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Christophe Didier, Jacques Leloup

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THE MRPP : A POWERFUL OPERATIONAL REGULATORY TOOL TO PREVENT AND MANAGE POST-MINING RISKS

DIDIER Christophe¹, LELOUP Jacques²

¹ INERIS – Direction des Risques du Sol et du Sous-Sol - Parc Technologique Alata BP n°2 – 60550 Verneuil en Halatte – France. Christophe.Didier@ineris.fr

² Ministère de l'Economie, des Finances et de l'Industrie – 5 Place des Vins de France, Bâtiment ATRIUM – 75573 Paris Cedex 12 - France. Jacques.Leloup@industrie.gouv.fr

ABSTRACT : Even if most French mining sites are definitively closed, potential risks remain above the abandoned exploitations. In addition to surface instability, some mining sites may be affected by dangerous gas emissions or by flooding events or environmental degradations. Those kinds of disorders strongly influence the land use management of the concerned areas. In order to post and manage properly those risks, French State has developed a powerful operational regulatory tool : the MRPP (Mining Risk Prevention Plan). MRPP aims to identify the most sensitive areas subject to "post mining hazards" and to define technical and regulation rules able to manage the principles of the future urbanism development on surface. The present paper proposes a methodological description of MRPP in order to explain the nature and objectives of the procedure.

KEYWORDS : post-mining management, prevention, hazard, regulation, MRPP.

RESUME : Bien que la plupart des sites miniers français sont désormais fermés, les risques liés à ces anciennes exploitations n'ont pas pour autant disparu. Outre les risques de mouvements de terrain, certains sites peuvent être affectés par des émissions de gaz dangereux, des phénomènes de type inondations ou des impacts environnementaux parfois sensibles. Ce type de désordres influence fortement l'utilisation possible des terrains de surface concernés. Afin d'afficher et de gérer au mieux ces risques, l'état français a développé un outil opérationnel et réglementaire puissant : le PPRM (Plan de Prévention des Risques Miniers). Les objectifs du PPRM sont d'identifier les secteurs les plus sensibles aux risques liés à l'après-mine et de définir le cadre réglementaire permettant de gérer au mieux les principes du futur développement de l'occupation de surface. L'article propose une description méthodologique de la réalisation des PPRM afin d'en expliquer la nature et les objectifs.

MOTS-CLEFS : gestion de l'après-mine, prévention, aléas, principes réglementaires, PPRM.

1 Introduction

For several centuries, the French mining industry, considered to be one of the flagships of national industry, was a source of wealth for the country. In just a few decades, under the combined effect of diminishing resources and international competition, most mining operations were gradually forced to close.

Once a symbol of pride and solidarity, this industry is now often identified with the development of problems or a source of nuisance. As a matter of fact, closing down mining operations has not led to the complete and permanent elimination of risks and harmful effects likely to affect surface land within the geographical limits of old workings. During the period following operations therefore, traditionally known as the "post-mining" period, several kinds of disorders may develop, sometimes as soon as work has ceased but also much later.

Apart from surface instability (subsidence, collapse), some old mining sites may be affected by emissions of gases likely to be dangerous. The irreversible disturbance to underground water circulation caused by mining operations may also be the source of nuisance, both for the water circulation scheme (low point flooding, changes in water course flowrates) and its quality (water or soil pollution).

These phenomena may have major consequences for people, activities and property on the surface (support work or development, moving populations). They are also likely to have a major influence on regional development in mining areas.

