, Decazeville town and Vialarels area. In the bottom right corner, Combes area.

As a consequence of these investigations in the field of mining groundwater and ground stability, the 195 m elevation was accepted as the best solution for the water level of the pit lake (Figure 10). In addition this level allows a quality scenery design around the pit lake.

## 6. Conclusion

As a conclusion, different major subjects that were investigated in the case of Decazeville-Firmi concession can be underlined.

The post-mining contexts are always complex and need integrated investigations mainly in the field of mining groundwaters, ground stability and gas emanations. The questions of underground waters have to be studied considering the discharge as well as the water pressure problems.

The monitoring of the mining aquifer by piezometric networks is necessary in order to improve the understanding of these complex groundwater systems.

The reference to colliery archives is essential to obtain a good knowledge of past mining works. Unfortunately the corresponding data are sometimes partial or difficult to be interpreted. So it is necessary to consider that boreholes investigations are sometimes necessary in order to accurately describe the subsoil conditions.

In the field of pit lakes, expertise begins to be accumulated but it is necessary to be careful and to implement monitoring devices in order to follow the chemical stratification process, as it is done in the case of Decazeville.

## 7. References


Al Heib M., Josien J.-P., El Shayeb Y. (2003). *Paramètres d'affaissement pour la hiérarchisation des zones à risque dans le bassin ferrifère lorrain.* Symposium Après-mines 2003, Nancy. 11p.

BRGM (2001). Carte géologique de la France à 1/50 000. N°859, Decazeville. Notice explicative 94p.

CESAME (2000). *Etudes hydrogéologique et hydrologique de la concession minière de Decazeville-Firmi (Aveyron).* 160p. et Annexes.

CESAME (2004). *Les travaux miniers sous le quartier de Vialarels à Decazeville. Bilan des connaissances.* 21p et Annexes.

Charbonnages de France – HBCM – Direction des Sites Arrêtés et de l'Environnement (2001). *Arrêt des travaux dans la concession de Decazeville-Firmi. Mémoire.* Tomes 1 et 2, 204p, Annexes techniques et plans.

Cojean R. (2002). *Compte-rendu d'expertise. Dossier d'arrêt des travaux miniers dans la concession de Decazeville-Firmi (Aveyron).* 36p. *Note complémentaire*. 9p. Rapports Armines-CGI.

Cojean R. (2003). *Note complémentaire au Compte-rendu d'expertise relatif au dossier d'arrêt des travaux miniers dans la concession de Decazeville-Firmi (Aveyron). Scénarios de cote du lac minier et impacts.* 11p. Rapport Armines-CGI.

Cojean R. (2004). *Note complémentaire au Compte-rendu d'expertise relatif au dossier d'arrêt des travaux miniers dans la concession de Decazeville-Firmi (Aveyron). Scénarios de cote du lac minier et impacts.* 4p. Rapport Armines-CGI.

Fabriol R. (2005). *La gestion de l'eau des mines en phase post-extractive.* Revue BRGM Géosciences, N°2, septembre 2005, 66-71.

Feuga B. (2005). *Quelques aspects de l'après-mine.* Revue BRGM Géosciences, N°1, janvier 2005, 24-29.

INERIS (2000). *Bassin houiller d'Aubin-Decazeville. Concession de Decazeville et Firmi. Analyse des effets en surface des travaux miniers souterrains.* 29p et Annexes.

INERIS (2001). *Guide méthodologique pour l'arrêt des exploitations minières souterraines.* 130p et Annexes.

INERIS (2003). *Bassin houiller d'Aubin-Decazeville. Concession de Decazeville et Firmi. Analyse des effets de l'ennoyage à la cote +170 m NGF des eaux de l'aquifère minier sur la stabilité des mines de fer.* 17p et Annexes.

INERIS (2003). *Bassin houiller d'Aubin-Decazeville. Concession de Decazeville et Firmi. Analyse des effets de l'ennoyage à la cote +210 m NGF des eaux de l'aquifère minier sur la stabilité des mines de fer.* 17p et Annexes.

Lefort D. (2000). *Etude hydrogéologique du bassin houiller de Decazeville (Aveyron).* Thèse professionnelle. Mastère Géologie de l'ingénieur et de l'environnement. Ecole des Mines de Paris - Centre de Géologie de l'Ingénieur et Bureau d'Etudes Cesame. 50p.

Paquette Y., Blachère A., Lefebvre O., Guise Y., Barrière J.-P. (2000). *Les lacs miniers des exploitations à ciel ouvert de charbon du massif central : qualité et évolution.* Chronique de la recherche minière, N°541, 85-101.

Piguet J.-P., Wojtkowiak F. (2000). *Affaissements et déformations au-dessus des exploitations minières : mécanismes et évolution dans le temps.* Mines et Carrières. Industrie Minérale. Juin 2000. 36-46.

Schmitt J.-M., Combes P., Ledoux E. (2003). *Qualité des eaux après fermeture des mines : remplissage initial, évolution transitoire, stabilisation à long terme et gestion environnementale.* Symposium Après-mines 2003, Nancy. 10p.

Vetter P. (1968). *Géologie et paléontologie des bassins houillers de Decazeville, de Figeac et du détroit de Rodez*. Tome1 : Description géologique, 442p. Thèse d'Etat. Houillères du Bassin d'Aquitaine, Albi.

Wojtkowiak F., Baubron J.-C., Cattaert P., Vassiliadis G. (2002). *Maîtrise de l'impact hydraulique, sur le bâti de surface, de l'ennoyage de mines souterraines arrêtées du bassin ferrifère lorrain (France).* 9ème Congrès International IAEG, Durban, Afrique du Sud, Décembre 2002. 10p.

Younger P. L., Banwart S. A., Hedin R. S. (2002). *Mine water. Hydrology, Pollution, Remediation.* Environmental Pollution, Volume 5. 442p. Klower Academic Publishers.