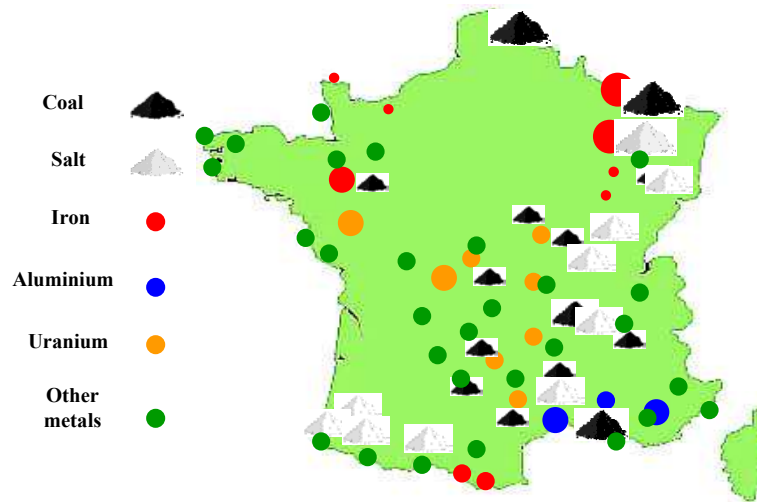


Figure 1. Major mining fields having been exploited in France.

To post and manage these various risks to an optimal degree, the French State has developed a high-performance and operational regulatory tool: Plans de Prévention des Risques Miniers (PPRM) (Mining Risk Prevention Plans - MRPP) are intended to identify the sectors most likely to develop risks or nuisances in the long term and draw up rules for managing land use according to the various constraints linked to the post-mining period.

The present paper gives a brief account of the principles subtending the drafting of MRPPs, with respect to both the administrative procedure and risk evaluation, as well as defining regulatory measures.

2 The MRPP, a tool for risk prevention management

2.1 The MRPP in French risk prevention policy

In France, the State is responsible for posting the risk and including it in regional development management. For this purpose, the State introduced "Plans de Prévention des Risques naturels prévisibles" (PPRN) (Predictable natural risk prevention plans - NRPP) in **law n° 95-101** of 2 February 1995.

Based on the successful application of these tools, their field of application was expanded to include mining risks through **law n° 99-245** of 30 March 1999. This law introduced the "Plans de Prévention des Risques Miniers" (PPRM) (Mining Risk Prevention Plans -MRPP). The rare differences which justify the introduction of a specific procedure for handling mining risks particularly include the type of risks involved and the funds and procedure for compensating victims in the event of accident.

2.2 Administrative procedure for drafting an MRPP

The Prefect, as the regional State representative, initiates the procedure for drawing up an MRPP via a "prescription order". This order defines the limits of the study and the type of risks involved. The prevention procedure is applied, as far as possible, to global physical units, called "risk basins" defined by natural parameters and/or operations and not by administrative limits.

Apart from the administrative departments involved, all town councils in the communities concerned are systematically requested to give their opinion. The Prefect also submits the draft plan for public enquiry among the populations concerned.

At the end of these various consultations, the possibly modified MRPP is approved by Prefectural order. The regulatory constraints it defines take precedence over the Local Town Planning plans drawn up by the individual communities.

2.3 The main phases of drawing up an MRPP

2.3.1 The Information phase

The information phase of an MRPP is designed to collect all available information (including further investigations if these are found to be strictly necessary). It requires an on-site investigation and consultation of archives.

This phase gives rise to the production of an informative map which is used as a basis for diffusing essential information to the population, because it helps to justify the prevention procedure undertaken by summarising the disorder and harmful effect which has affected the site in the past.

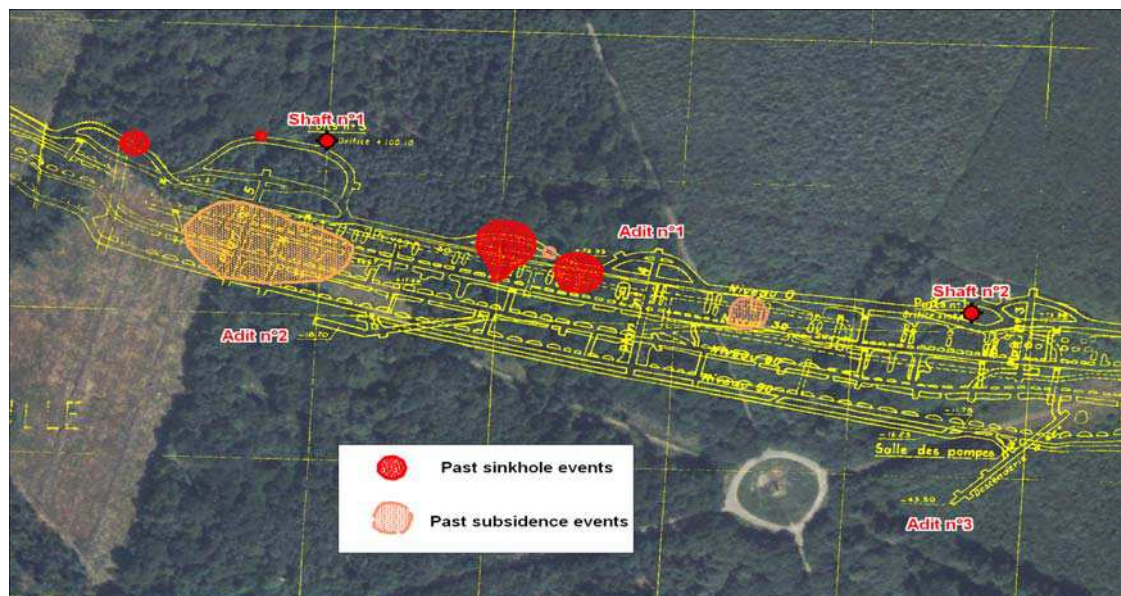


Figure 2. Example of an information map.

2.3.2 The Hazard evaluation phase

The hazard evaluation phase is intended to locate and list the zones exposed to potential phenomena, according to the intensity of the predictable events and the zone's predisposition to their development. This evaluation does not include the type of surface occupation.

It ends with the drafting of maps which locate the hazard zones identified by the evaluation procedure.

2.3.3 The Factor assessment phase

This phase includes drawing up an inventory of all existing factors in areas subject to one or more risks and identifying the potential future projects which could develop as a result. It is used to identify populations subjected to a non-zero risk level, particularly listing the most sensitive equipment or public establishments. It results in the production of a map including all the factors concerned.

2.3.4 The Regulatory zoning phase

The regulatory zoning phase defines homogeneous zones in terms of prohibitions, instructions or recommendations concerning land use, for both new and existing projects. The principles of this zoning are particularly based on confrontation between the levels of risks previously identified and the assessment of existing and future factors characterising the surface.

A set of rules is drawn up which is directly linked to this zoning. It is intended to define, clearly and operationally, the regulatory measures which apply to each regulatory zone.

3 Description of the main mining-related risks covered by the MRPP

Edict n° 95-101 of 5 October 1995 limits the risks covered by MRPPs to phenomena which are potentially dangerous to people and property. They will be grouped into four main themes detailed in the following paragraphs.

3.1 Modification of water flow scheme

Almost all underground mining took place below groundwater level, therefore requiring the use of dewatering pumps to allow ore extraction to take place. At the end of extraction operations, stopping the dewatering pumps allows the groundwater to rise to a level close to its premining level, which leads to the development of an underground reservoir which is discharged at one or more points, into the surface hydrographic network.

During operations, major modifications may have irreversibly altered the initial conditions in the supporting rock formation. Extraction work may also have led to surface subsidence, for instance, or created artificial groundwater vents. In addition to this, benefiting from dewatering pumping and lowering of the groundwater level, some sensitive zones may have taken advantage of this "dry period" to undertake development in terms of surface and/or underground occupation.

It is therefore easy to understand the need to pay particular attention to the possible consequences of rising groundwater levels on surface property and activities once dewatering is no longer taking place.

Several potential risks can be identified. They are described briefly below:

- Modification of the discharge scheme (change in flow, appearance of new discharge points or reactivation of old ones).
- Appearance of wet zones or marshes (inadequate drainage capacity for surface land).
- Flooding of subsoil and low points (groundwater level shallow beneath the surface, with possible impact on underground structures such as cellars, etc.).

- Modification of water flow scheme (may increase flood flow in certain water courses or reduce flow in others, particularly at low water).
- Sudden flooding (sudden discharge of a very strong water or mudflow, through an exit connected to a mining reservoir).



Figure 3. Discharge through an adit (left) and development of a wet zone close to an other adit (right).

3.2 Surface instability

Mining operations consist of extracting large quantities of material with the intention of marketing part of it in the form of usable ore. These excavations, whether underground or open-cast, have irreversibly altered the rock formations in which the ore is found.

Concerning **underground workings**, which represent most French mining operations, the method of exploitation used depends mainly on the geological configuration of the seam and the evolution of techniques. From the point of view of residual risks, there are two main methods: operations providing voids backfilling after extraction and those which lead to persistent residual voids once the workings are closed down.

For the first (working, stopping...), surface instabilities are generally limited to low amplitude movements. It is mainly the development of subsidence which is to be feared, as well as damage to buildings or infrastructure. For operations leading to large persistent residual voids (rooms and pillars, dissolution cavities...), the stability of old workings may be compromised by aging material or changes in the environment of underground mining works. Apart from the possibility of subsidence, this type of operation may also be the source of collapses.

In **open-cast mining**, extraction consisted of digging large pits from which the ore was extracted. The choice of operating method was based on the optimisation of economic profitability (limit the volume of waste to be cleared) and the stability of the mine structure (avoid slopes which are too steep). These rocky fronts often eventually suffer instabilities from simple rock falls to the massive slumping of an entire slope front. The combination of rock fracturing and the morphology of the slopes of the pit generally determine the volume of rock mass which is potentially unstable. The nature of the surrounding rock formation also plays a major part in the development of any instability.

At the same time, mining operations, whether underground or open-cast, have often led to the constitution of bulky **mine waste deposits** close to the extraction sites. Although waste materials are generally stored in dry conditions and constitute piles of material commonly known as slag heaps or waste dumps, operating residues are mostly discharged into basins confined by retention dykes built round the edge of the storage zone. The rupture of deposit structures of any kind generally leads to the unfavourable evolution of one or more factors governing the mechanical behaviour of excavation or other waste.

The main potential risks characterising the potential for earth movement is described in the following.

- Settling (recompaction of a mound of loose rock affected by underground workings. The induced movement is usually only slight).
- progressive subsidence (gradual, flexible re-adjustment of surface layers. Phenomena which often cause damage but are rarely dangerous).
- Sinkholes (sudden appearance on the surface of a sink-hole. The sudden nature of the instability makes these potentially dangerous events).
- General collapses (collapse of all or part of an operation, often dynamic. Phenomena which are potentially very dangerous).
- Slides or slope movements (characteristics of deposits or slopes of stripping operations in loose rock: slides, gully erosion).
- Flows: (potentially dangerous disorders likely to affect people and property in the neighbourhood of old deposit structures).
- Rockfalls (characteristic of pit slopes in open-cast mines excavated in hard rock formations, with steep slopes).



Figure 4. Example of a sinkhole (on the left) and of a general collapse (chalk mine on the right).

3.3 *Mine gas emission on surface*

After closing a mine, if not completely flooded, mining voids form an underground reservoir in which mine gasses accumulate. Depending on the ore extracted and the gases present in the deposit, the residual mine atmosphere may differ greatly in composition from one site to another.

Under the effect of various mechanisms, usually resulting from the pressure gradient between the underground workings and the outdoor atmosphere (rising groundwater, atmospheric

pressure drop), mine gases may be forced to the surface through natural (fractures, cracks...) or artificial (shafts, drifts...) drains.

Depending on the type and composition of this mine gas, surface gas emissions may constitute several risks or nuisances to people and property. The safety of surface occupants may be affected if the gas is trapped in non-ventilated spaces (cellars, underground networks...). The main dangers for people are: ignition or explosion (methane), intoxication (CO, CO₂, H₂S...), asphyxia (oxygen deficit) or irradiation (radon).

- Ignition (CH₄): methane, generally trapped in coal, is a non-toxic gas which is physiologically inoffensive. It is essentially its inflammability or explosivity which, when mixed with oxygen in certain proportions, makes methane such a dangerous gas.
- Intoxication (CO, CO₂, H₂S): found in the ore being mined, resulting from the slow combustion or decomposition of organic or sulfuretted material, or resulting from the action of acid water on land, these gases are highly toxic and can be fatal at high concentrations. They attack the nervous system and the body's respiratory system.
- Irradiation (radon): Radon is found in old underground uranium mines, but also in other underground spaces if the surrounding land contains even tiny quantities of uranium. Radon is a radioactive element which can be dangerous to humans when inhaled. Its effects increase the risk of lung and bronchial cancer.
- Deoxygenated air: Oxygen deficit situations (accumulations of mine gas or oxygen consumption) are likely to be encountered in all kinds of mining operations, particularly coal mines. Mine gas therefore represents a risk of asphyxia for people. An oxygen-poor atmosphere leads to a disturbance of the respiratory and blood systems of anyone exposed to it. A strong deficit can rapidly lead to death.

3.4 Water and soil pollution

Environmental modifications and disturbances induced by mining operations are likely to cause more or less important deterioration in the quality of environmental parameters in the area of the mine, reflected in the appearance of abnormal environmental contamination. This deterioration mainly affects underground or surface water and sediments and soils. It may also concern the atmosphere, particularly in the presence of ionizing radiation or toxic particle emissions.

The environmental impact results from complex and varied physico-chemical phenomena, closely linked to the type of substance mined and the mineralogy of the surrounding rock formations as well as the mining method used.



Figure 5. Effect on surface water of an abandoned coal mine discharge.

To assess the importance of environmental risks and nuisances, it is usual to reason in terms of "sources" (pollutant type and toxicity), "vectors" (water, soil, air) and "targets" in contact with this pollution (human activities, ecosystems...).

The main **sources** involved result from inorganic chemical contaminants (metals, sulfates...) or organic contaminants (hydrocarbons, phenol compounds...). They may particularly originate in old mine workings (soil leaching as the groundwater level rises), deposits of surface processing residues or structures storing industrial products used during mining operations.

Concerning contamination **transfer vectors**, underground and surface waters play a major role with air carrying toxic dust or ionizing radiation.

The main **targets** likely to be affected by these environmental nuisances are humans and, more generally, land and water ecosystems (biotopes and the organisms living in them). These targets may come into contact with various contaminants, either directly or indirectly via the food chain: water, plants, fruit and vegetables, fish, farm animals, etc.

4 Identifying, listing and mapping the hazards and factors involved

4.1 Principles for identifying and mapping hazards

4.1.1 Definition

A hazard corresponds to the probability that a given phenomenon will take place on a given site during a reference period, reaching a qualifiable or quantifiable intensity. Characterising a hazard is therefore usually based on the **predictable intensity of the phenomenon** with its **probability of occurrence**.

The **intensity of the phenomenon** corresponds to the amplitude of disorder, sequels or harmful effect likely to result from the feared phenomenon. This notion includes both quantification of the consequences of the feared events (size of a crater, height of water...) and the potential severity of their effect on humans, property and soil use, likely to potentially characterise the site after a certain time (possibility of victims or damage, existence and/or cost of prevention measures...).

The **probability of occurrence** reflects a site's sensitivity to being affected by any of the phenomena analysed. This is a concept which is particularly difficult to quantify considering the complexity of the mechanisms of evolution, the heterogeneous nature of the environment and the very partial nature of the information available. Therefore, within the context of hazard evaluation linked to the post-mine period, priority is given to the notion of a site's **predisposition** to suffer disorder or nuisance. Evaluation of this predisposition depends on the combination of different factors which are favourable or unfavourable to the initiation and development of the mechanisms in question.

4.1.2 Qualification of classes of intensity

The intensity of the phenomenon characterises the amplitude of the expected repercussion if the feared event takes place. Each type of phenomenon has one or more corresponding representative physical values which can be used to characterise the consequences of the feared events. It is therefore the size of craters which defines the intensity of sinkholes and the estimated flowrate or depth of water which characterises the impact of flooding.

To evaluate the intensity of the feared phenomena, the expert attempts to evaluate the predictability, even approximate, of the physical values judged to be representative, for each selected phenomenon, using all the information collected. By referring to guide values which define the main classes of intensity, he can then define the class to which the feared phenomenon belongs within the context studied.

These reference values have been defined as part of the production of the methodological guide covering drafting of an MRPP. Some of the main national experts who are well-known in their field met in working groups, each dedicated to a particular theme. The guide values proposed are provided for information and can be adapted to the context by the expert in charge of evaluating risks. They also help to produce a homogeneous approach at national level, by limiting the subjectivity of the analysis inherent in the sensitivity of each expert.

As an example, the following table shows the classes of intensity of various phenomena which are representative of several classes of sequels.

Classes of intensity	Flooding	Surface instability
	Discharge modification (flowrate in dm ³ /s).	Diameter of crater left by sinkholes
Limited	Seepage (< 1)	Ø < 3 m
Moderate	Small stream (< 10)	3 m < Ø < 10 m
High	Large stream	Ø > 10 m

4.1.3 Qualification of classes of predisposition

Determining predisposition is first based on a back analysis of the same type of disorder or nuisance on the site or a similar site. In addition, evaluation is also based on the analysis of scenarios and mechanisms of occurrence of phenomena likely to affect surface land, the combination of parameters promoting this occurrence and helping to raise the class of predisposition. For example, a very thick overburden, limited dimensions of residual voids and the presence of resistant layers in the overburden will make this site less predisposed to develop surface subsidence than a shallow site of operations located under an exclusively marly overburden.

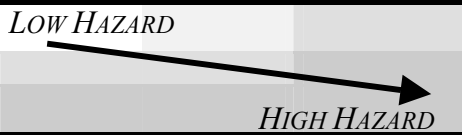
Predisposition to triggering disorder can also be affected by the "incompleteness" of information available, which is often considerable in the case of very old operations. It is regularly necessary to manage the lack of available information by using the idea of "presumption".

While it would not be safe to limit yourself to only proven data, it would also be unreasonable to assign the same level of susceptibility to zones for which you only suspect that the feared phenomenon could develop as with those for which the hazard is confirmed. Therefore, a site's predisposition to the occurrence of disorders can be weighted by this idea of presumption, incorporating doubt resulting from gaps in the information.

4.1.4 Identification of classes of hazards

The principle of hazard qualification consists of combining criteria used to characterise the intensity of a feared phenomenon with criteria used to characterise its class of predisposition. Several principles, explicit or implicit, can be used to combine qualitative values or cross-reference qualitative and quantitative criteria. For information, techniques can be noted by rating, upgrading, multi-criteria listing etc.

If the cross-referenced table principle is selected, a synthesis matrix is used, constituted as shown in the following table. To avoid complicating restitution maps, we shall limit ourselves to **three classes of hazard level** as far as possible: low, moderate and high hazard level.

Predisposition	Slightly sensitive	Sensitive	Very sensitive
Intensity			
Limited			
High			
Very high			

4.1.5 Hazard mapping

The hazard has to be mapped for the entire sector concerned by the MRPP so as to reveal which sectors are most likely to develop risks or nuisances. Feedback tends to show that a scale of 1/10 000 is often used to reach a satisfactory compromise between MRPP principles (small scale) and communities' requirements (large scale). 1/5 000 can also be envisaged, mainly in small operations in an urban environment. Depending on the size of the study zone, diffusion could be envisaged in "paper" form but it is increasingly in "computer" form, using the powerful tools of Geographical Information Systems (GIS).

The hazard zoning contours are based on technical parameters (geology, operations...). They therefore have no reason to follow the contours of the plots of land. When, as is often the case, several potential phenomena coexist on the same plot, several risk maps can be drawn up, one per phenomenon, to avoid overloaded graphics and making them illegible.

Hazard mapping includes surface areas concerned by the possible effects of phenomena resulting from mining activities. It therefore takes into account the possible lateral extension of disorders or nuisances initiated in underground spaces and developing as far as the surface. It also includes the uncertainties inherent in the available information and results of estimates and models required to evaluate the area of influence of the risk.



Figure 6. Example of a hazard map above abandoned iron mines (North-West of France) .

4.2 Principles of assessing and mapping the factors involved

4.2.1 Factor assessment phase

The procedure for assessing factors involved in mining risks consists of identifying the main types of land occupation or activities, both existing or future, which are likely to interfere with the risk prevention procedure. The major factors concerned will naturally include urbanised and particularly urban sectors in which the regulatory measures applied are likely to differ considerably from those defined for open land. The analysis will also identify industrial or urban wasteland which could be strategic for the development of towns with mining risk restrictions on other parts of their territory.

Assessing all the factors concerned also includes evaluating populations in danger and listing the main factors affecting safety, crisis management and vital functions in the area concerned. Therefore, public establishments, particularly the most strategic in terms of emergency aid organisation (schools, hospitals...) are identified, whether they are subject to risk or not, as well as sensitive equipment including networks (roads, electricity, gas, telephone...) so as to identify their sensitivity relative to the expected consequences of the occurrence of disorder. For example, routes used by traffic circulation which must be secured in priority to facilitate public assistance.

4.2.2 Factor mapping

The map including factors concerned is produced at the scale selected for drawing up the MRPP (often 1/10 000). It locates the main factors identified, giving them references if necessary so that descriptive sheets can be drawn up as required.

Depending on the different objectives to be reached (personal safety, future development of urbanisation...), several maps can be drawn up, giving priority to the factors most concerned by the objective in question.

5 Drawing up the zoning plan and regulations

5.1 Principles for regulatory zoning

Posting hazard and drawing up a regulatory zoning plan are two specific procedures with fundamentally different objectives. Whereas the first identifies the different types of disorder likely to develop on the surface and locates them, the second marks out the limits of the zones within which homogeneous instructions can be defined to ensure the safety of existing and future people and property.

The zones are marked out by cross-referencing hazard and factor maps, i.e. combining the type and intensity of predictable disorder with the occupation of surface land. Apart from exceptions, definition of the different zones is based on constructibility criteria (zones which are non-constructible or constructible under certain conditions...). As for hazards, the aim is to avoid multiplying the number of zones, to facilitate the legibility of the maps. For this purpose, the number of zones selected will be limited to three or four (a white zone within which requirements are minimal or non-existent, a red one for sectors considered to be non-constructible and one or two blue ones in which urbanisation remains possible but with more or less severe constraints and restrictions).

Generally speaking, priority will be given to the development of a new urban area in zones outside areas with mining-related risks. However, although this rule can be applied relatively strictly for areas not yet urbanised, constraints may be relaxed locally in urbanised areas with strong constraints due to mining-related risk over a major part of the area occupied by the communities in question. In this case, building permits may be envisaged in low or moderate risk zones.

The regulatory zoning plan must be drawn up, as far as possible, on a scale which is compatible with studies held during risk evaluation and factor assessment phases.

5.2 Drawing up the regulations

At the same time as the zoning regulations are drawn up, the State Department in charge of drafting the MRPP draws up the regulation which defines the regulatory provisions applied to each zone within the regulatory zoning area. These measures are mainly intended to improve the safety of people and property in zones subject to mining-related risks and prevent increasing vulnerability of property and activities in the most exposed zones, reducing it if possible.

The regulations must be as simple and operational as possible to make it easier for the public to understand and assimilate them. It is generally presented by type of regulatory zone (red, blue, white...) after defining the general measures applied to all the plots within the limit of the MRPP.

For each zone, it is usual to organise the measures in two groups: those designed for existing property and those intended for future projects. The different measures may take the form of prohibitions, obligations or simple recommendations.

It will be noted that one of the regulatory specificities of MRPPs, which make them a powerful tool, is their retroactive nature which means that measures can be applied to property existing before it was drawn up. However, if there is no existing restriction to future projects, the work imposed on property built before MRPP approval can only affect limited changes, costing less than 10% of the market value of the property before the risk was posted.

For successful drafting and application of the MRPP, all available expertise (administrative, technical and political) must be federated. A concertation procedure must therefore be systematically used between State Departments and local authorities, to facilitate understanding, appropriation and participation of local authorities in the risk prevention policy.

It is therefore essential to obtain the participation of local representatives when drawing up the regulatory zoning plan and regulations because they are the main authorities who will be in charge of applying it on a daily basis and explaining it to the population.

6 References

French **law n°95-101** of February 2nd 1995, relative to environment protection reinforcement (nowadays integrated through articles L.562-1 to L.562-7 to the Code of environment). The elaboration principles are described in the **edict n°95-101** of October 5th 1995.

French **law n°99-245** of March 30th 1999, also called « post-mining law ». The elaboration principles are described in the **edict °2000-547** of June 16th 2000.

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